Improved methods to evaluate realised energy savings

Verbeterde methoden voor het evalueren van gerealiseerde energiebesparing

(met een samenvatting in het Nederlands)

PROEFSCHRIFT

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Contents

Preface

This thesis is based on work that has been performed in past years at ECN Policy Studies. It is mainly composed of a number of papers, published or accepted for publication, in international journals on energy, economy and policy (Chapters 2 to 6). Some papers describe methods and analysis tools developed earlier at ECN, or present results of past analysis. Other papers extend the scope of earlier work, as to describe the specific features and the capabilities of the tools developed, or to present results that are of scientific interest. Although each paper is self-contained and deals with different issues, they all contribute to the notion how to improve evaluation and monitoring of past energy trends. This general idea, and how the papers fit in, is described in the first introductory chapter. A synthesis of the results of the case studies and an overview of methodological improvements achieved is presented in Chapter 7. Most parts of this thesis depart from experiences in the Netherlands. However, most of the problems, issues and methodologies dealt with are relevant for other developed countries too.

Chapter 1 INTRODUCTION AND PROBLEM FORMULATION

1.1 Developments in energy savings and evaluations

Definition of energy savings

This thesis regards the question how to evaluate realised energy savings at national or sectoral level. Energy savings are defined here as the difference between reference energy consumption, valid in absence of saving activities, and actual or observed energy consumption (see Figure 1.1). At country level the development of reference energy consumption is determined in conformity with changes in socio-economic activities that demand energy; the trend in observed energy use is based on statistical data.

In literature the terms ‘energy conservation’ and ‘energy efficiency improvement’ are frequently used when discussing energy savings. Energy conservation is often used in the sense that total energy consumption is reduced owing to saving activities. As shown in Figure 1.1, this is not necessarily the case. Energy efficiency improvement means that the ratio between energy use and an achievement is decreased, for instance fewer litres of petrol used per km driven by car. However, in many cases it is difficult to define or quantify the achievement, such as ‘a comfortable house’ in case of energy use for space heating. Therefore, the term energy savings is generally used in this thesis.

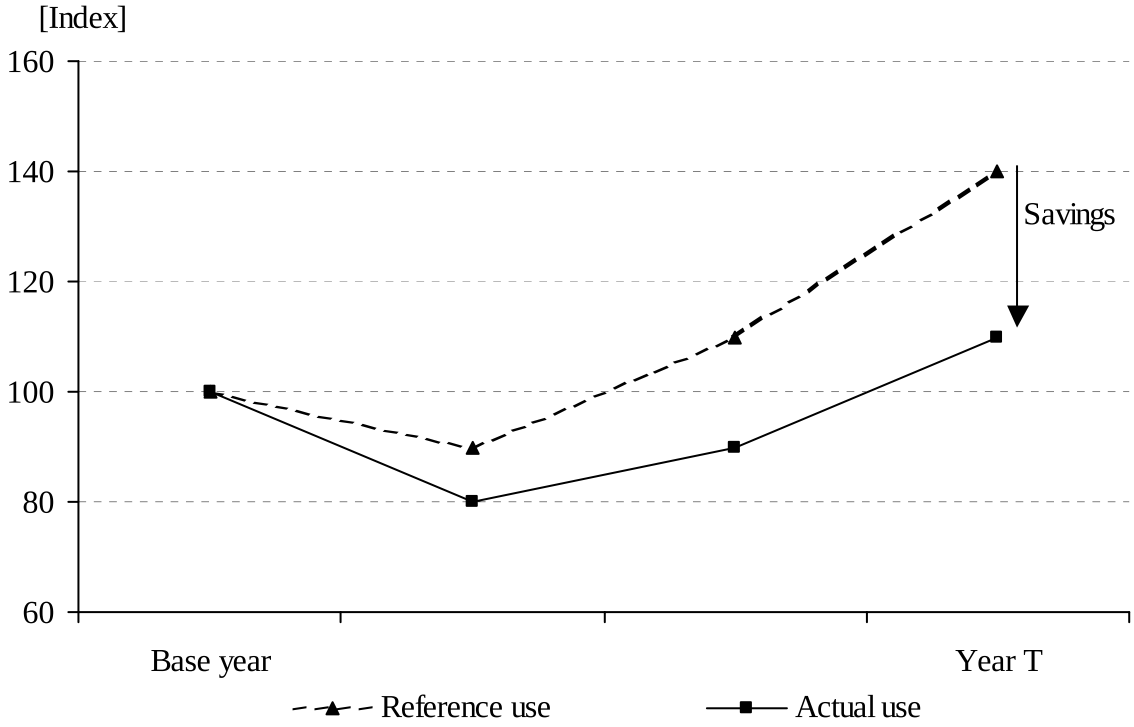

Figure 1.1 Reference energy use, actual energy use and energy savings (example)

International energy developments, and need for energy savings in the Netherlands

In the Netherlands, more efficient use of energy did hardly receive interest from policy makers until the **first oil crisis** in 1973. Then preservation of own Dutch gas reserves, discovered in the fifties, became a policy issue, as to EZ (1974). The growth in gas consumption had to be limited, mainly by introducing higher market oriented gas prices. After the **second oil crisis** energy savings became an explicit policy goal in EZ (1979); they should contribute to a more secure energy supply and to lower costs for energy users as well. In the eighties **acidification** of soil and woods ('wald sterben' in Germany) became a political issue. Since acidification was to a large extent caused by energy related emissions of SO_2 and NO_x, it contributed to the need for energy savings. This was also true for the **Chernobyl accident**[1] in 1986, which forced to look for alternatives to the proposed building of nuclear power plants in the Netherlands according to Jong (2005). One of the alternatives was combined heat and power production at the site of industrial users, reducing primary energy consumption. Meanwhile, the **sharp drop in oil prices** in 1986 and the relaxation of oil supply tensions undermined the need for energy savings. Some years later, initiated by publication of the **Brundtland report** 'Our common future' in WCED (1987), the greenhouse gas problem became a new driver for energy saving policy making in EZ (1990). International negotiations on absolute limits for total future greenhouse gas emissions, e.g. the UN conference on Environment and Development in 1992, led to many new activities to increase energy efficiency in EZ (1993). A target of 33% energy efficiency improvement was formulated, to be achieved between 1995 and 2020. Later, this yearly energy efficiency improvement of 1.6% was increased to 2% per year (see also Table 1.3). However, from the mid nineties on **liberalization** of European electricity and gas markets influenced the way energy saving policy was formulated in EZ (1998). Electricity and gas suppliers could not act any more as the semi-governmental actors they used to be in the past. Due to liberalization the favourable tariffs for grid delivered electricity from combined heat and power production disappeared. In addition, Dutch gas- and electricity prices developed in such a way that this technology became less attractive according to Rijkers (2003). Energy efficiency policy became more and more part of policies to reduce total CO_2 emissions. The new and lower energy efficiency target of 1.3%[2] per year should be sufficient to reach the target for CO_2 emisssions in 2010 (see EZ (2002)). However, realised energy savings proved to be even lower than the target, according to Boonekamp (2004). Recently, **security of supply** has become a political issue again in EZ (2005), enhancing the need to slow down growth of energy consumption by energy saving policies.

Because of the formulation of directives, such as on energy services in EC (2005), the role of the EU has become increasingly important with regard to national energy saving policy development. EU-policy has increased the geographical scope for national energy saving policy, as the **CO_2 emission trading** system (ETS), described in EC (2003), allows savings of large energy users to be realised abroad.

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[1] Earlier accident in Harrisburg in 1978 slackened policy choice for nuclear but did not halt it.

[2] This 1.3% is not comparable with the 2% mentioned, due to changes in the definition of energy efficiency at national and sectoral level (see appendix C in Boonekamp (2002)).

Role of energy savings as a solution to energy problems

As indicated in the preceding paragraph, major policy issues related to the energy system are security of energy supply, high cost of energy carriers and environmental problems (caused by the energy system). Potential solutions to these problems are substitution between fossil fuels or with nuclear energy, increased use of renewable energy sources, enhanced savings on energy consumption, and implementation of advanced technologies to capture (and store or recycle) the harmful emissions. In energy policy of many countries the problems mentioned have been rendered into three policy goals: the energy supply system should be reliable, affordable and clean (see Figure 1.2). Energy savings can contribute to each of the policy goals, in 'competition' with the other solutions.

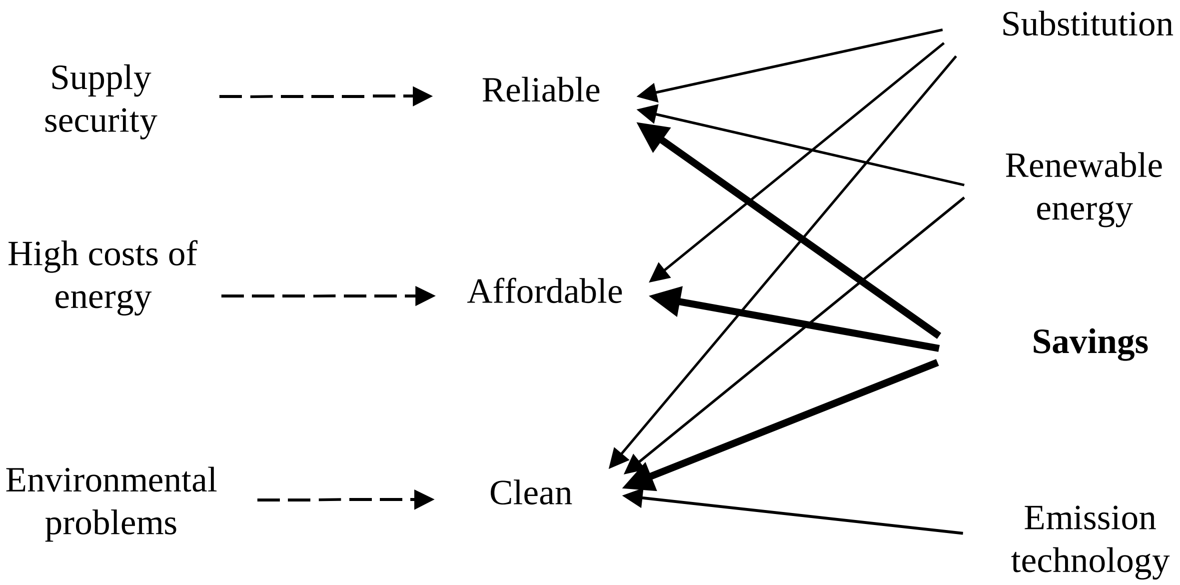

Figure 1.2 Role of energy savings as to problems and policy goals for the energy system

To give some idea about the role of energy savings in the past thirty years, Table 1.1 provides the contribution of achieved energy savings in limiting growth of energy consumption for OECD-countries. Within the OECD the energy intensity, the ratio between total energy consumption and GDP, has decreased during the whole period 1973-1998. Until the mid eighties substantial efficiency gains were realised owing to very high oil prices and ample saving options after decades of ignoring efficient use of energy, according to IEA (2004). These savings more or less counterbalanced the increase in energy consumption on account of economic growth. But after the drop in oil prices in 1986 the level of energy savings has decreased. In the nineties energy consumption grew considerably despite a lower GDP growth and despite policy support for energy savings as part of a policy to reduce the emissions of greenhouse gasses (see Table 1.1).

Table 1.1 Trends in economic development, energy consumption and energy savings in OECD-countries in the period 1973-1998

	1973-1982 [%/yr]	1982-1990 [%/yr]	1990-1998 [%/yr]
Economic growth	2.2	3.5	2.2
Energy consumption	-0.6	1.7	1.5
Change in energy intensity	-2.8	-1.8	-0.8
Energy savings	-2.4	-1.5	-0.7

Note: Based on Figure 3.11 in IEA (2004)

In the World Energy Assessment (see WEA (2000)) some energy developments are presented for non-OECD countries until the year 1995. It is shown that the energy intensity has increased for most of these countries, with the exception of China and eastern European countries. Recent trends for EU-15 countries are provided by the Odyssee-project of the EU; Lapillonne (2004) shows that total improvement of end-use energy efficiency amounted to 0.8% a year in the period 1990-2002 (see Figure 1.3), slightly above the average figure for total energy consumption in OECD-countries after 1990 (see Table 1.1, last column).

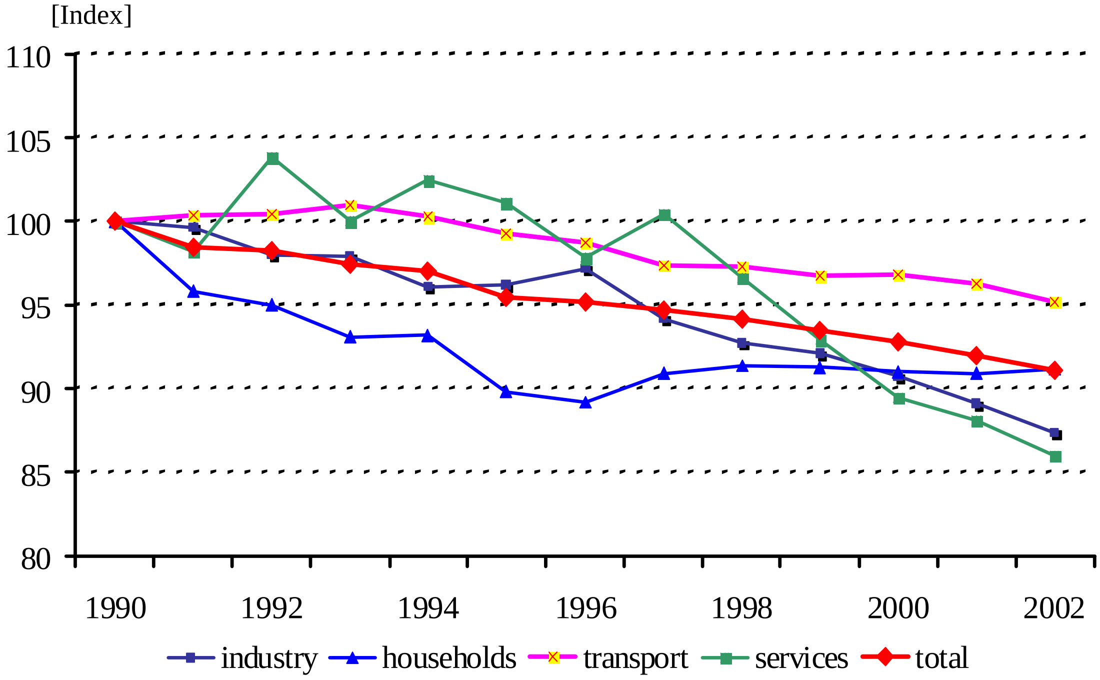

Figure 1.3 Energy efficiency index for EU-15 countries, total and per end-use sector

Overview of energy saving policies in the Netherlands

The important role that was assigned to energy savings in the last few decades resulted in the formulation of policy measures and programs on energy savings in many countries. The measures regard subsidies on investments into efficient energy technologies, (performance) standards for new buildings and for appliances, energy taxes, voluntary agreements with energy users on implementing saving measures, and dissemination of information (campaigns, education, advice). As an example, Table 1.2 shows the most important policy measures introduced in the Netherlands, together with studies in which these measures are evaluated.

Table 1.2 Important policy measures and evaluation studies for energy savings (Netherlands)

Policy measure	Period	Evaluation studies	Remarks
Insulation standards	1978-1992		Tightened regularly
National Insulation Plan	1978-1987	SNIP, 1988	
Energy investment support (WIR)	1980-1988	Van der Doelen, 1989	
CHP-promotion scheme	1988-1996	Berenschot, 1993	
Various subsidy schemes[3]	1990-1996	EnergieNed, 1995	
Environmental action plan	1991-2000	Berenschot, 2001	Final evaluation
Voluntary Agreement-industry	1989-2000	Glasbergen, 1997	
Voluntary Agreement-agriculture	1993-2010	Knijff, 2004 (LEI)	Yearly evaluation
Fiscal facilities[4]	1990/'97-	IBO, 2001	Various schemes
Energy performance standards	1995-	Novem, 2003	Tightened regularly
Regulatory energy tax	1996-	Bode,1998/Berkhout, 2001	Raised regularly
Energy premium scheme	2000-2004	BD, 2002	
Benchmark covenant industry	1999-2012	PWC, 2003	
VA energy extensive sectors	1998-	Arentsen, 2004	

Source: Oudshoff (1997), Das (1996) and Boonekamp (2002)

The first regular policy measure[5], introduced in 1978, regarded **insulation standards** for new dwellings. These standards for wall, roof, floor and windows were strengthened several times until 1992. The **National Insulation Plan** (NIP) focused on space heating in existing dwellings. Next to information campaigns on energy saving behaviour it contained the first large-scale subsidy scheme to enhance energy savings, mainly by cavity wall insulation, double-glazing and more efficient boilers. The law on investment support (WIR), introduced to stimulate general investments of firms by providing a tax deduction, was extended in 1980 with a supplemental facility **WIR-energy** for investments in energy saving measures. The **CHP scheme** to stimulate cogeneration consisted of various measures, such as investment subsidies and favourable tariffs for electricity fed into the grid. After a standstill for new policy measures at the end of the eighties, some major long term saving programs were introduced in the nineties. The **Environmental Action Plan** (MAP) of the Dutch energy distribution companies aimed at CO_2 emission reduction, mainly by stimulating and supporting energy saving measures in non-industrial sectors. The MAP-program was supported by **various subsidy schemes** for insulation, high-efficiency boilers, energy efficient appliances and lighting, and advanced saving options, such as the heat pump. The **Voluntary Agreements (VA)** between government and almost all industrial sectors aimed at 20% energy efficiency im-

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[3] E.g. SEBG (buildings), BSET (new technology), ISO-HR (insulation/boilers) and STIMEV (lighting).
[4] Tax deductions for investments, e.g. VAMIL (environment) and EIA (energy).
[5] Not regarding temporarily measures, such as limiting car use and speed during the first oil crisis.

provement, in final demand as well as by the application of cogeneration. The **VA with horticulture**, although started in 1993, used 1980 as base year for evaluation of the results The VA's were supported with subsidies, technology demonstration programs and **fiscal facilities** for energy related investments (instead of the abolished WIR). The VA's for internationally active energy intensive industries have been replaced by the **benchmark covenant** stating that the companies should be part of world top in energy efficiency. By the mid nineties, standards for insulation and efficiency of boilers were replaced by **energy performance standards** for new dwellings and new buildings. The r**egulatory energy tax (REB)** was introduced as part of 'greening' the tax system, shifting taxes from labour to energy use. Due to the degressive tariff structure, the tax is most important for small energy users, such as households. Both performance standards and energy tax were step by step strengthened. The **energy premium scheme**, financed from part of the REB-receipts, was mainly used to transform the market for efficient appliances (in combination with the EU-label scheme). Finally, the **VA with energy extensive sectors** not only regards implementation of more efficient energy processes and systems, but also so-called 'broader options', such as introducing energy saving products in the market and reducing the need for transportation of goods.

Overview of policy evaluation studies on energy savings in the Netherlands

For most of the important policy measures on energy savings in the Netherlands evaluation studies have been executed (see Table 1.2, third column). In the following some methodological remarks are made with respects to these evaluations. The evaluation of the National Insulation Plan (NIP) for existing dwellings was focused on the realisation of the targets for the number of dwellings to be insulated. The evaluation study on the WIR-facility for energy saving investments focused mainly on its saving effects, but also on the issue of free riders, meaning energy users that got a subsidy but would have invested in savings anyhow. The CHP scheme was evaluated in 1993 and proved to be very successful; it was terminated still because it led to overcapacity in electricity production. The evaluation of the first phase of the Environmental Action Plan (MAP) of the distribution companies, in 1994, showed such positive results that a higher emission reduction target for the period until 2000 was decided upon. However, in the final evaluation of Berenschot (2001) it was concluded that it was not possible to relate the realised emission reduction to the MAP-program solely. The realised saving effects of the Voluntary Agreements (VA) with industrial sectors were registered yearly by Novem and evaluated at regular intervals by other parties, such as Glasbergen (1997) and Rietbergen (1999). The VA with the sector horticulture has been evaluated yearly, as to keep track of the trend towards the target for 2010. Subsidies for cogeneration and fiscal facilities for investments in energy savings were evaluated in a study IBO (2001), which focused on cost efficiency, i.e. the ratio between financial support and energy savings owing to policy. Realised saving effects of Energy Performance Standards for dwellings and buildings have been checked incidentally at first, but were later evaluated regularly by Novem. The effect of the generic energy tax (REB) on energy consumption was analysed for households in Berkhout (2001) and for companies in Bode (1998). Due to low price elasticities (households), or low tax levels (industry), the impact on energy savings was judged to be small. The evaluation of the energy premium scheme showed a large fraction of free riders. However, the deliberate choice for providing ample subsidies for all kind of efficient appliances was meant to facilitate the introduction of the energy tax. The 2003 evaluation of the benchmark covenant did not regard the energy savings achieved, but the procedures and methods applied to implement and monitor the covenant. Finally, the evaluation of the VA for energy extensive sectors in Arentsen (2004) showed that the uptake of the broader options, mentioned earlier, is not yet successful.

Most evaluation studies mentioned here focused on the saving effects and cost efficiency of the policy measure analysed. Realised energy savings were calculated bottom-up from the penetration of saving options affected by the measure, and the estimated savings per option. Costs of programmes and schemes, and the amount of free riders, were estimated to determine cost efficiency. A meta-study Oudshof (1997) was conducted to evaluate the effects of various policy measures on energy savings in household and tertiary sectors in the period 1980-1996. For each policy measure a number of aspects were looked at, such as realised savings, financial support and long-term effects. The evaluation studies of interest were analysed as to the reliability of results and the approach taken. It proved that most studies focused on realised savings and not on cost efficiency of the measure (the ratio between saving results and means, i.e. government support). Although in this meta-study the conclusions on policy-induced savings are not disputed, they are thought to be based, in general, on too few quantitative data and therefore not very reliable. This is partly caused by the vague formulation of the target that should be met with the policy measure. Another meta-evaluation Das (1996) regards policy measures on energy savings and the use of renewable energy sources in all sectors from 1980 on. Realised CO_2 emission reductions, per sector or energy application, were analysed in conjunction with the mix of policy measures deployed. However, because the saving effects of specific policy measures were not regarded, this study offers no information on the quality of the various evaluation studies mentioned in Table 1.2. More recently the general accounting office of the Netherlands made an assessment of energy and climate policy in the period 1989-2001 in RK (2001). Subjects were target setting, policy formulation (the use of ex-ante evaluations), policy execution and results achieved (using ex-post evaluations), per sector as well as per policy measure. Main points of criticism were the lack of integration between the various stages in the policy process and insufficient information on the contribution of policy measures to improved energy efficiency or reduction of CO_2 emissions.

Evaluation of total energy savings achieved

Besides evaluations of the saving effects of policy measures, total realised energy savings and general energy trends are evaluated as well. International examples of calculated realised energy savings were already presented in Table 1.1 and Figure 1.3. However, these realisations cannot be judged, as no international targets for primary energy consumption or total savings have been formulated in the past. Only few countries have targets for total energy savings.

In the Netherlands between 1979 and 2005 goals or targets for total energy savings have been formulated in various White Papers, at national as well as sectoral level. In Table 1.3 the figures for energy efficiency improvement at national level are given. However, in some cases the target value includes (policy induced) dematerialization, which reduces total primary energy consumption. Moreover, in Appendix C of Boonekamp (2002) a number of other differences in the definition and calculation of efficiency figures at sectoral level are described. Therefore care should be taken when comparing the target values.

Table 1.3 Target values for total energy efficiency improvement in the Netherlands, according to various white papers

Source	Period	Total period [%]	Yearly [%]	Dematerialization [%]
EZ (1979)	1977-2000	30	1.5	>0
EZ (1990)	1989-2000	20	2.0	×
EZ (1993)	1989-2000	17	1.7	×
EZ (1995)	1995-2020	33	1.6	0.3
EZ (1998)	1998-2010	×	2.0	0.4
EZ (2002)	2001-2010	×	1.3	×
EZ (2005)	2005-2020	×	1.3-1.5	×

Evaluations were executed incidentally, such as Groot (1996), Farla (1997) and Boonekamp (1998). However, differences in definitions, methods and data used led to much misunderstanding when using results for policy making. Therefore the Platform Monitoring Energy savings (PME)[6] was founded. From 2000 on, regular evaluations of total energy savings, achieved at national and sectoral level, were executed, based on a common database and methodology (see Chapter 2 of this thesis and description in Boonekamp (2004)). According to PME-calculations for 1995-2002 realised total energy savings represented an energy efficiency improvement of 1.0% per year, which was lower than the target of 1.3%.

Changing reasons for performing evaluations

In the early days of saving policy, evaluations regarded the performance of specific energy saving programs and measures only. In addition to registration of realised savings, the expenditures of government on energy savings were monitored as part of financial control procedures. Since then the demand for evaluations has expanded for the following reasons:

- Many new policy measures, of different types, were launched after 1990 (for EU-countries, see database on policy measures in MURE (2005)).
- Targets on total energy savings were formulated that asked for regular evaluations, to check whether targets were met.
- Often increasing amounts of government money were spent on measures to save energy (see Figure 1.4 for the Netherlands). This led to more pressure to render account of the results.
- In the Netherlands the effectiveness of policies and the efficiency of programs was questioned by parliament. In reaction, government launched a new general evaluation procedure, called ‘from policy budget to policy accountability’ (see VBTB (1999)). This led to stronger demands on monitoring and evaluation in the field of energy savings too.
- International obligations, such as the Kyoto-agreement on greenhouse gas emissions, ask explicitly for regular reporting on realised efforts and effects for countries involved.

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[6] Consisting of the energy research institute ECN, the environmental institute NMP-RIVM and the agency SenterNovem, with assistance of the statistical bureau CBS.

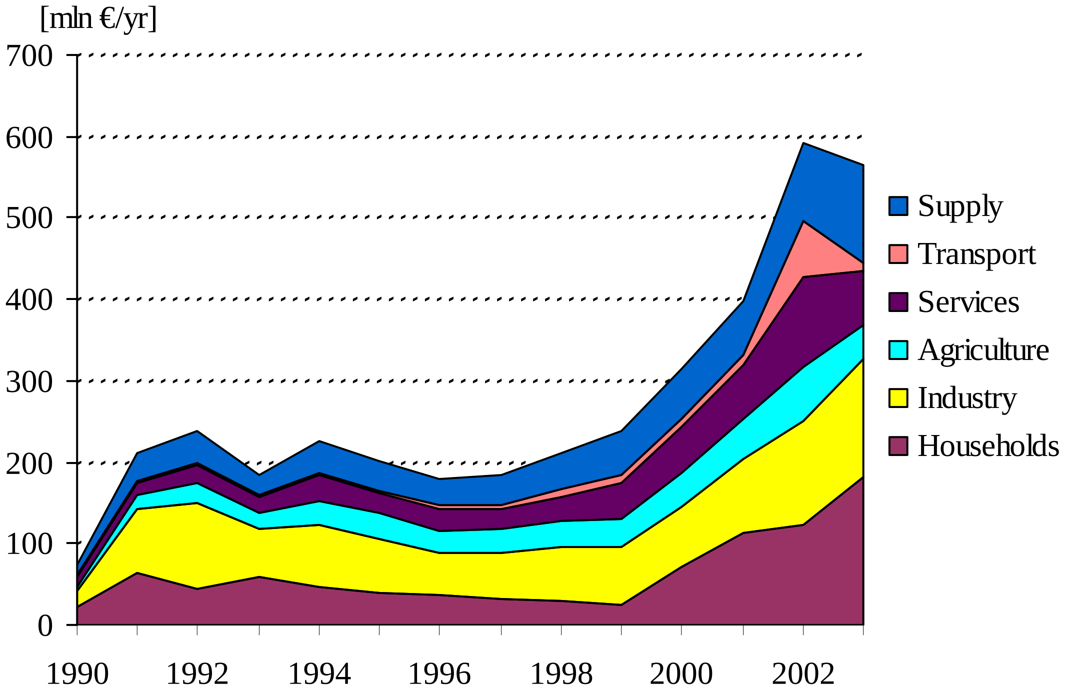

Figure 1.4 Annual government expenditures on energy savings in the Netherlands 1990-2003
Source: Boonekamp (2005).

Consequently the scope of evaluation has broadened from separate policy measures to total (policy induced) energy savings, and from judging savings on its own merits to comparing them with targets set. Moreover, relating the energy savings achieved to government expenditures that match has become standard practice nowadays. The character of evaluations changed from voluntary to obligatory.

Evaluation in present Dutch energy saving policy

Evaluation has become an indispensable part of energy saving policy. The VBTB procedures, established in 1999, prescribe a careful formulation of targets for new policy, preferably based on an ex-ante evaluation. When implementing the policy measure, the data collection and the method used in ex-post evaluation should be decided upon. At regular intervals, ex-post analyses have to be executed according to TK (2004). International developments, such as the Kyoto agreement on reduction of greenhouse gas emissions of countries, ask for a close monitoring of the contribution of energy savings. Because of international reporting obligations from the EU and the Conference of Parties to the UNFCCC[7], evaluations of energy and emission policy are executed at fixed points in time. The new Energy Service Directive of the EU may increase the demand for monitoring and evaluation of energy savings further. Also it's common policy that goals should be reached in a cost-efficient way. This has lead to a more

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[7] United Nations Framework Convention on Climate Change.

dynamic view on policy making, meaning that the execution of intermediate evaluations should improve the cost efficiency of policy measures. An example is the evaluation of the energy premium scheme, less than two years after the introduction of this subsidy scheme, in BD (2002).

However, in practice a proper evaluation meets substantial problems. Firstly, in the past the introduction of energy saving policy has not been accompanied by a plan to specify and collect the data needed in the evaluation. At present, evaluations are seriously hampered according to Harmsen (2005). Other problems regard the lack of ex-ante evaluations for new policy measures and insufficient quality of ex-post policy evaluation (see evaluation of VBTB in TK (2004)). The difficulty in executing a sound policy evaluation is enhanced by the increasing numbers of policy measures which makes interaction between various policy measures more probable (see Chapter 5 of this thesis). Moreover, in the evaluation of energy trends and total savings there exist persistent problems with availability and reliability of some statistical data, both for energy consumption and for variables that may help to explain energy trends. According to Boonekamp (2004) this leads to a 30% uncertainty margin in total calculated energy savings in the Netherlands. This makes it hard to draw robust conclusions and to formulate useful recommendations for current energy saving policy.

1.2 Scope of monitoring and evaluation

Monitoring and evaluation

In this thesis monitoring regards the registration and observation of changes in energy consumption. Evaluation has a broader meaning as it regards an analysis and explanation of the changes in energy consumption as well. It includes judgment of the role of influencing factors, such as energy prices, availability of saving options and policy measures, and side effects, such as costs to users or government and labour requirements. In this section the various subjects in monitoring and evaluation will be presented, followed by the limitations of the analysis applied in this thesis.

In literature often a distinction is made between ex-ante and ex-post evaluations. Ex-ante evaluations regard possible energy savings to be obtained in the future. Because the calculation of these savings often depends on many uncertain developments, including the effect of the policy measures, ex-ante evaluations often are based on scenario studies and calculations using energy models. Ex-post evaluations focus on observed trends in energy consumption, the energy savings achieved and the contribution of various policy measures to realised savings.

Trends in energy consumption

At the national level the evaluation generally starts with a mapping of trends in energy consumption. Trends at the national level can be traced back to trends at the sectoral level. Changes in sectoral energy consumption partly can be the result of yearly variations in climate. For instance, space heat demand of dwellings is dependent on the average outdoor temperature during the heating season. Because evaluations focus on man-made changes in energy use, the statistical energy consumption figures must be corrected for these yearly climate variations. The changes found for climate corrected energy consumption form the starting point for further evaluations (see Figure 1.5).

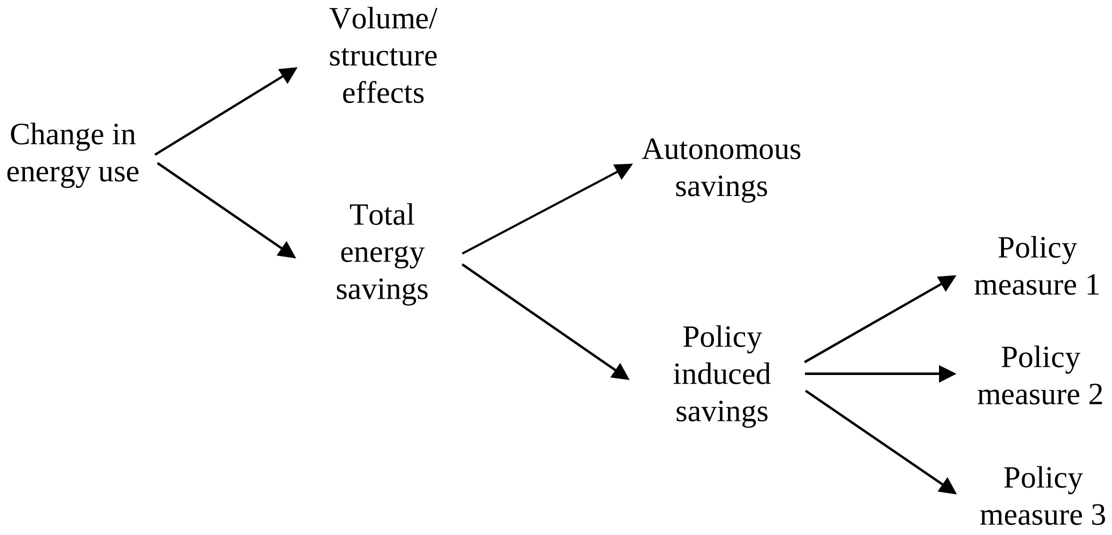

Figure 1.5 Relation between various subjects in monitoring and evaluation of energy savings

Total energy savings achieved
In Figure 1.5 it is shown that (climate corrected) observed changes in energy consumption are either the result of energy savings or so-called volume and structure effects. The volume effect is the increase in energy use owing to growth in energy using activities, represented by growth of GDP at the national level. Structure effects are connected to shifts between the activities; these shifts can either increase or decrease total energy consumption (see also Section 1.3). Because volume and structure effects normally are not subject of energy policy, evaluations in general focus on energy savings achieved. These savings regard different aggregation levels, such as:

- the appliance or system using energy,
- the sector that consumes energy,
- the country/national economy.

Calculated energy savings at these levels serve different needs. The efficiency gain of appliances or systems is evaluated because of regulation procedures (labels or minimum efficiency standards), because it defines the amount of subsidy to be given (e.g. in case of cogeneration plants), or because standards have been set that should be met (e.g. energy performance of new dwellings). In case of energy savings at sector level, results are used to check efforts agreed upon by parties (e.g. agreement with horticulture sector, Knijff (2004)). Realised savings at national level are of interest for development and evaluation of energy policy in general. According to VROM (1999) international reporting obligations ask for this information.

Contribution of policy to energy savings achieved

The majority of evaluation studies regard the investigation of policy-induced energy savings, meaning the part of total savings achieved that can be ascribed to policy measures or programs on energy savings (see Figure 1.5). Often applied types of policy measures are:

- subsidies on investment in saving options,
- standards for insulation of new dwellings or appliances,
- energy taxes,
- voluntary agreements,
- advice on saving measures,
- information campaigns.

EC (2003) constitutes a recently implemented policy instrument that states maximum CO_2 emissions, in combination with tradable emission rights for large energy users. A new instrument for smaller energy users is announced in EZ (2005). It regards an obligation for energy suppliers to save energy at their customer's premises, in combination with tradable white certificates that are attached to realised saving measures (see Bertoldi (2005) for description of the system).

Some policy measures are very specific (e.g. insulation standards), others are much more general in nature (e.g. an environmental awareness campaigns). Programs often encompass different policy measures and focus on specific sectors or energy applications. E.g. the MAP (environmental action plan of the distribution companies) made use of information campaigns as well as subsidy schemes for energy saving options.

The part of total savings not obtained by energy saving policies is called 'autonomous', because it is the result of factors largely outside the control of national energy policy, e.g. high world oil prices or general technological progress. However this division is somewhat too simple as Figure 1.6 shows. Normally energy savings are investigated for a fixed evaluation period and it is assumed that only actual policy measures have an impact (see contribution 'actual policy' in Figure 1.6). But often, earlier policy measures contribute to the savings achieved in the evaluation period as well (see 'earlier policy' in Figure 1.6). A clear example is the improved efficiency boiler that has become standard owing to earlier policy support. In later years this device still contributes to savings, while policy support has ceased to exist. This contribution will diminish in time, when all improved-efficiency boilers have been replaced by high-efficiency boilers. Therefore, total energy savings achieved should be split into three parts:

- energy savings owing to actual policy measures,
- energy savings owing to earlier policy measures,
- autonomous energy savings.

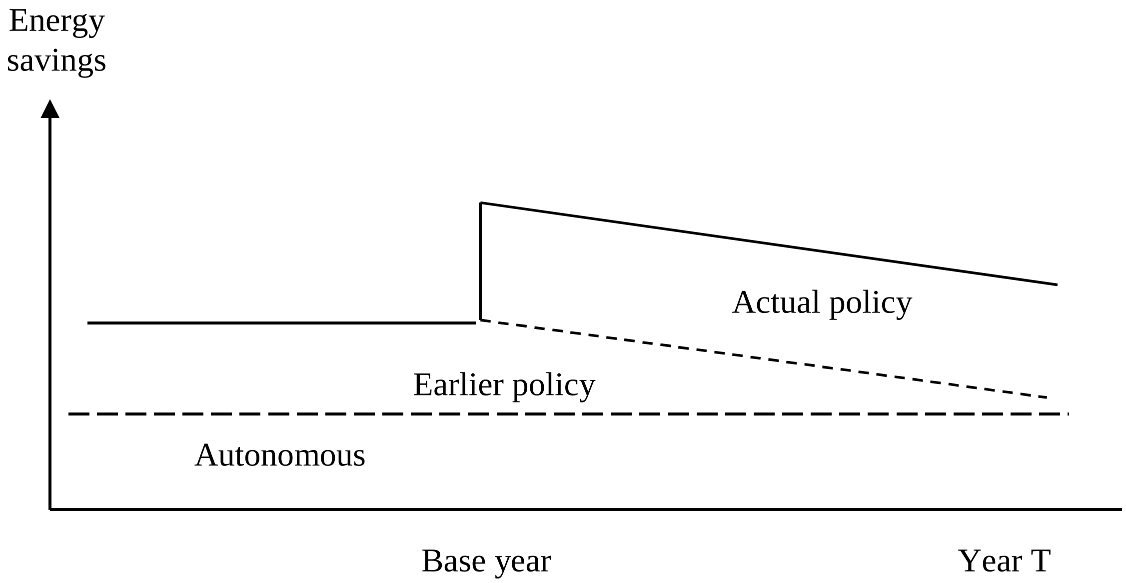

Figure 1.6 Composition of total energy savings in the evaluation period (example)

As in many developed countries energy saving policy already exists for 25 years, it is difficult to discern autonomous energy savings from savings resulting from 'earlier' policy measures. Especially for governmental expenditures on RD&D it is difficult to allocate the corresponding energy savings, as results take a long time to emerge.

Effectiveness of policy measures on energy savings

Evaluations normally are part of a policy process that starts with the formulation of goals or targets for energy savings. The evaluation not only must determine the achieved savings, but should relate them to the set target as well. In principle, this check of effectiveness of policy regards a simple comparison of two figures: the expected energy savings and the achieved savings. However, in practice there often are problems with the definition of both figures, as will be highlighted in Section 1.4.

With respect to the effectiveness of separate policy measures the issue of interaction between the saving effects of various policy measures must be taken into account. An example for the Netherlands regards realised electricity savings for appliances as a result of a combination of energy efficiency labels and energy premium scheme. Here total savings should be split into a label effect and a premium effect. However, it is thought in Ybema (2002), and supported by BD (2002), that the combination provides more savings than the sum of the savings for each measure apart. Thus, apart from calculation problems, the question arises how to attribute the extra savings of the combination to both policy measures.

Cost efficiency of policy measures for energy savings

In VBTB (1999) three criteria are formulated to judge policy results:
- Goal attainment: has the goal, e.g. 2% energy savings per year, been reached?
- Policy effectiveness: how much has policy contributed to the goal and does this agree with earlier assumptions?
- Cost efficiency of policy: how much did it costs for government, and does the result confirm earlier expectations?

The first two issues have been dealt with already. The third one, cost efficiency for policy, is generally defined as the ratio between means and effects; for energy savings it regards the ratio between government expenditures on savings and realised savings owing to policy measures. Government expenditures on savings encompass:
- financial support for implementation: subsidies, fiscal incentives,
- organizational costs for subsidy schemes,
- expenditures for information/awareness campaigns,
- RD&D-expenses.

Financial support for implementation is well documented in general and can be easily attributed to the resulting energy savings. Organizational costs are more difficult to assess. Moreover, often they must be attributed to several support schemes, each with its own savings achieved. Costs of media campaigns are known but it can be troublesome to assign costs to specific energy savings achieved. For RD&D it is most complicated to attribute these expenditures to savings achieved with newly developed saving options. Not only there is a considerable time lag between expenditures and saving effects, but part of RD&D-expenditures will never result in energy savings.

Often mentioned issues in discussions on cost efficiency of policy are ‘free riders’ and ‘spill over’ effects. Free riders decrease the cost efficiency of policy measures because they apply for financial support, but would have taken the saving measure anyway. Spill over effects regard additional saving effects realised by actors that not belong to the target group of the policy measure. For instance, government support for efficient boilers of social housing corporations can decrease the extra costs of these boilers, thus stimulating the penetration at dwellings of house-owners as well. Spill over effects increase the cost efficiency of policy measures.

The energy users spent time and effort to make choices on investments in energy saving systems. It demands skills and time too to become acquainted with new technology. The associated costs constitute the so-called transaction costs of energy savings. The same applies to other parties involved, such as energy suppliers that stimulate energy savings with their customers. These costs have to be taken into account too, but generally are not part of the analysis directed at efficiency of saving policy.

Supplemental effects of energy savings

Saving energy can lead to other effects that are important from policy viewpoint. Therefore the scope of evaluation is sometimes extended outside the energy domain. Presently, the effect of energy savings on emissions of CO_2 is a regular part of national evaluations in the Netherlands (e.g. Harmsen (2005)). In general, possible impacts of energy savings regard:

- import dependence of energy supply,
- competitiveness for industry,
- energy costs as fraction of household incomes,
- employment effects in business,
- reduction of emissions (CO_2, SO_2, NO_x, small particles),
- change in demand patters for electricity,
- health and comfort effects.

Generally speaking, these issues are often part of policy formulation and scenario studies, but they are hardly dealt with in ex-post evaluation studies regarding realised energy savings. For instance, in EC (2003) most of the supplemental effects are mentioned as reasons to save energy. On the other hand, the study IEA (2004) does not focus on the import dependency effect due to realised energy savings in OECD-countries, nor does it pay attention to other supplemental effects. In an evaluation of voluntary agreements on increased industrial energy efficiency, in Glasbergen (2001), the effect on competitiveness lacks too. An exception for ex-post evaluations is energy savings in combination with electricity demand patterns in the USA (see overview on Demand Side Management program analyses in Fels (1993)). Health and comfort effects of energy savings are treated in Clinch (2000) for low-income households in the UK. Part of realised energy savings is used to increase indoor temperature above minimal levels and thus prevent health problems.

Process of implementing energy saving options

Recently the focus of evaluation has broadened from investigating output (saving results) and inputs (e.g. government expenditures) to the analysis of the process in between. In process oriented analyses, such as Harmelink (2005), the various steps from formulating policy to actual delivery of energy savings are distinguished. The activities of various parties are mapped in detail, intermediate quantities are defined, and the (theoretical) relation between drivers and effects is specified. For instance, in case of a subsidy scheme for insulation of dwellings, not only total subsidies provided and total savings are viewed at. The evaluation also regards intermediate results, such as the fraction of households that is aware of a subsidy scheme and the efforts of various parties. This detailed process analysis enables the detection of weak parts in the application of the policy measure, or to find the causes for not complying with targets. Process oriented evaluation often regards dedicated saving programs but in Joosen (2004) it has been applied at the sector level too.

Integral energy savings for products/services

In the preceding sections the scope of evaluation has been limited to direct energy savings at the point of energy consumption. These savings are attained by means of lowering energy demand or increasing the conversion efficiency. Energy savings are looked at separately for each part of the chain, ranging from energy extraction, via conversion and end-use to meeting socio-economic needs with products and services. In a different approach, called energy analysis, the energy-content of products and services is calculated. The energy content is based on the energy efficiency of energy supply and the amount of energy used for all activities that have contributed to the product or service (see e.g. Vringer (2000)). This ‘chain efficiency’ approach offers the opportunity to analyse energy savings that arise outside direct energy use, e.g. less use of materials, or shifts between products/services that meet the same socio-economic needs. Such an integral approach has already been part of Dutch saving policy in the nineties, when dematerialization became part of the target in the white paper EZ (1995) on energy savings. Probably due to difficulties in developing policy measures to influence the use of materials, dematerialization is no longer part of national policy targets on energy savings. Presently, voluntary agreements with industry offer the opportunity to use an integral approach. For instance, limiting transportation needs of production can be part of the voluntary agreement. However, in practice the integral approach is still hardly implemented according to Arentsen (2004).

Other factors affecting energy trends

Changes in energy consumption were attributed to volume and structure effects and energy savings (see Figure 1.5). However, other factors are mentioned in literature too, such as:

- fuel substitution and renewable energy production,
- import and export of energy.

Substitution between fuels often changes total energy consumption because of differences in conversion efficiencies. For instance, in the past the change from coal or oil to gas in space heating has lowered energy consumption because of the higher efficiency for gas[8]. However, lower energy consumption because of a shift between fuels is not the same as energy savings. Substitution can enhance energy consumption as well, as is the case when expensive natural gas is replaced by cheaper coal in electricity production. Generally speaking, substitution aims at other goals than just energy savings, such as a reliable supply or lower energy costs. Therefore the effect of fuel substitution should be presented separately from energy savings (see also Chapter 3 of this thesis). The same applies to introduction of renewable energy that can be regarded as a special form of substitution, as it replaces the use of fossil fuels.

Import and export of secondary energy carriers can affect trends in national energy consumption as well. For the Netherlands, with two-thirds of its refinery activity aimed at foreign markets, more export of oil products means an increase in refinery production and conversion losses, and thus an increase in total energy consumption. As a result, for the same level of inland use it appears that energy supply has become less efficient. On the other hand, the substantial increase in Dutch electricity imports after liberalization of European electricity markets led to less inland electricity production and conversion losses. In this case the electricity supply system seems to become more efficient. Consequently, the energetic effects of changes in export or import should be separated from saving effects, for the same reasons as given for substitution.

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[8] For gas it is possible to use the heat contained in the water vapour from combustion. At condensation it pre-heats the relative cold return water, thus increasing the total efficiency of space heating.

Driving factors for energy use

In ex-ante evaluations, such as Dril (2005), often the scenario approach is applied. Expected energy savings are calculated with energy models, using assumptions about driving factors such as economic growth, energy prices, technological developments and policy measures. Ex-post evaluations focus on observed trends for energy consumption, energy savings achieved and actual contributions of other effects, e.g. structure effects. The scope of ex-post evaluations can be extended to analysis of the driving factors used in ex-ante evaluations. This approach can show the influence of driving factors, such as energy prices and policy measures, and thus explain energy developments and realised savings. This broadening of the scope of (ex-post) evaluations constitutes a major issue in this thesis.

Scope and subjects in this thesis

The overall goal of this thesis is to provide improved methods to analyse and explain energy trends and energy savings achieved at national and sectoral level, taking into account specific needs of policy makers. Given this goal the scope of evaluation is limited to the following subjects. Firstly, the analysis focuses on **total energy savings** and other factors that define energy consumption trends, such as **volume and structure effects**, owing to economic and socio-demographic developments, **fuel substitution** and **energy import/export**. Energy related **CO_2 emissions** are also part of the analysis but other related effects, such as SO_2 or NO_x emissions, are omitted. Integral energy savings at product or services level are not taken into account either. Secondly the work regards changes and effects at the **national or sectoral level**. This does not prohibit that in the underlying analysis a (much) lower aggregation level can be used. But evaluation of the saving effects of specific saving programs is not part of this thesis. A major subject is the **policy contribution** to total energy savings. This encompasses the issue of **effectiveness**, the comparison of targets and realisations, the role of **driving forces** and the **interaction** between the contributions of various policy measures. However, the cost efficiency of saving policy for government (ratio between expenditures and realised savings) is not part of the analysis. The same applies to analysis of the process of implementing energy savings.

1.3 Methodologies for determining energy savings achieved

Energy savings, energy use and socio-economic trends

In Figure 1.7 it is shown that socio-demographic-economic developments with respect to a chosen base year influence energy consumption. Assuming that the amount (volume) of socio-economic activities (represented by GDP) increases over a period of time, while all other factors remain equal, energy consumption increases too. A changing composition (structure) of economic activities may further increase energy consumption, but it can mitigate the volume related increase as well, depending on the energy intensity of the various economic activities. Other factors influence energy consumption too. The trend for fewer persons per household increases energy use because more (heated) dwellings are needed for the same population. However, working at home instead of at the office can decrease energy consumption. The volume and structure effects generally result in a reference energy consumption that increases compared to base year energy consumption. Energy saving activities lead to lower energy demand and to more efficient conversion of energy carriers into end-use energy forms. These savings can be the result of policy measures or they can represent an autonomous development, e.g. general technological developments. Energy savings lead to an actual energy consumption that is lower than the reference energy consumption.

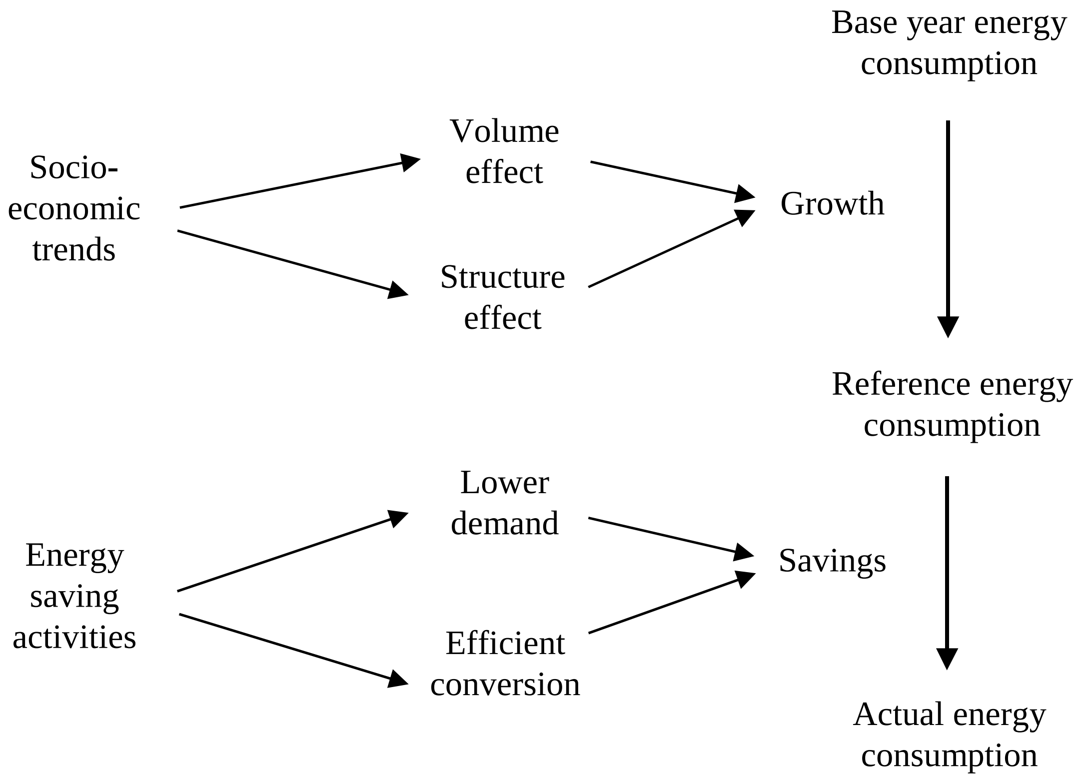

Figure 1.7 General framework for determining energy trends and energy savings

The difference between reference energy consumption and actual energy consumption is by definition equal to total energy savings (see also Figure 1.1). As figures on actual energy consumption are generally known, the problem of determining achieved savings boils down to answering the question: *what is the reference consumption that, compared with the actual consumption, shows energy savings achieved?*

The scheme in Figure 1.7 is valid for various aggregation levels, from national to sub-sector to energy application. However, the definition of volume and structure effects is not always the same. At application level, e.g. car driving, the volume effect is defined as growth of person-km driven by car. Structure effects constitute e.g. changes in the occupation rate of cars or changes in average driving speed. At sectoral level the volume effect often is defined in terms of Value Added. Here the structure effect can constitute dematerialization, i.e. realising growth in economic terms with relatively smaller growth in physical production. Because physical production predominantly defines energy demand, this structure effect will mitigate growth of energy consumption. At national level growth of GDP is generally taken as the volume effect. All shifts between contributions of various (sub)sectors to GDP, and structure effects mentioned earlier, compose the national structure effect.

The ratio between energy consumption and GDP is called the energy intensity. The change in energy intensity is caused by energy savings or by structure effects. In addition, it must be remarked that in the approach applied in this thesis, substitution between energy carriers and changes in energy import/exports are part of the structure effect.

Applied methods in determining total energy savings achieved

In this introduction a short overview of methods, mentioned in the literature, used to calculate energy savings at sectoral or national level will be presented. An extensive overview of methods, as well as problems and limitations, is presented in Chapter 2 of this thesis.

For calculation of total energy savings the following methods are mainly applied according to literature:
- decomposition analysis
- energy efficiency indices
- energy efficiency indicators
- frozen technology
- engineering calculations.

In **decomposition analysis** total energy consumption is divided into segments, and energy use for each segment is scaled according to the trend for a variable that defines energy use. Summing over all segments delivers total reference energy consumption, being the result of volume and structure effects. The difference with total actual energy consumption provides the figure for energy savings achieved (see Figure 1.7). Actually, the change in total energy consumption is decomposed into a volume, a structure and a saving effect. Decomposition in general is presently the method applied most in evaluations of energy trends and total energy savings, e.g. Schipper (2001), Howarth (1991), IEA (2004) and Fischer (2002). An example of decomposition, applied for the Netherlands, is presented in Hoen (2004). However, in general the calculated saving effect only approximates true energy savings because, in most decomposition analysis, not all structural factors are captured (see Chapter 2 of this thesis).

When applying the **energy efficiency indices** method, the reference energy consumption is determined at sub-sectoral level, on the basis of detailed production trends (‘volume’ factor) and some correction factors (for e.g. higher product quality demands and extra environmental measures, constituting the ‘structure’ factor). The results are aggregated, providing the reference energy consumption for industrial sectors. This quantity is compared with observed energy consumption, providing an index that shows efficiency improvement compared to a base year. The method has been applied in the evaluation of voluntary agreements in Dutch industry, presented in Glasbergen (1997). The use of detailed confidential data limits transparency of the calculations. Moreover, the relative index figures do not provide information on absolute energy consumption and amount of PJ’s saved. Finally, in some cases it is not clear how use of energy carriers is split into energetic use and use as feedstock (not being part of the analysis).

So-called **energy efficiency indicators** are constructed to provide information on realised energy savings for specific parts of total energy consumption, for instance space heating in dwellings or cement production in industry. The indicator shows the development in the ratio between actual energy consumption and reference consumption. Aggregated over all indicators an estimate of total energy savings can be made. In the international Odyssee-project, sponsored by the EU from 1993 on, a great number of indicators have been composed (e.g. see Odyssee (2003)). For the same reasons as with decomposition, the energy efficiency indicator method can only approximate 'true' energy savings achieved. Moreover, the method does not guarantee a complete coverage of national or sectoral energy consumption.

In the **frozen technology method** energy savings are calculated by replacing the actual energy efficiency values of energy applications by the values from the base year. This method is often applied to investigate future saving potentials too, for instance for the Netherlands in in Blok (2001) on the ICARUS database, in which national and sectoral saving potentials are presented. Contrary to other methods this approach demands a (very) low aggregation level where specific technologies and saving options can be identified.

Engineering calculations are often used to calculate energy savings for dedicated energy systems, mainly on the supply side of the energy system. For a given output the difference in input between an efficient and a conventional system is calculated. A clear example is the calculation of total energy savings from cogeneration, where fuel input is compared with that of replaced electricity production in power stations and replaced heat production in boilers. A drawback of engineering calculations regards the limited scope of the analysis. For instance, when calculating cogeneration savings over a period, the changing conversion efficiency of conventional electricity production often is not taken into account.

Although all methods use the reference approach in one way or another, they differ as to the amount of detail, the definition of energy use (e.g. including or excluding feedstocks), the coverage of relevant energy consumption and the interaction with other saving developments (see next Section 1.4).

Applied methods in determining policy-induced energy savings

For calculation of policy-induced energy savings the following methods are used according to literature:

- engineering calculations based on total implemented saving options,
- engineering calculations based on policy measure monitoring,
- field surveys on investment in saving options,
- regression analysis.

Detailed surveys on applied energy systems and **implemented saving options** provide figures on yearly penetration of various saving options. In combination with engineering estimates of energy savings per option, total savings can be calculated for each year. However, it is not always clear which part of calculated energy savings is the result of the policy measure analysed. For instance, in the evaluation of the environmental action plan (MAP) of Dutch distribution companies, Berenschot (2001) states that it is not clear which part of realised energy savings was the result of the MAP scheme, and which part was the result of other policy measures or even exogenous factors, such as energy prices.

Policy measure monitoring constitutes the registration of implemented saving options measures because of the introduction of a specific policy measure. For instance, in evaluating the introduction of performance standards for new dwellings or appliances, monitoring regards the total number of new dwellings built or appliances sold where these standards were applied. In combination with engineering calculations on savings per device, total policy related savings can be calculated. This method has been applied for e.g. calculating the policy related CO_2 emission reduction in the Netherlands in the period 1990-2000 in Jeeninga (2002). Energy savings owing to several fiscal support schemes have been calculated in the same way in Senter (2001).

Field surveys can provide information on the saving measures taken, as well as the reasons for investing in energy savings. In case of energy saving investments stimulated by financial support, this enables a correction for free riders (actors that had invested anyway, even without subsidies). The corrected figures on savings are referred to as policy-induced savings. For a number of investment subsidy schemes, aimed at firms in the Netherlands, results are presented in IBO (2001).

Finally **regression analysis** is used often to evaluate energy saving programmes. Participants are compared with non-participants and (cross-section) regression analysis is used to ascribe differences in observed energy consumption to the saving programme. Some examples about various saving programmes in the USA are given in Horowitz (2005). Other evaluation studies use time-series regression to detect the influence of a (temporally) saving programme on energy consumption trends. In the Netherlands regression analysis has been applied to estimate realised energy savings for horticulture in RK (2002). For a number of firms and for various years it was tried to relate the observed specific energy use per unit of production to the presence of energy saving devices and a number of production characteristics.

1.4 Issues and problems in evaluation studies

An elaborated description of issues and problems in many evaluation studies on energy trends and savings is given in the following chapters. Here an overview is presented. The issues and problems regard both bringing about results (**calculation**) and meeting demands of users of the results (**presentation**). Further on, it can regard either **energy trends and total savings** or **policy-induced energy savings**. For each of these four cases a number of issues and problems are highlighted (see summary in Table 1.4). Some other issues, presented in the table too, are of a general or miscellaneous nature. It must be remarked that the indicated issues and problems mentioned do not play a role in each evaluation study. Many are valid only for part of the evaluation studies encountered in literature.

Table 1.4 Overview of issues and problems in evaluation studies on energy trends and savings

Energy trends and total savings		Policy-induced energy savings		Miscellaneous/general
Calculation	Presentation	Calculation	Presentation	
Aggregation level in decomposition	Uncertainty in saving results	Policy/autonomous savings	Ex-post/ex-ante formats	Lack of general framework
Reference variables used	Integrated effects/ consistency	Earlier policy measures	Flexible format for policy demands	Emission factors
Energy quantities used	CHP, import/export and substitution	Interaction between policy measures	Explanation of policy contributions	Coupling analysis and statistics
Value of primary factors	Saving target versus realisation	Interaction policy and other factors	Policy target versus realisation	Change of base year in presentation
Interaction between saving effects	Explanation of saving effect		Possible interaction in set of measures	Data quality and margins in results
Interaction savings and other effects				Combination top-down/bottom-up
Temperature correction				

Issues in calculation/energy trends and savings

Despite many evaluation activities in the last decades, **a general framework lacks** to perform calculations on total energy savings achieved. At Dutch national level this problem was solved when the Platform Monitoring Energy savings (PME) was established, which provides saving figures, e.g. in Boonekamp (2001). But it is still valid at international level where different databases and methods are used by individual countries, by the indicator project of the EU in Odyssee (2003) and in IEA (2004). Therefore saving figures published are method dependent entities. Moreover, it is not clear how the results of the various calculation methods can be brought in line. Therefore energy saving figures do not have the same robust meaning for policy, as figures on GDP, total energy consumption and employment have.

Even when the same evaluation method is used, saving results are hardly comparable. For decomposition studies the problem regards the way the reference energy consumption is constructed (see Figure 1.7). Studies use different **aggregation levels** in the decomposition, and different **variables** to calculate **reference** energy consumption. Consequently different saving figures result, even if they are based on the same data set (see also Chapter 2 of this thesis).

Another issue is the use of different **energy quantities** in the calculation of total energy savings. Most studies use *energy consumption*, i.e. the energy content of all energy carriers used. Other studies use *primary energy consumption*, where electricity is not valued at its energy content but at the amount of fuel to produce it in power stations. A few studies use final energy demand of heat and electricity, in which further conversion of delivered energy carriers is taken into account. The energy quantity chosen also defines the definition of energy savings, for instance *savings on energy consumption* or *primary energy savings*. Consequently the results will differ, as will be illustrated in Chapter 2 of this thesis.

When using the concept of primary energy consumption, one should define primary multiplication factors that represent the conversion losses for delivered energy carriers. Given the usual conversion efficiency of power plants in developed countries, based on fossil fuels, a multiplication factor of roughly 2.5 results for electricity. In case of substantial contributions of nuclear and hydropower, or electricity imports, this value can range between nearly 1 and 3. For oil products from refineries a multiplication factor of about 1.07 must be used when calculating primary energy consumption. Primary multiplication factors can differ for various consumers due to varying transmission losses. More fundamental issues regard the choice between using **static or dynamic** primary energy consumption in the analysis. In the static case primary multiplication factors are based on conversion losses in the base year, and in the dynamic case on losses in the current year. Another choice regards **average or marginal** efficiency of power plants that would be the alternative for saving electricity. In case of calculating energy savings for cogeneration, the assumed conversion efficiency of boilers must be specified too. Here differences regard the use of mean boiler efficiency, or the efficiency of heat production that is replaced by cogeneration.

Interaction between saving effects can lead to a total saving effect that is not equal to the sum of the separate effects. One form of interaction regards savings on end-use (e.g. electricity savings) and savings in supply (e.g. more efficient power stations). Evaluation studies, focused on end-use sectors only, often disregard this interaction. Decomposition analysis can deal with this interaction but other evaluation methods have to take note of it specifically (see Chapter 2 of this thesis).

The same issues as mentioned for interaction between various saving effects are valid for **interaction between energy savings and other effects**, such as volume and structure effects. Again decomposition analysis takes account of these interactions but for other methods it is not always clear how the separately calculated effects add up to the observed change in energy consumption

An issue related to realised energy consumption trends regards the correction for yearly variations in outdoor temperature that affects energy use for space heating. This **temperature correction** on energy statistics is needed to discern between changes owing to climate variations on the one hand, and changes owing to socio-economic factors and energy savings on the other hand. Evaluation studies differ with respect to taking into account climate variations and the way variations lead to corrections on energy consumption.

Issues in presentation/energy trends and savings

Apart from the problems with calculation, also problems arise for presentation. Often results on realised energy savings are presented as robust figures. However, as already mentioned, often it is difficult to determine reference energy consumption, and therefore results only approximate true energy savings. Calling results ‘energy savings’ or ‘energy efficiency improvement’ should be no problem provided that **uncertainty margins** are attached to the results. However, hardly any evaluation study pays attention to margins in the values of the input data and the errors made in the calculation of reference energy use.

National decomposition analysis regards by nature all effects that contribute to the change in energy consumption at national or sectoral level. However, if decomposition is applied to parts of national energy consumption only, for instance industry or households, it is not clear how sectoral effects add up to the national total. Next to this issue of **integrating effects** over different aggregation levels, there is the issue of maintaining **consistency** between various effects. For other methods than decomposition, often it is not clear how calculated saving effects add up with volume and structural effects to the observed total change in energy use.

Other factors than volume, structure and total saving effects are important too, when gaining insight into energy consumption trends. Firstly, **CHP production** at sites of end users is an important subject of energy policy, both national and at EU level. However, most evaluations do not provide separate saving figures for cogeneration. In addition, for a small internationally oriented country like the Netherlands, energetic effects of changes in import (electricity) and export (refinery products) can be important too. However, most evaluation studies hardly pay attention to energy **import/export**. To a lesser degree this also applies to **fuel substitution** that is taken into account as separate factor in some decomposition analysis.

Calculated total energy savings sometimes must be compared with a policy target value. Comparable formats (sectors, energy quantities, etc.) are a condition for a sound comparison. However, in many cases the target has been based on assumptions for exogenous trends (economic growth, energy prices) that are different from actual values. Therefore the comparison should also account for effects of these diverting exogenous trends on total savings. This **saving target-versus-realisation** comparison asks for an evaluation method that enables corrections for diversions in exogenous trends.

Evaluation studies calculate values for growth, structure and saving effects but they do not **explain the size of the effects**. Explanation asks for analysing the relationship between influencing factors, such as interest rates and energy prices, and total energy savings. This is quite different from the bookkeeping analysis deployed in for instance decomposition studies.

Issues in calculation/policy-induced energy savings

A great part of evaluation studies regards calculation of energy savings owing to policy measures. The methods deployed often focus on the penetration of specific saving options, from which total policy-induced energy savings are calculated. But other methods, such as regression analysis, are used too. However, even more than for evaluation of total energy savings, a **general framework** lacks to calculate policy-induced energy savings.

Evaluation studies often focus on policy-induced energy savings only. Because in this restricted approach total energy savings are not determined, it is not possible to analyse **policy versus autonomous** savings and to check policy savings against total savings. Thus the policy question ‘how much of total energy savings is autonomous and how much is policy-induced’ cannot be answered.

The contribution of policy measures to realised energy savings will regard a chosen evaluation period. However, as already discussed, in this period there can exist a saving effect of

earlier policy measures. If this is not taken into account, it will be part of autonomous energy savings in the evaluation and the contribution of policy measures will be underestimated.

Analysis of policy effectiveness often regards the saving effect of one policy measure, without taking into account **interaction between policy measures**. Two measures can overlap as to their saving effects, or reinforce each other's effect (see Chapter 5 of this thesis). Interaction is sometimes mentioned in evaluation studies, but hardly **quantified**.

Evaluation studies on policy measures should take into account **interaction between policy and other factors** as well. For instance, if rising fuel prices stimulate the application of efficient technologies, these extra savings can show up as policy-induced savings. In some program evaluations, e.g. Horowitz (2005), this problem is solved using a reference group of energy users that do not participate in the programme. However, in evaluations of programmes executed at country-scale, such as in EnergieNed (1995), this kind of analysis is not possible.

Issues in presentation/policy-induced energy savings

The results of evaluation studies on policy-induced energy savings often are compared with policy targets based on scenario studies. However, it is questionable whether the results are comparable as to format, inputs used and calculation method. For instance, in the Netherlands present saving targets are based on calculations with bottom-up models that take into account all specific saving options. However, realised figures on savings are presently based on a top-down method (adapted decomposition, see Chapter 2 of this thesis). Thus it is not possible to directly compare the values for realisation and targets, due to differences in **ex-post and ex-ante formats** for policy-induced savings.

Apart from differences in format there are also differences in definition between ex-ante and ex-post saving results. If realised policy-induced energy savings are compared with policy targets, a correction must be made for actual trends in exogenous variables, being different from assumptions made when formulating the target. These exogenous variables, such as economic growth and energy prices, can affect energy consumption, total energy savings and the fraction of policy-induced savings. Therefore **policy target versus realisation** comparison asks for policy-induced savings to be analysed in conjunction with total energy savings as well as structure and volume effects.

Most (decomposition) methods are based on standard statistical data that dictate the format of the saving results. Policy makers on the other hand ask for results that comply with their own information needs. For instance, energy savings obtained by **cogeneration** should be separately presented to be able to evaluate cogeneration-policy. However, not all evaluation methods offer a flexible format for policy results.

Present evaluation studies offer information on the contribution of policy measures to realised energy savings but do not **explain contributions**. This explanation asks for analysing the relationship between policy measures, other influencing factors and the resulting policy-induced savings. This is quite different from the book-keeping methods deployed in most evaluation studies on policy measures.

In the paragraph on calculation of policy contributions, the need to take account of interaction between the effects of policy measures was already mentioned. Given the increasing number of policy measures (see MURE (2005)) this becomes more important. However, due to the non-linear increase in possible interactions the analysis of interaction for all combinations of measures will ask quite some effort. In practice not all combinations will show substantial interaction effects. Therefore, a procedure is needed that effectively investigates **possible interaction in sets of policy measures.**

General and miscellaneous issues

Evaluations of observed energy trends and savings achieved are more and more extended to the field of accompanying CO_2 emissions and emission reductions. Changes in the use of fuels can be transferred directly into emission changes, using fixed CO_2 emission factors for various fuels. However, to analyse emission effects of changes in electricity use, **indirect emissions** have to be determined. These emissions depend on the fuel input of power stations; the calculation resembles that of calculating primary energy consumption described earlier. It asks for an integrated analysis of end-use and supply sectors as well. Finally, an important source of differences in emission results originates from the reference system for electricity: the inland production system or the total system including import and export of electricity.

Evaluation studies at national or sectoral level will use standard statistical data. However, the format of input data and the results often diverge from that in energy balances with its well-known set of energy carriers and sectors. Another problem regards updates of statistical data, where it is not clear how updates affect the evaluation results. Thus the **statistics-analysis coupling** is not always transparent.

A complicating factor in comparing various evaluation results is the difference in base year used. In policy-oriented evaluations, the choice of the base year often is defined by the needs of the user of the results. For instance, evaluations with respect to achievements as to the Kyoto targets to mitigate greenhouse gas emissions use base year 1990, agreed upon internationally. In scientific analysis however, data availability often dictates the choice of the base year. On the other hand, most evaluation methods can apply another base year if needed. But often it is not possible to **change the base year** in the presentation at one’s discretion, or without increasing uncertainty in the results.

As already mentioned, hardly any evaluation study quantifies uncertainty in results. Consequently, the effect of quality and availability of input data on margins in calculated saving figures is not known. Because improved data normally ask more effort, information is needed about the most efficient way to improve the quality of results. To this end a method to **relate data quality and margins in result** is needed.

Recently the merits of **top-down versus bottom-up** evaluation methods have been discussed in Bowie (2005) as part of drawing up the new Energy Service Directive of the EU. The directive proposes a saving target for all EU-15 countries and it has been decided to use both type of methods mentioned to evaluate achievements. However, it is not clear how the (conflicting) results should be combined to draw conclusions on fulfilment of targets. Furthermore it is not clear whether the combination of top-down and bottom-up methods covers the information needs of the directive. Possibly this asks for further development of evaluation methods.

1.5 Problem formulation and research questions

As already described the overall goal of this thesis is: "*to provide improved methods to analyse and explain energy trends and energy savings achieved at national and sectoral level, taking into account specific needs of policy makers*".

To reach this goal, it is necessary to take hold of the preceding issues and problems with regard to monitoring and evaluation. Therefore, in the problem formulation of this thesis the problems and issues are transposed into a number of research questions. Addressing these questions will show the improvements that are needed. In this thesis the research questions are grouped to the following themes:
A. Improved methods for monitoring and evaluating energy savings achieved.
B. Interaction in calculated energy saving effects and contributions of policymeasures.
C. Presentation of evaluation results, focusing on information needs of policy makers.
D. Explanation of the causes of observed total and policy-induced energy saving trends.

The first theme regards issues and problems that are treated differently in existing evaluation studies. Possible improvements are illustrated, using the results of new methods presented in this thesis. Theme B regards a specific phenomenon in evaluations, namely interaction between calculated saving effects and interaction between the saving effects of various policy measures. The treatment of interaction is one of the goals of the new methods presented in this thesis. Theme C does not regard the calculation itself, but the way evaluation results (should) meet policy information needs. These needs may require adaptations of existing methods that mainly focus on the calculation itself using (easily) available data. The last theme deals with specific scientific and policy demands: the explanation of results found in the analysis, using observed trends for deciding factors. As for the second theme, this asks for new approaches too.

With respect to **improved methods** the general problem is formulated as:
How can existing calculation methods on energy savings at national and sectoral level be improved as to provide meaningful results in a consistent, reliable and transparent manner?
The following research questions, each relating to a specific problem or issue, can be formulated here:
A.1 What aggregation level and which reference variables must be chosen as to construct reference energy consumption?
A.2 Which energy quantity should be used, that both meets demands of sound calculation and presentation of meaningful results?
A.3 In case of primary energy consumption, which calculation approach must be chosen (static or dynamic) and which factor to convert electricity use (average or marginal)?
A.4 How can indirect CO_2 emissions from electricity use be determined in a consistent manner as to the primary energy consumption approach?
A.5 How to assure an integrated and consistent calculation of sectoral results?

A.6 How to increase transparency between energy statistics used and results presented?
A.7 How to correct energy statistics for yearly variations in outdoor temperature?

With respect to the specific issue of **interaction** the problem can be formulated as: *How to deal with various interaction effects in the calculation of total energy savings and policy-induced energy savings?* Research questions regarding specific issues are:

B.1 How can interaction between various energy saving effects be dealt with?
B.2 How to deal with interaction between energy savings and other (growth) effects?
B.3 How can interaction effectively be investigated in sets of policy measures to stimulate energy savings?
B.4 How to quantify interaction between specific policy measures that stimulate energy savings?
B.5 How do policy measures and energy prices interact as to stimulating energy savings?

With respect to **policy focus** of results the problem can be formulated as: *How to define the analysis structure and presentation format, as to provide more useful information to policy makers on energy savings achieved and on the policy contributions to these savings?* This leads to the following research questions regarding specific problems and issues:

C.1 How to supply policy relevant results for cogeneration, import/export and substitution between energy carriers?
C.2 How can policy-induced, autonomous and total energy savings be calculated consistently?
C.3 How to determine uncertainty margins for calculated energy savings?
C.4 How can the quality of calculated figures about energy savings be improved?
C.5 What possibilities exist for changing the base year in presentation of results?
C.6 How can ‘top-down’ and ‘bottom-up’ evaluation demands of the EU-directive on energy savings be met?
C.7 How can realised saving figures be compared with targets for energy savings?
C.8 How to deal with energy saving effects of former policy measures?

For the specific policy issue **explanation of saving trends** the problem is formulated as: *How can calculation of energy saving effects be extended to explanation of the saving effects found?* Research questions (for household energy use) regard:

D.1 How do factors with system wide effects influence energy consumption and energy savings?
D.2 How do energy prices affect energy savings?
D.3 How much do energy taxes, subsidies and regulation contribute to energy savings achieved?

1.6 Approach taken and outline thesis

Even with the limitations in scope mentioned earlier, it is obvious that the preceding problem formulation encompasses a broad field of evaluation issues and problems. Answering the many research questions formulated, and providing necessary improvements, asks for a systematic and broad analysis.

The analyses presented in Chapters 2 to 6 of this thesis rely mostly on current work in the unit Policy Studies of ECN. For this thesis, the scope of the analysis has been extended in order to investigate problems and issues further, and to present the capabilities of new evaluation methods developed. As can be seen in Table 1.5, the analysis presented in each chapter only covers a limited set of research questions of this thesis. However, the table also shows that the combined results of Chapter 2 to 6 cover most of the research questions.

Subjects of analysis in Chapter 2 to 6 of this thesis

In Chapter 2 six evaluation methods on total energy savings are analysed and judged as to their dealing with a number of evaluation issues and problems (see Table 1.5). These issues and problems regard themes A, B and C, excluding theme D ('explanation of changes'). Adverse effects of certain choices and problems are illustrated. An optimal treatment is proposed and methods are scored in fulfilling the demands of this treatment. Finally a number of improvements, to be applied in energy savings evaluation methods, are suggested.

In Chapter 3 a system to present and analyse national and sectoral trends in energy consumption and CO_2 emissions is described. This system is called MONIT (Monitoring Of National energy use, Information and Trend analysis). The analysis method used is based on the concept of reconstructed energy balances. Energy use developments are mapped with a step-by-step constructed set of energy balances, starting from the base year balance, and ending with the energy balance for the year of interest. The observed changes in energy use are unravelled into 14 explanatory factors, including four energy-related structural changes, five saving factors, fuel mix changes and changes in export and import of energy. Next to energy consumption per energy carrier and per sector, also changes in final demand for electricity or heat, cogeneration, primary energy use and CO_2 emissions are dealt with. This policy oriented monitoring and evaluation system has a close connection with standard available energy statistics. The themes dealt with in this chapter mainly regard A and C.

Chapter 4 describes a bottom-up model, used for scenario studies, that simulates past trends in household energy consumption. The change in total energy consumption can be attributed to a great number of saving and structure effects. Because all saving options are present, total calculated savings are thought to represent the 'true' energy savings. A special feature is the calculation of various direct and indirect energetic effects of system wide changes (e.g. smaller household size or the introduction of district heating). Because of the detailed modelling it is also possible to calculate the fraction of fuel use that is dependent on average outdoor temperature during the heating season. The issues that are taken account of regard mainly theme A on improved methods.

Table 1.5 Research questions related to evaluation issues and problem, covered per chapter[1]

		Evaluation of methods	Reconstructed balances	Simulation households	Interaction of policies	Price elasticities	Synthesis of results
	Chapter	2	3	4	5	6	7
	Improved methods						
A1	Aggregation/reference variable	×		×			
A2	Energy quantities used	×	×				
A3	Value of primary factors	×	×				
A4	Indirect CO_2 emission		×				
A5	Integrated sectoral results	×	×	×			
A6	Transparency statistics/results		×				
A7	Temperature correction		×	×			
	Interaction effects						
B1	Interaction for saving effects	×	×	×			
B2	Interaction saving/other effects	×	×				
B3	Possible interaction P&M				×		
B4	Quantifying interaction P&M				×		
B5	Interaction policy/other factors					×	
	Policy focused results						
C1	CHP, im-/export, substitution	×	×				
C2	Policy/autonomous savings				×	×	
C3	Uncertainty in saving results	×	×				
C4	Data quality/margin in result	×					
C5	Change of base year		×				
C6	Top-down and bottom-up	×					
C7	Realised savings versus targets						×
C8	Effects of earlier policy						×
	Explanation of changes						
D1	System wide effects			×		×	
D2	Explanation price effects					×	
D3	Explanation policy effects				×		

[1] Issues not dealt with explicitly here: lack of general framework and flexible format for policy.

The focus in Chapter 5 is on interaction between energy saving effects in households, as a result of various policy measures, both in a qualitative and a quantitative way. The qualitative method uses the mechanism behind the implementation of saving options to rate the interaction between various combinations of (two) policy measures. The method is deployed to the actual set of measures to improve energy efficiency in households. It delivers a matrix in which each cell contains qualitative information on the strength and type of interaction (overlapping, reinforcing, or independent of each other). The quantitative analysis uses the same simulation model as used for the analysis in Chapter 4. The contribution of the specific policy measures, i.e. regulatory energy tax, investment subsidies and regulation of space heating, and their interaction, are determined quantitatively. The main focus in this chapter is on interaction issues (theme B), but theme D about explanation of results is dealt with too.

Chapter 6 too deals with simulation of household energy consumption in the period 1990-2000. Here the focus is on energy prices and realised savings, in conjunction with policy measures. First, elasticity values are analysed for a number of price cases, and explained using the detailed results from the simulation model as to changes for energy systems and saving options. Next, price elasticities are analysed with and without the policy measures applied, i.e. energy taxes, subsidies and standards. Research questions dealt with in this chapter regard theme D and theme B.

Synthesis of results and conclusions

In Chapter 7 of this thesis a synthesis is made of the information in preceding chapters with respect to improved evaluation. The research questions, mentioned in the problem formulation, are addressed one by one, using information from Chapter 2 to 6. Improvements in the evaluation of energy trends and savings, found in this thesis, are presented too. Research questions not covered in these chapters (see Table 1.5, last column) are addressed, using additional information provided in Chapter 7. An overview of improvements, including the newly developed methods that provide them, is presented too.

In Chapter 8 the results obtained are summarized and some general observations are made on the present use of evaluation results, and ways to improve this. Finally conclusions are drawn about improvements, new methods developed and some quantitative results of analyses performed.

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Chapter 2 EVALUATION OF METHODS USED TO DETERMINE REALISED ENERGY SAVINGS[9]

Abstract

Most methods to determine realised total energy savings at national or sectoral level make choices, or neglect problems, which hamper the calculation of sound and useful energy saving figures. Issues are the choice of the right aggregation level, the appropriate variables to construct a reference energy consumption trend, the energy quantities to be applied and interaction between various effects. Uncertainty margins for results lack in most presentations as well. This paper presents six methods, illustrates the adverse effects of certain choices and problems, and investigates how these methods deal with them. The methods are scored with respect to the issues mentioned above. Finally a number of improvements are suggested, among which the use of final energy demand expressed in primary energy units, and bottom-up analyses at the level of real saving options. The last option is the more important, as it could provide top-down evaluation results (total savings from decomposition) as well as bottom-up policy monitoring results, both being crucial to new European energy saving policy.

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[9] Accepted for publication in Energy Policy.

2.1 Introduction and problem formulation

Energy savings represent energy that is not used; therefore it cannot be measured directly, except in some cases, such as a straightforward energy conversion process where savings are calculated from improvement of the ratio between measured output and input. But in most practical cases, e.g. heating a dwelling or driving a car, the output or ‘achievement’ is difficult to define, let alone to be measured. Just measuring the change in energy input often is not enough because the achievement could have changed too. At the level of total energy consumption of sectors or countries things get even more complicated, as will be illustrated later. In all cases the determination of realised savings boils down to answering the question: *what would energy consumption have been without the saving activities, keeping the actual achievement the same?* Or, as shown in Figure 2.1 in a dynamic fashion, *what is the reference consumption trend that, compared with the actual energy consumption trend, shows energy savings realised*?

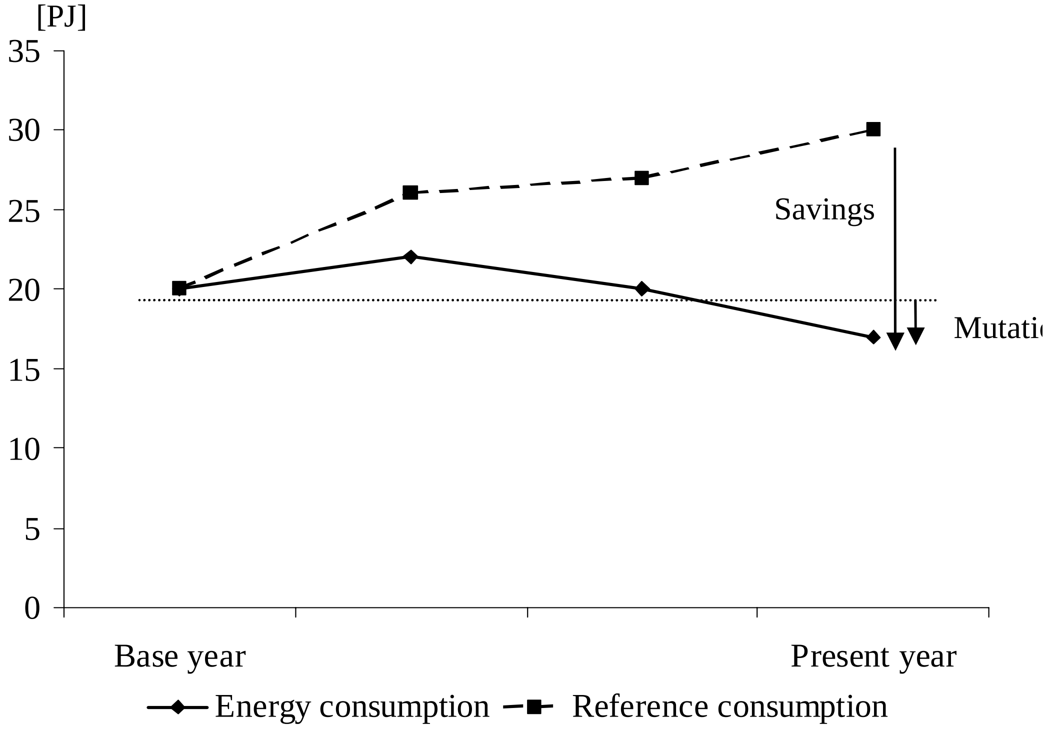

Figure 2.1 Actual energy consumption, reference consumption and resulting energy savings

Various methods, ranging from simple indicators to sophisticated decomposition methods (see Section 2.2), have been developed to answer this question. However, most methods make choices, or meet calculation problems, that lead to less valuable results for realised energy savings. A first and rather fundamental issue regards the **choice of the reference system** to be applied in determining energy savings. For instance, in case of replacing an old refrigerator with the most efficient new type, the chosen reference system can be the old type, the average type in base year or in current year, the type with the lowest efficiency that is currently sold in the shop, etc. Depending on the choices made, different saving figures are found. This problem gets more complicated if savings have to be determined over a longer period. Then the question arises how to calculate savings when the **reference system changes**. No choices on dedicated systems have to be made at the aggregated level, for instance sectoral energy use. But here a similar problem arises with respect to aggregated reference energy consumption. This regards the **choice of the appropriate variable** to construct reference energy consumption. For instance, in the sector Services the reference trend for electricity consumption can be related to either number of employees or total floor area. Different saving figures will be found, depending on the choice made. In some cases the problem can be mitigated, by executing the analysis at a lower aggregation level. Part of reference electricity use (for lighting) can be coupled to the trend for floor area and other electricity use, for office equipment, to the number of employees. Now the total saving figure found may be 'better' compared to using either floor area or number of employees only. However, this asserts that the amount of savings found depends on the chosen level of aggregation in the analysis. Thus questions about the **appropriate level of aggregation** arise. This choice not only regards the energy users, but energy use itself as well. Some analysts discern use of fuel and use of electricity in their analysis, while others work with total energy consumption. Another problem is how to cope with **interaction between two saving effects**. An example, at the aggregation level of home heating, constitutes savings owing to insulation and savings owing to more efficient boilers. Combined savings are less than the sum of savings of the two separately analysed options. At a higher level of analysis the same applies for savings on final electricity consumption and higher conversion efficiency of power plants. A similar problem regards **interaction between saving effect and other effects**, such as growth in energy using activities. For instance, if industrial production increases faster, more new energy systems are needed, thus speeding up electricity savings owing to efficient electric motors. Finally the **chosen quantities to value energy consumption** differ. Sometimes total energy consumption is set equal to the sum of energy content of all energy carriers, e.g. in Howarth and Schipper (1991), Fisher (2002) or IEA (2004). But some energy carriers have by nature higher end-use efficiency than other carriers, e.g. electricity versus fuels. A shift from fuel to electricity consumption could show up as energy savings in the analysis. The actual effect on total energy supply constitutes higher input though, as the production of electricity causes substantial conversion losses. Using the alternative quantity 'primary energy consumption' may avoid this misinterpretation of energy saving trends.

This paper will show that figures on realised energy savings depend strongly on choices made, and on (not) coping with calculation problems. Various calculation methods are compared as to the choices made and the extent they can deal with the problems cited. The focus is on methods to determine energy savings at sectoral or national level. These include new methods: a variant to decomposition analysis, described in Boonekamp, Gijsen en Vreuls (2004), reconstructed energy balances, described in Boonekamp (2004) and bottom-up simulation of household energy use, described in Boonekamp (1997). It will be shown that these new methods could contribute to solving calculation problems. Even so, in practice all methods can only approximate 'real' energy savings. Therefore attention is paid to treatment of **uncertainty** in the results provided by various methods.

It must be stressed that this paper regards total realised energy savings, and not the contribution of policy measures or saving programmes most evaluations focus on. The analysis regards historical savings, but most issues presented here are of relevance for calculation of future energy savings in scenario studies. Although cases often regard the Netherlands, reasoning and outcome of analysis are valid for all developed countries. It does not cover problems of comparing country efficiency trends, as highlighted in Phylipsen et al (1998). Finally this overview may contribute to the debate on top-down versus bottom-up monitoring for the new EU-directive on energy savings in EU-countries, as presented in Bowie (2005).

Section 2.2 provides for a brief overview of generally applied, or new, methods. In Section 2.3 choices and problems in determining savings are described. Showing effects on saving results underlines the relevance of the issues. In Section 2.4 various methods are compared as to their choices and their coping with calculation problems. Section 2.5 presents features of an optimal approach and how various methods fit in. Meeting the evaluation demands of the new EU-directive is discussed too. Conclusions and observations follow in Section 2.6.

2.2 Overview of methods to determine energy savings

General concept of determining energy savings

Before methods and their properties are described, some clarification is given on the connection between socio-economic activities and energy consumption at different levels of aggregation, and how the methods fit in. At every aggregation level it is possible to define energy using systems, ranging from a simple light bulb in an office to the national economy. In Table 2.1 examples of energy using systems are given, classified according to the aggregation levels micro, meso or macro. Input of these systems is by definition energy; output is much more diverse and often difficult to define. Therefore, the general term ‘achievement’ has already been introduced in Section 2.1. In literature ‘energy services’ is mentioned as well, but it does not cover all achievements shown in Table 2.1. Generally, ‘energy services’ is not applied in cases such as energetic outputs of conversion processes or achievements in economic terms (value added or GDP).

At the **micro-level** one finds stand-alone energy using systems, where achievements can be defined rather easily. Owing to straightforward relations between energy input and achievement it is rather easy to define energy savings. For instance, if a light bulb is replaced with a more efficient CFL, providing the same amount of light (measured in lumen), savings equal the decrease in electricity used. Car engines on petrol can be replaced with more efficient diesel engines (providing the same amount of horsepower) and conventional gas fuelled power plants can be replaced with very efficient combined cycle units.

Table 2.1 Energy-using systems at different aggregation levels, achievements and factors affecting energy consumption

Level	System	Achievement	Energy savings	Structure
MICRO				
A	Bulb	Lumen	CFL-kWh	×
B	Engine	Horsepower	Diesel	×
C	Power station	kWh	Combined cycle	×
MESO				
A	Office	Lighted space	Daylight switch	Occupation rate
B	Car	Km driven	Driving style	Weight, airco
C	Electr.production	kWh	Scheduling	Fuel mix
MACRO				
A	Services	Value added	×	Subsector shifts
B	Transport	Pkm + tkm	×	Modal shift
C	Energy supply	PJ per fuel	×	Import/export
	Economy/society	GDP	Total savings	Total structure

At the **meso-level** energy using systems are composed of a (great) number of 'micro' systems. For instance, the system 'office' encompasses not only lighting devices, but boilers for space heating and air-conditioning for cooling as well. Achievements generally can be defined in physical terms (e.g. m^2 of offices with prescribed lighting levels). Energy savings at meso-level not only comprise all related savings at micro level, but some specific saving options at this level too. Examples are daylight dependent switching of lights in offices and, for electricity production, an optimal scheduling of power plants (to save fuels). Energy savings owing to behaviour, such as fuel saving driving style of car drivers, are often found at the meso level. Total energy consumption at meso level is not only the result of savings mentioned, but is influenced by other so-called structural factors as well. For offices a higher occupation rate generally increases electricity use for lighting, offsetting the decrease owing to savings. For electricity production a change in fuel mix may either strengthen or offset fuel savings.

At the **macro-level** the 'system' is of an abstract nature, such as industrial production or 'households'. In that case achievement must be defined in non-material quantities, such as value added for Services. Energy savings at this macro-level are the aggregate of meso level savings that match. Total energy consumption at this level is also influenced by various structure effects (see Table 2.1), but mostly by growth in activities. At the highest aggregation level, the energy using system regards the socio-economic system of a country. Generally achievement is defined here in terms of GDP. Total energy consumption is the result of all savings at lower aggregation levels, all structure effects and growth of GDP.

The methods described here focus on calculation of total energy savings, generally starting with total energy consumption. As can be seen from Table 2.1, it is not possible to extract total savings from the overall energy trend because many growth and structure effects influence total energy consumption too. Therefore, all methods apply a lower aggregation level in the analysis, sometimes up to the micro level. The analysis of energy consumption trends at this lower level can take hold of growth and structure effects down from the national level (see examples in Table 2.1), thus enabling calculation of energy savings. In the following it is described how various methods deal with separating these growth and structure effects from saving effects. Actually, this boils down to constructing reference energy consumption trends, from which energy savings follow (see Figure 2.1).

The ratio between achievement in monetary quantities and energy use is called ‘energy intensity’, expressed in MJ/€. For achievements in physical quantities the ratio is called ‘specific energy use’. However, in conformity with many references, here the term energy intensity is applied in all cases.

Methods for determining energy savings at sectoral or national level

Table 2.2 presents six methods, currently practised to determine energy savings at national or sectoral level, and some information on the scope of application. More about properties of these methods will be said in Section 2.4.

Energy indicators provide information on efficiency trends for (small) parts of total energy consumption only, e.g. litres of petrol per km driven by car. A number of these indicators can be combined into an aggregated savings indicator, weighting each indicator trend with the fraction the energy application has in total energy consumption. An example of such an aggregated savings indicator is the **ODEX indicator** on energy efficiency for EU-countries, described in Odyssee (2003) and Lapillonne et al (2004). The ODEX indicator presently consists of 26 separate indicators valid for the end-use sectors industry, households and transportation.

Table 2.2 Evaluated calculation methods on energy savings at sectoral or national level

Method	Scope
ODEX (aggregated savings) indicator	EU-countries, total end-use savings
Frozen technology	Various cases, all saving options
Decomposition analysis	Various countries and sectors
PME decomposition	Netherlands, main sectors
Reconstructed energy balances	Netherlands, statistical sectors
Energy trend simulation	Netherlands, households

The method **frozen technology** can be characterised as ‘bottom up’ because it regards changes at the level of energy systems and saving options. Total reference energy consumption in a chosen year is determined by means of replacing every actual efficiency value with the base year value. The difference with actual total energy consumption is equal to realised savings. The method demands a detailed description of the total energy system, and related socio-economic factors, where every technology has its place. This method is applied for the Netherlands, using the Icarus database of energy saving options, and for Europe, using the European version Genesis, described in Alsema and Nieuwlaar (2001) and Blok (2001).

Decomposition analysis is a 'top-down' method where the analysis generally sets out from total energy consumption and GDP. The change in total energy consumption over time is decomposed into a volume effect (GDP growth), a structure effect (structural changes in the economy) and an energy intensity effect. The intensity effect, normaly a decrease in intensity, is often referred to as 'energy efficiency' gain. In partial (Laspeyres) decomposition a residual term, due to interaction between the effects mentioned, is found. More sophisticated 'complete' methods eliminate the residual term, distributing it to the three effects. An overview of (complete) decomposition algorithms is presented in Ang (1995). Often the structure effect only regard shifts in the sector contributions to GDP; the intensity effect represents changes in the ratio MJ/Euro at the (sub)sector level. Sometimes diverging economic and physical trends in subsectors are taken into account as well. Now the intensity effect, e.g. decreasing MJ/kg steel, more closely represents realised energy efficiency, as there is a close relationship between physical developments and energy use (see Schipper et al (2001)). Other examples of index decomposition analysis are given in Howarth and Schipper (1991), Farla and Blok (1997), Sun (1999) and IEA (2004). Another method, structural decomposition analysis, applies input/output matrices. It enables the analysis of changes in final demand for goods and services, and import and export (see Hoen and Mulder (2003)). This decomposition version is not dealt with any further in this paper.

Realised energy savings for the Netherlands are calculated according to the so-called Protocol Monitoring Energy savings (PME), described in Boonekamp, Gijsen and Vreuls (2004). The **PME decomposition** method is a policy oriented mix of partial decomposition analysis and engineering calculations. Energy consumption is divided in final energy demand, conversion in end-use sectors (e.g. cogeneration) and conversion in the energy supply sector. Final demand is split into demand for heat, electricity and feedstocks (see Section 2.4). For final demand analysis decomposition is applied; for both conversions engineering calculations are deployed.

The MONIT system for presentation and analysis of national energy trends, described in Boonekamp (2004), applies the concept of **reconstructed energy balances**. Starting from the base year energy balance, the factors that have changed energy consumption are used to reconstruct step by step the energy balance of the year of interest. This method resembles the PME decomposition approach with its separate dealing with final demand, cogeneration and energy supply sector. Moreover, the effect of other structural effects, e.g. substitution between energy carriers and energy import/export, are taken into account too (see Figure 2.2). A special feature regards expressing all energy consumption figures in primary energy units. For end-use sectors the first eight steps in the reconstruction process regard static primary energy consumption, where each energy carrier is valued according to conversion losses in the base year. Therefore, analysis of end-use trends is not disturbed by energy sector changes. The last six reconstruction steps regard various changes in energy supply. These show the influence of developments in energy supply on primary energy consumption of end-use sectors.

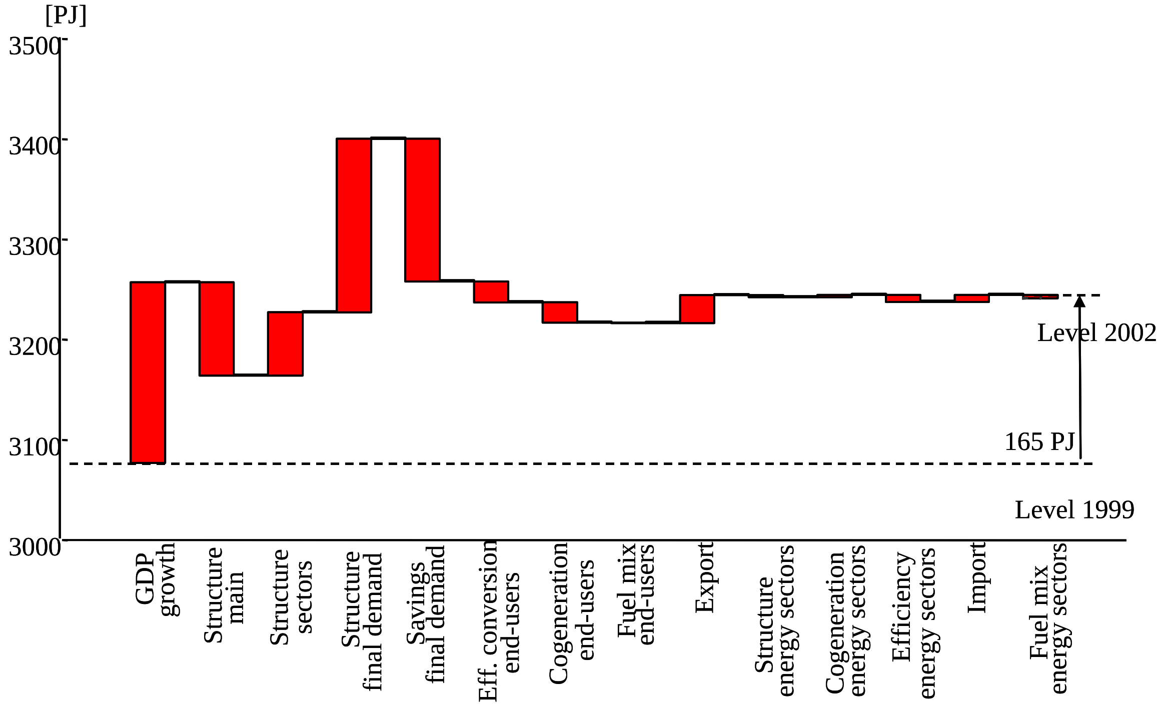

Figure 2.2 Decomposition of the change in total energy consumption 1999-2002 for the Netherlands, using the reconstructed energy balances method

Energy trend simulation is, like frozen technology, a bottom-up method to calculate realised savings in conjunction with other factors. The case to be evaluated regards the household sector in the Netherlands, as described in Boonekamp (1997). Here energy consumption is split into seven energy functions (space hating, food cooling, etc.), each comprising a number of energy systems or appliances. For all systems/appliances a vintage approach is applied to describe the shifting composition of the stock with respect to efficiency. For each fifth year a complete picture of systems and actual energy use is composed, using information from detailed surveys and general statistics. Reference energy consumption is calculated, setting the mix of more or less efficient systems and appliances equal to that in the base year, while growth and structural factors change the amount and utilization of systems and appliances. Comparison with actual energy consumption delivers realised energy savings. A special feature of this method regards simulation of historic energy trends, using a cost/benefit approach, energy prices and policy measures to model decisions to implement saving options. This enables to trace causes for realised savings, as is shown in Boonekamp (2005). At EU-level the MURE-simulation tool is available to determine impacts of different policy measures in EU-countries. Applications regard effects of past policy measures in various end-use sectors, described in the back-casting cases of MURE (2003).

To complete the overview, the regression analysis method should be mentioned too. However, reported cases in literature generally regard policy related applications, such as effects of government sponsored saving programmes. Regression analysis attributes the observed decrease in energy use to either the saving programme or to other factors. In Blasnik (1995) an overview is given of applications and methodological issues. One known example of regression analysis, applied for calculating realised energy savings in the Dutch greenhouses sector, is described in RK (2003). Given the different focus, this method is left aside in this paper.

2.3 Choices or problems and their adverse effect on energy saving results

In this section the choices or problems already mentioned in Section 2.1 are elucidated (see Table 2.3). These issues regard either the micro- or macro-level, or show up at both levels (see table). Issues at the micro-level are only relevant for some calculation methods that regard savings at micro as well as national level (see Section 2.4).

Table 2.3 Overview of calculation issues relevant at different aggregation levels of analysis

	Micro	Macro
Choice of reference system	R	
Choice of variables for reference trend		R
Shifts in reference system	R	
Choice of aggregation level		R
Interaction between saving effects	R	R
Interaction saving effect and other effects	R	R
Choice of energy quantity to be applied	R	R

Note: R=Relevant at this aggregation level.

Choice of reference system

At the micro level energy savings are accomplished by implementing new, more efficient, systems. Then one should decide on the reference system, to be used in calculation of energy savings. Take for instance a small industrial CHP unit installed in 1997, as part of the Environmental Action Plan (MAP) of the Dutch distribution companies. The reference system consists of a gas fired boiler and central electricity supply. Given parameters at actual start up of the plan in 1992, the industrial CHP unit uses 34% less energy (see Table 2.4). In 1996 central capacity has been extended with very efficient combined cycle units. This increased average conversion efficiency to 41.3% (including transport and distribution losses). Now the same unit saves only 30%. Finally one could postulate that without CHP very efficient combined cycle units with at least 54% efficiency (excluding grid losses) would be in place. This marginal approach results in 21% savings only.

Table 2.4 Energy savings of CHP units, related to the choice of reference systems

	Conversion efficiency			Savings CHP
	Boiler [%]	Central power[1] [%]	CHP[2] [%]	 [%]
Reference system				
Average central, base year	85	38.2	35/50	34
Average central, 1997	85	41.3	35/50	30
Marginal central, 2000	85	51.0	35/50	21

[1] including 5% transmission losses

[2] electric/thermal efficiency

Choice of variables to construct the reference trend

At the macro level it has to be decided how the reference trend for energy consumption (without savings) is determined. A major problem is choice of variable(s) to construct reference energy consumption, i.e. reference or scaling variables. This is illustrated in Table 2.5 for total primary energy consumption of households in the Netherlands (with electricity use converted to primary energy). Given an actual increase in primary energy consumption of approximately 0.9% per year, calculated energy savings vary between -0.2% and 2.2%. Scaling of reference energy consumption with number of inhabitants provides negative savings because extra energy use due to a faster increase in number of dwellings is not taken account of. Scaling with number of dwellings leads to small savings only, because it omits factors that increase energy use per household, such as larger new dwellings and higher ownership rates for appliances. If these two factors are taken into consideration, again higher savings result. Much more factors are accounted for in a bottom up simulation of household energy use, described in Boonekamp (1997) and updated in Boonekamp (2005). Almost all additional factors contribute to increased energy use per household; given realised energy consumption, energy savings must be higher than resulting from simple analyses.

Table 2.5 Total energy savings and choice of scaling variables for reference energy consumption (Dutch Households, yearly average change 1990-2000)

Scaling variable(s)	Energy use [%]	Reference use [%]	Energy savings [%]
Number of inhabitants	+0.9	+0.6	-0.2
Number of households	+0.9	+1.3	+0.4
Item+surface+appliances	+0.9	+2.1	+1.2
All relevant factors	+0.9	+3.1	+2.2

Not taking into account relevant structure effects may even produce negative figures on energy savings. Especially in constructing reference electricity consumption it proves to be difficult to incorporate the scaling variables that account for new electricity applications. Sometimes the reference trend lies below the actual trend. Such cases with negative saving figures have been found in Farla and Blok (1997) and Groot (1996) for electricity trends for Services in the Netherlands. Even so, according to programme evaluations in EnergieNed (1995) some energy savings were realised here.

Shifting reference system

The problem of shifting reference systems regards the micro level only. This differs from the earlier presented issue 'choice of reference system' where changes in reference system were a matter of opinion, while here it regards a trend to be dealt with. When savings have to be determined over longer periods, the reference system probably does not remain the same. Due to technological development or prolonged successful introduction of efficient systems, conventional systems may disappear from the market altogether. Then another, more efficient, option becomes the reference system. This mechanism is highlighted in Table 2.6 for replacement of refrigerators.

Table 2.6 Varying energy savings for shifting reference system (refrigerator example)

	New appliance [kWh/yr]	Reference appliance [kWh/yr]	Energy savings [kWh/yr]
1990-1995			
Efficient versus old	350	450	100
Better versus old	280	450	170
1995-2000			
Best versus old	200	450	250
2000-2005			
Better versus efficient	280	350	70
Best versus efficient	200	350	150

In the first period 1990-1995 efficient or better versions replace old refrigerators. In the next period saving possibilities increase owing to introduction of even more efficient refrigerators (best). But after disappearance of the old type from the stock of refrigerators (period 2000-2005), the alternatives save less electricity than in earlier periods.

Choice of aggregation level

As already highlighted in the introduction, determination of energy savings can provide better results if energy consumption is split into parts. For every part a separate reference trend is constructed, and the sum of these trends is compared with actual total trend, providing energy savings. In this way diverging developments for various energy using activities do not influence the saving result. However, the overview for industry in Ang (1995) shows that energy consumption is disaggregated into a limited number of sectors only in most decomposition studies. The reason is that the statistical data often are not easily available at lower aggregation level. The effect of aggregation level on saving results is shown in Fisher (2002) where decomposition results are presented for one-digit to four-digit level, applied in statistical classification of industrial activities. For each case contributions of sectoral shifts and subsector energy intensity changes are presented (see Table 2.7). Analysis at two-digit instead of one-digit level halves the observed lowering of energy intensity. Three-digit level results show again 15% less intensity decrease, but at the four-digit level the intensity decrease stabilizes. It must be concluded that in this (Chinese) case decomposition should be best applied at the three-digit level or lower.

Table 2.7 Calculated decomposition effects at various aggregation levels for the Chinese industry, average values 1997-1999

Statistical aggregation level	Sectoral shift	Energy intensity
1-digit	+0.038	-0.121
2-digit	-0.024	-0.059
3-digit	-0.034	-0.050
4-digit	-0.036	-0.051

Source: Fisher (2002)

In Seibel (2003) comparable results are found for decomposition of total industrial CO_2 emissions in Germany. For 1993-2000 the decrease owing to lower energy intensity is 56% stronger for 58 subsectors than for 12 sectors (51.8 and 33.2 Mton). The sensitivity of results to aggregation level is recognized as a general problem of decomposition in Ang (1995).

Interaction between various energy saving effects
Sometimes an efficiency increase in one part of the energy system influences energy savings owing to an efficiency measure elsewhere. Then the combined effect may be lower than the sum of effects of both measures apart. An example is the combination of savings on final electricity use of appliances and increased efficiency in electricity production. Table 2.8 first shows the effect of more efficient appliances on primary energy use, using standard efficiency values of power plants. Then the separate effect of higher power plant efficiency is calculated. The sum of both proves to be 7% higher than primary savings in the combined case. Next to this example at the macro level, interaction shows up at the micro level as well, for instance between savings owing to insulation of dwellings and savings owing to high-efficiency boilers for space heating. Results for households in the Netherlands are given in Boonekamp (1997). Here it is shown that boiler savings would have been 35% higher (6.6 versus 4.9 PJ) if savings on space heat use are not taken into account.

Table 2.8 Example of interaction effect between saving options in end-use and energy supply

	Electricity use appliances			Power stations efficiency	Savings (primary)
	Without	Savings	With		
	[PJ_e]	[%]	[PJ_e]	[%]	[PJ]
Efficient appliances	20	20	16	40	10.0
Efficient power stations	20	0	20	44	4.5
Sum of energy savings					14.5
Combined energy savings	20	20	16	44	13.6
Overlap					0.9

Interaction between energy saving effect and other effects

The amount of energy saved depends on factors that influence growth of energy consumption as well. For instance, if the number of dwellings or the surface area per dwelling increases, application of high-efficiency boilers saves more fuel. On the other hand, saturation in demand for building materials may decrease industrial energy savings connected to more efficient kilns. In general this mechanism applies for all shifts in production and consumption activities. The interaction between energy savings and these socio-economic developments (called intensity respectivily structure/volume effects) has been extensively dealt with in many decomposition studies, e.g. Ang (1995), Schipper et al (2001) and Sun (1999).

Choice of energy quantity to be applied

At the aggregated level of end-use sectors, different energy quantities can be applied in the analysis, for reference energy consumption as well as actual energy consumption:

- energy consumption (total energy content)
- primary energy consumption
- final demand, per end-use form.

In Figure 2.3 a general overview of the relationship between the three quantities is given.

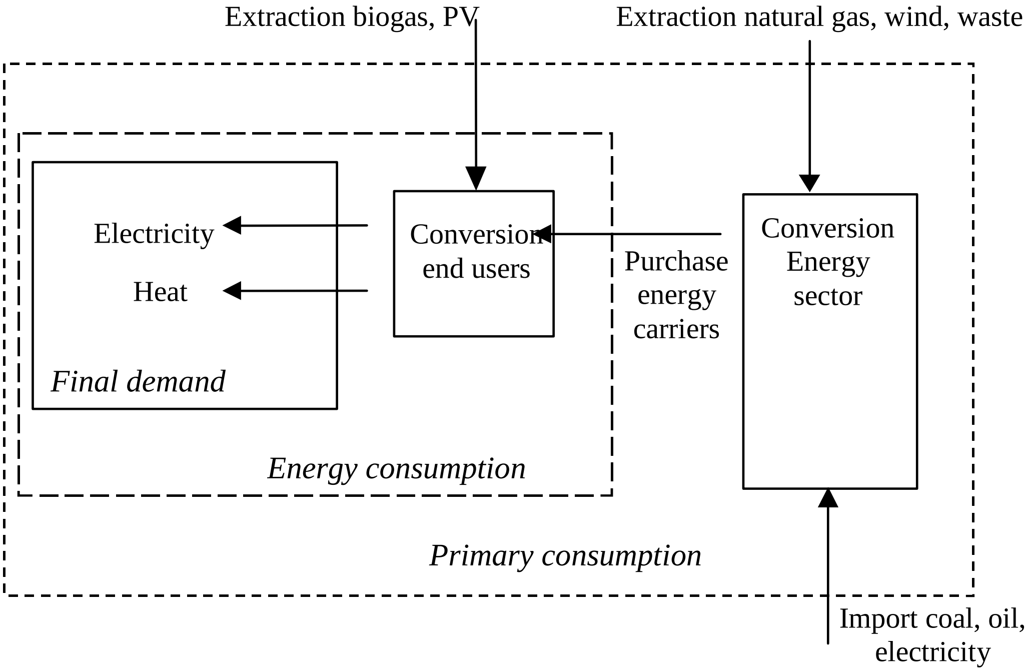

Figure 2.3 Connection between final energy demand, energy consumption and primary energy consumption (inputs regard the Netherlands)

First, effects of a choice between energy consumption and primary energy consumption are highlighted. The effect on calculated savings is illustrated in Table 2.9, for a case that resembles energy use in Services in the Netherlands for 1990-2000. The use of gas and electricity has risen because of growth in activities, but this has been partly compensated for by energy savings. Actual energy consumption, being the sum of energy contents for gas and electricity, has increased; total savings of 50 PJ equal 16% of total energy consumption in 2000. If electricity use is expressed in primary terms, using an average conversion efficiency of 40%, primary energy consumption is found to increase stronger (see last column). Savings in primary terms score 13% only, due to the increased weight for electricity showing relatively low savings. These less favourable efficiency trends from applying primary energy are found in Doblin (1998) and Zarnikau (1999) as well.

Table 2.9 Energy savings in relation to energy quantity used in the analysis (example)

	Gas [PJ]	Electricity [PJ_e]	Energy consumption [PJ]	Primary energy [PJ]
Actual energy use 1990	200	80	280	400
Growth effect 1990-2000	40	50		
Use without savings 2000	240	130		
Saving effect 1990-2000	-40	-10	-50	-65
Actual energy use 2000	200	120	320	500
Savings/Actual 2000	**20%**	**8%**	**16%**	**13%**
Substitution variant				
Substitution effect	-10	+5		
Saving effect corrected	-30	-15	-45	-68
Savings/Actual 2000	**15%**	**13%**	**14%**	**13-14%**

Substitution between fuels and electricity can influence energy use developments, as electricity causes fewer losses than fuels in end-use applications. For instance heat can be produced from electricity with an efficiency of 100%, as opposed to the 50-90% for fuels. Therefore a shift from fuels to electricity shows up as savings in case total energy consumption is looked at. In Table 2.9 this is highlighted in the lower part of the table. There it has been supposed that 10 PJ of gas has been replaced with 5 PJ of electricity. With given realised values for 1990 and 2000, and the same growth effects, less gas savings and more electricity savings must have been realised than was calculated earlier. Earlier found savings on energy consumption (16%) prove to be too high compared to the value of 14% after correction for substitution. However, the new and old figures for savings in primary energy units (13%) are about equal.

The second choice regards the use of the quantity ‘final demand’ instead of energy consumption. In Figure 2.3 it is shown that delivered energy carriers (energy consumption) are converted at the end-users site into the end-use forms heat and electricity (final demand). The amount and composition of energy consumption do not always resemble that of final demand, which ultimately provides for the needs from the socio-economic system. This difference may lead to wrong results for constructed reference energy consumption trends, especially if substantial amounts of electricity and heat are produced in cogeneration units. This is illustrated in Table 2.10 where gas is used to produce heat in boilers, and a cogeneration unit to produce heat and electricity (see ‘actual 1990’). The consumption of (grid delivered) electricity is lower than final use of electricity because of on site production. For 2000 a 50% higher production level is supposed; in the conventional approach reference consumption of (delivered) gas and electricity increases by 50% as well. With the chosen actual values for 2000 total savings of 25 PJ result. However, it is more probable that in the reference case final demand for heat and electricity rise by 50% (see ‘Reference 2000-II’). Given unaltered output from cogeneration and boiler efficiency, this results in diverging reference consumption for gas and electricity, compared to the conventional approach. Total energy savings are just 10% lower but the composition is quite different, causing greater differences in primary energy consumption.

Table 2.10 Energy savings in relation to scaling either energy consumption or final demand for increase in production

	Energy delivered			Final demand	
	Gas [PJ]	Electricity [PJ$_e$]	Total [PJ]	Heat [PJ$_{th}$]	Electricity [PJ$_e$]
Actual 1990	100[1]	40	140	67[1]	60[1]
Growth 1990-2000	+50%	+50%			
Reference 2000-I	150	60	210		
Actual 2000	125	60	185		
Energy savings	**25**	**0**	**25**		
Growth 1990-2000				+50%	+50%
Reference 2000-II	137	70	207	101	90
Actual 2000	125	60	185		
Energy savings	**12**	**10**	**22**		

[1] cogeneration: 59 gas used for 30 heat and 20 electricity, boiler: 41 gas used for 37 heat.

In the preceding example the same growth factor is applied to final heat demand as well as final electricity demand. In reality, electricity demand generally is determined by quite other factors than that for heat. Therefore final demand should be split into different end-use forms to construct realistic reference trends. This choice has already been dealt with in the paragraph on aggregation.

In the Protocol on calculating energy savings, described in Boonekamp, Gijsen and Vreuls (2004), it is shown that both preferences presented here can be combined. For end-use sectors final demand for heat and electricity, both expressed in primary energy units, are applied throughout the analysis. Finally it should be remarked that choices regarding primary energy and final demand are not relevant at the national level. At this level energy consumption consists of primary energy carriers, and the quantity final demand is only valid for end-use sectors.

2.4 Treatment of calculation issues in evaluated methods

Now it is investigated how various methods (see Section 2.2) make choices, and deal with the calculation problems, as described in the previous section.

Choice of reference variables and aggregation level

Choice of reference variables and choice of aggregation level generally coincide. For instance, in the analysis of industrial energy trends the aggregation level chosen often regards subsectors or energy applications, where appropriate physical production quantities are available to construct the reference trend. In Table 2.11 the various methods are rated as to their handling both issues.

Table 2.11 Choice of reference variables and aggregation level for various methods

Method	Reference variables	Lowest aggregation level
ODEX indicator	Socio-economic-physical	Application/subsector (end-use sectors)
Frozen technology	Not needed (implicit)	Energy system/application+efficient versions
Decomposition analysis	Socio-economic	Sector/sub-sector
PME decomposition	Socio-economic-physical	Application + end-use type
Reconstructed balances	Socio-economic	Sub-sector + end-use type
Energy trend simulation	All relevant variables to describe trends	Energy system/application+efficient versions

The **ODEX indicator** is very flexible with respect to aggregation level and choice of reference variables. Even so, a low aggregation level is not always possible because variables at the level of subsectors or energy applications are not always available in all EU-countries. The **frozen technology** method is forced to apply a low aggregation level where changes for energy technologies can be analysed. At this level energy consumption must be specified in great detail for each year of analysis. Moreover, all penetration rates of saving options and average efficiency values per application must be known, for base year as well as year of analysis. **Decomposition analysis** often applies generally available statistical figures, restrictting itself to the sectoral level and the use of economic reference variables, as illustrated in IEA (2004). In specific cases, such as Farla and Blok (1997), available physical quantities at sub-sector level are applied as well. **PME decomposition** applies as much as possible physical variables; especially in industry many physical production quantities from Neelis et al (2004) are used to construct the reference trend. The restrictions, described for decomposition analysis are valid for **reconstructed balances** as well. But here energy use is split into final demand for heat, electricity and feedstocks, each with their own reference variables. The **energy trend simulation** method is the only method that does not start from the national level. Like frozen technology it applies the lowest aggregation level where changes for saving options are analysed. Many variables, at different levels, are needed in the simulation, among which the mix of more or less efficient energy systems or appliances.

Interaction between energy saving effects

At the micro level interaction between energy saving effects regards two saving options; at the macro level it regards interaction between savings on end use and increased electricity supply efficiency. In Table 2.12 it is shown how the various methods take account of these interactions in the calculation. For methods designed for the macro level, interaction at the micro level is not relevant (depicted with '×'). This interaction is (in principle) incorporated in total savings, calculated at higher aggregation level.

Table 2.12 Treatment of interaction between energy saving effects at micro and macro level for various methods

Method	Micro	Macro
ODEX indicator	yes	no
Frozen technology	yes/no	yes/no
Decomposition analysis	×	yes/no
PME decomposition	×	no
Reconstructed balances	×	yes
Energy trend simulation	yes	partly

Note: × = not relevant.

For the **ODEX indicator** method the set of separate indicators determines how micro level interaction is taken care of. For instance the indicator 'energy use for space heating in dwellings' shows the combined saving effect of insulation and high-efficiency boilers. Macro level interaction, between end-use and supply, is not dealt with because the present ODEX indicator regards end-use sectors only. Treatment of interaction for **frozen technology**, micro as well as macro, depends on how this is incorporated in the scheme to calculate energy savings. Macro level interaction poses no problem in **decomposition analysis,** provided a separate electricity supply sector is present in the analysis. However, if decomposition analysis focuses on one end-use sector only, this interaction is not taken account of. The **PME decomposition** method calculates savings for three categories: final demand, cogeneration and central electricity production. In conformity with policy evaluation rules in the Netherlands, interactions between the three categories of savings are neglected. The **reconstructed balances** method applies a fixed sequence of 14 analysis steps (see Figure 2.2). One of the steps regards calculation of savings on final demand, another one regards conversion efficiency in end-use sectors, and a third step efficiency changes in electricity supply. Savings on final demand are calculated first (with base year conversion efficiency); therefore savings owing to higher efficiency of supply are calculated after dealing with end-use savings (see Section 2.2). In bottom up **energy trend simulation**, total savings are the result of penetration of a large number of saving options. The saving effect of every saving option is calculated, introducing saving options one by one in the analysis and keeping track of the cumulative increase in total energy savings (see figure on cumulative total savings in Boonekamp (1997)). For two interacting saving options, the calculation sequence defines how combined savings are attributed to both saving options. The average efficiency trend for electricity production constitutes a pseudo saving option. This enables analysis of interaction on savings at macro level, although the efficiency change is not only due to more efficient plants but to fuel substitution as well.

Interaction between energy saving effect and other effects

Other effects constitute changes in energy consumption related to volume growth and structural changes in the socio-economic system. The resulting size of energy using activities defines in part the scope for implementation of saving options, and thus energy savings. This interaction can regard micro as well as macro level analysis (see Table 2.13). As already shown in Table 2.12, the micro level is not relevant for some methods.

Table 2.13 Treatment of interaction between energy saving effect and other effects at micro and macro level for various methods

Method	Micro	Macro
ODEX indicator	partly	no
Frozen technology	yes/no	yes/no
Decomposition analysis	×	yes
PME decomposition	×	yes
Reconstructed balances	×	yes
Energy trend simulation	yes	yes

Note: × = not relevant.

Individual indicators that are part of the **ODEX indicator** take into account some, but not all, interaction effects at the micro level. For instance, the efficiency indicator 'average fuel use/m^2 floor area' in dwellings accounts for larger dwellings but not for changes in the type of dwelling. In composing the ODEX indicator, weighting of individual indicators is performed with fixed values for their fractions in total energy consumption. This way of weighting does not account for structural changes at the macro level. The **frozen technology** method focuses on realised energy efficiency improvements for all energy systems (e.g. boilers) in the year of analysis. In combination with the actual numbers and utilization rates for all systems total energy savings result. These numbers and utilization rates depend on volume and structure effects with respect to base year (e.g. more boilers due to extra dwellings and central, instead of local, heating). Saving effects are calculated after processing the volume and structure effects. This fixed calculation order defines how interaction is dealt with. **Decomposition analysis** generally applies algorithms (complete decomposition) that treat interaction between volume, structure and saving effects quite well at the macro level. Structural changes at lower aggregation level are not observed and become automatically part of the calculated 'efficiency' gain. This mixed saving/structure result incorporates interaction effects at the micro level. The same reasoning is valid for end-use analysis in **PME decomposition** and **reconstructed balances** methods as well. In the last case the effect of other factors, such as import, export and fuel substitution, on (primary) energy savings is determined separately. For **energy trend simulation** the same reasoning applies as described in the preceding paragraph. The sequence of introducing volume and structural changes and energy savings in the analysis defines how interaction works out on calculated savings.

Chosen energy quantity

As highlighted earlier, energy consumption can be defined as total energy content of all energy carriers delivered, or can be expressed in primary energy units that account for losses to deliver energy carriers (see Section 2.3). In the last case a further choice regards static primary, with base year conversion efficiency values, or dynamic primary, with efficiency values in the year of analysis. Delivered energy carriers to end-use sectors are transformed into heat, electricity or feedstocks; these final demand quantities can be applied too in the analysis.

Table 2.14 presents the choices, made per method, with respect to primary energy and final demand in end-use sectors. The **ODEX indicator** is composed of indicators that usually regard one type of energy carrier. In aggregating indicator results no account is taken of differences between fuels and electricity; therefore primary energy is not dealt with. The **frozen technology** method deals with saving options that usually regard one energy carrier. Here, electricity is generally converted to primary units, using a fixed conversion efficiency value. **Decomposition analysis** often applies total energy consumption, without taking into account the special features of electricity. According to Ang (1995), sometimes a split is made between fuels and electricity, the contribution of electricity production efficiency to the observed change in energy use is analysed separately. Even so, this does not provide results for end-users that are based on their primary energy consumption. **PME decomposition** deliberately applies static primary energy units in all energy consumption figures. The method of **reconstructed balances** uses a combination of static and dynamic primary units (see description in Section 2.2). The **energy trend simulation** method expresses energy consumption in primary units, with fixed conversion factors for electricity.

Table 2.14 Applied primary and final demand energy quantities in end-use sectors for various methods

Method	Primary energy units	Final energy demand types
ODEX indicator	No	Fuel and/or electricity
Frozen technology	Static	Fuel, electricity
Decomposition analysis	No/yes	No
PME decomposition	Static primary	Heat, electricity, feedstocks
Reconstructed balances	Static/dynamic primary	Heat, electricity, feedstocks
Energy trend simulation	Static primary	Heat, electricity

With respect to final demand categories Table 2.14 shows the following pattern. Energy consumption data, used to construct the **ODEX indicator,** are corrected for energy consumption of cogeneration systems. Therefore the analysis regards final demand. **Frozen technology** applies all kind of final demand technologies and implicitly makes a distinction between fuel and electricity. **Decomposition analysis** generally does not focus on final energy demand, as studies are based on standard energy (consumption) statistics. **PME decomposition, recon-**

structed balances and **energy trend simulation** all apply the final demand categories heat and electricity. The first two methods regard feedstocks as final demand category in industry as well.

Treatment of uncertainty
In most evaluation studies there is lack of (reliable) data to disaggregate energy consumption to the lowest aggregation level, and to find appropriate variables to construct reference consumption trends. Therefore it is of importance to know uncertainty margins in results. According to Odyssee (2003) no uncertainty margins are calculated for individual energy indicators; the same applies for the aggregated **ODEX indicator**. **Frozen technology** regards a very detailed description of energy developments, which makes it cumbersome to calculate uncertainty margins. No results on uncertainty are known for this method. **Decomposition analysis** has a residual term in the decomposition formula, which sheds light at the quality of the decomposition algorithm. In contrast to attention to improved algorithms in Ang (1995), no attention is given to margins in input data and the combined effect on results. **PME decomposition** is the only method that delivers margins in the resulting figures on savings. In Gijsen and Boonekamp (2004) margins are specified for all inputs and a Monte Carlo method is applied to calculate an uncertainty distribution for sectoral and national saving figures. For industry uncertainty margins have been determined at a more detailed level in Neelis et al (2004). The substantial margins found, e.g. 0.3% point in total national energy savings of 1.0% per year, stress the importance of uncertainty analysis. The **reconstructed balances** method does not calculate margins, but in Boonekamp (2004) qualitative information is given on margins in the calculated 14 contributions to observed change in energy use. For **energy trend simulation** the same applies as for frozen technology.

2.5 Rating of methods as to optimal calculation approach

The optimal approach is defined here as the method which addresses calculation problems and choices in such a way that detrimental effects on saving results, as described in Section 2.3, are minimized. The optimality of the six methods presented in this paper is analysed, using a number of criteria that cover the problems and choices described earlier. Special emphasis has been laid on usefulness of methods for policy evaluation purposes. Therefore, flexibility with respect to aggregation, calculation and presentation is added to these criteria. For the time being practical problems, such as availability of data, are left aside. Results are summarized in Table 2.15 at the end of this section.

Aggregation level
It is obvious that at the national level the change in energy intensity (energy consumption per unit of GDP) does not represent energy savings realised. The reason is that structural changes in the socio-economic system influence energy consumption too. Taking account of these influences is the main reason why each method deals with energy consumption and activity variables at lower aggregation level. Decomposition methods generally use readily available data at a rather high aggregation levels. But at lower levels there probably exist more structural changes that influence reference energy consumption and calculated savings (see

Table 2.7). The example for household (see Table 2.5) shows that incorporating more structure effects may deliver substantial higher calculated savings. The same reasoning is conceivable for transport and for non-uniform sectors, such as other metal industry or services. With the exception of uniform energy-intensive processes, it can be said that lower aggregation levels are needed to provide better saving figures. Preference should be given to methods that span the whole range from macro (national) to micro (energy technology) level. The **frozen technology** and **energy trend simulation** methods meet this requirement most.

Appropriate reference variables

It has been pointed out that methods disaggregate energy consumption up to the level where so-called reference variables exist which are thought to have a close relationship with energy demand. In industry this regards various physical production quantities in the base metal, paper, base chemical and cement production (see Phylipsen et al (1998)). In other sectors physical variables exist as well, but it is often questionable whether they are fit to calculate the reference consumption. For services the problem of using either floor space or number of employees has been discussed earlier. The earlier given household example highlights that even a set of three or four variables is not enough to construct reference consumption. From these cases it follows that only at a (very) low aggregation level it is possible to find appropriate variables to construct reference consumption trends that incorporate all structural factors. Only in very uniform production, e.g. primary aluminium or cement, physical production variables at medium aggregation level can be applied. Again **frozen technology** and **energy trend simulation** offer ample opportunities to apply appropriate reference variables.

Reference system

The choice of reference system is relevant only if the analysis regards energy using systems, e.g. boilers for space heating or cars for personal travel. In that case the bottom line in the choice of reference system is the ‘oldest’ type still available in the market. Normally this type is the least energy efficient and the cheapest as well. If this type is not supplied any more, the next best type can be chosen. Calculation of energy savings asks for a vintage approach that, at any moment in time, maps the fractions of more and less efficient types. The changing mix of types and the (changing) reference determine energy savings realised. It is possible to apply more stringent definitions of reference systems as well. For instance, the type with no extra costs to the energy user could be chosen. But this is not a robust choice as investments costs, energy prices or subsidies could change. Another possibility is to define the base year average as reference system; this approach is applied in the Icarus analysis of saving options in Alsema and Nieuwlaar (2001). However, negative savings may result if total number of systems rises, and implicitly the number of efficient types as well, while the actual number of efficient systems does not. The method of **energy trend simulation**, applied to historic household energy consumption in Boonekamp (1997), uses the vintage approach and is flexible as to choice of reference systems.

Interaction between (specific) energy saving effects

Next to more efficient supply and savings in end-use, energy savings due to cogeneration should be provided, as this issue is a focus points in national and European energy policy.

With respect to cogeneration the literature (see overview in Ang (1995)) shows that hardly any decomposition method explicitly looks at energy savings of cogeneration. Generally this is impossible because total energy consumption is looked at, instead of final energy demand (see Figure 2.3). In that case cogeneration savings are part of total end-user savings. In some energy statistics (e.g. Eurostat) cogeneration is made part of the supply sector, and cogeneration savings are concealed in total energy savings of the supply sector. With respect to efficiency of energy supply, the average conversion efficiency of central electricity production is the most important subject. Methods should separately show the saving effect, due to efficiency changes per type of plant, and the substitution effect, due to changes in fuel mix. Only few decomposition studies split average efficiency trends into these two factors. Savings on end use are provided by all methods but are mixed up with that of cogeneration often. Overall, **PME decomposition** and **reconstructed balances** discern the preferred saving categories best.

As to interactions three types are important:

- between end-use savings on electricity and higher efficiency of power plants,
- between cogeneration and more efficient heat and electricity production,
- for end users, between lowering final demand and more efficient conversion.

The first interaction is important, as policy makers are not only interested in energy savings on its own, but in ultimate effects on total energy consumption and CO_2 emissions as well. To take account of this interaction, it is obligatory to discern between fuel and electricity in final energy demand of end users. Moreover, the analysis should be able to analyse the saving effects for final electricity and that for electricity production in conjunction. This should be possible in standard decomposition analysis, provided enough detail is present. These interaction effects can be highlighted too, applying dynamic primary energy consumption in the calculations (see Section 2.4). For cogeneration savings, not only a trade off with power plant efficiency exists, but one with boiler efficiency as well. Therefore, trends in fuel conversion efficiency of end-users should be available too. Moreover, the quantity primary energy consumption must be applied in the analysis to make cogeneration savings visible. Analysis of the third interaction mentioned requires energy consumption trends for end-users be split into final energy demand and fuel conversion (excluding cogeneration). Given these demands, the **reconstructed energy balances** method is best suited to take account of all three interactions (compared to other methods designed for analysis at the macro level, see Table 2.12). **PME decomposition** comes a long way in taking account of the interactions. However, the third type of interaction can be best accounted for at lower aggregation levels where energy technologies are present. The calculation scheme defines how the overlap in saving effects is dealt with. Both **frozen technology** method and **energy trend simulation** method are best suited with regard to interaction for end users.

Interaction between energy savings and growth factors

All methods deal with energy savings and the effect of other factors regarding growth of energy consumption, but they do not treat interaction between the two in the same way. The bottom-up methods frozen technology and energy trend simulation calculate savings as the difference between two cases, one using efficiency values for the base year and the other using values for the chosen year. In both cases the same energy trends, based on volume and structural developments, have been composed. This approach resembles the partial or Laspeyres-like decomposition where the sum of savings, structure and volume effects can diverge from total observed change in energy consumption, due to interaction between the effects. The reconstructed balances and PME decomposition methods also apply partial decomposition, as they calculate one effect after another. Various 'complete' decomposition algorithms (see Ang (1995)) that minimize the interaction effects are applied in **decomposition analysis**, being the optimal method with respect to properly accounting for this kind of interaction.

Energy quantity applied

Total energy consumption is the worst quantity to be applied in the construction of reference energy trends and calculation of savings. In contrast to final demand it often has no well defined relationship with socio-economic trends (see Table 2.10). Moreover, substitution between electricity and fuels may show up as energy savings in the results. Further on, energy consumption does not give a sound picture of the ultimate burden, especially for the electricity part in it. The alternative quantity 'final energy demand', split into electricity, heat and feedstocks, takes account of quite different growth factors for each type of final demand. The quantity 'primary energy consumption' shows real energetic effects on the total energy system. Moreover this quantity is needed to reveal the savings of cogeneration. The best solution will be a combination of both quantities, i.e. 'final demand of heat, electricity and feedstocks, expressed in primary energy units'. This approach has been applied in the **PME decomposition** method. In **reconstructed balances** static as well as dynamic primary energy consumption figures are part of the analysis.

Reporting uncertainty

In conformity with standard scientific practice, uncertainty margins should be given for every saving figure presented. Preferably, sources of uncertainty should be made clear too. Bottom-up methods demand much effort to specify margins for the numerous input data and to calculate the uncertainty in saving results. Top-down methods ask fewer inputs but here it is often difficult to estimate the uncertainty in reference energy consumption. This uncertainty depends on how good the variables, used to construct reference consumption, act as 'predictor' of energy consumption in case of absent saving activities. As mentioned earlier, the only method that quantifies uncertainty is **PME decomposition**.

Flexibility as to policy evaluations demands

In practice flexibility in the set up of calculation and presentation is important because of the changing availability of data and because of changing needs of policy makers. Even so, most methods cannot supply information in a new preferred policy format, e.g. sheltered versus exposed sectors, or specific energy applications that are subject to policy measures (e.g. cogeneration or new dwellings). Some methods are not flexible because of the information sources used. For other methods the calculation scheme has to be adapted for new policy questions. The **ODEX indicator** method, being an aggregate of indicators to be chosen at one's discretion, proves to be the most flexible method.

Overall scores of methods

Table 2.15 presents an overview of the relative ratings for each method, based on the preceding analysis. The results show that none of the methods presented provides high scores on all criteria. The energy trend simulation method has non-zero scores on all criteria.

Table 2.15 Scores of calculation methods on various criteria with respect to optimal calculation of energy savings

Methods	Aggregation level	Reference variables	Reference technology	Inter- action savings	Interaction growth	Energy quantity	Uncertainty	Flexibility
ODEX indicator	++	++	+	0	+	++	0	+++
Frozen technology	+++	0	++	++	0	++	0	+
Decomposition analysis	+	+	0	+	+++	+	0	+
PME decomposition	+	++	0	++	++	+++	+++	++
Reconstructed balances	+	+	0	+++	+	+++	++	++
Energy trend simulation	+++	++	+++	++	++	++	+	++

Note: 0 = none, + = limited, ++ = fair, +++ = complete

Top-down and bottom-up evaluation for EU-directive

The emerging Energy Service Directive (ESD, see EC (2005)) specifies targets for energy savings to be realised in EU-countries in the period 2006-2012. The attainment of the saving target for each country will be checked in two ways. Total energy savings achieved are calculated using a top-down decomposition method, in this case the ODEX indicator. Part of total energy savings should be ‘proved’, using bottom-up evaluations for policy measures and programmes aimed at specific energy applications or sectors. In Figure 2.4 total energy savings have been split into three categories. The ESD-target regards energy savings owing to specific policy measures (e.g. subsidies on saving options) or general measures (e.g. an energy tax). The ODEX indicator covers all three categories, but does not provide separate information on saving effects of various policy measures and programmes.

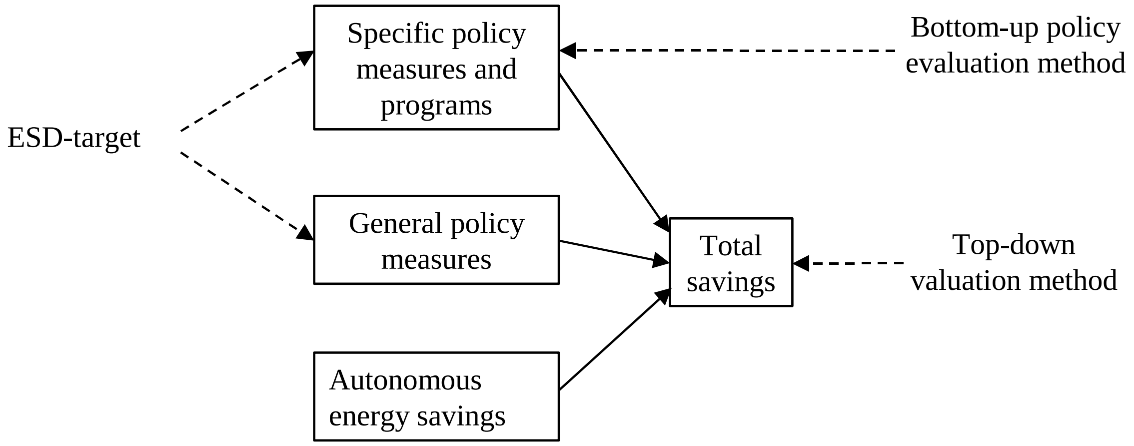

Figure 2.4 Energy saving categories valid for evaluation methods and ESD-target

The two bottom-up methods presented here, frozen technology and energy trends simulation, supply results at the detailed level of specific policy measures. The latter method can provide saving effects of general policy measures as well (for households in the Netherlands, see Boonekamp (2005)). The simulation method can deal with interaction between these policy measures and energy prices that cause (autonomous) energy savings. Given these results, it is expected that the energy trend simulation method can meet the ESD evaluation needs.

2.6 Conclusions and observations

In past decades much work has been done on developing methods to quantify realised energy savings at national or sectoral level. Even so, the following calculation issues got too little attention so far:
- appropriate aggregation level for analysing energy savings,
- most suitable variables to construct reference consumption,
- appropriate energy quantities to be applied in the analysis,
- interaction between energy saving effects and other factors,
- uncertainty margins in the results.

The first four issues could lead to unreliable saving figures or misinterpretations of results presented. Then it is the more surprising that hardly any publication in this field provides information on uncertainty margins in results.

Although the calculation methods regarded differ in scope and approach, they all try to answer the same question: *what would energy consumption have been without energy saving activities?* This boils down to the problem of constructing a reference consumption trend that, compared with actual energy consumption, shows energy savings. The analysis presented in this paper shows that there is not one method that addresses all calculation issues. But the analysis also suggests a number of improvements, which provide more reliable, transparent and policy relevant saving figures.

Energy quantities to be applied
Instead of the frequently applied quantity ‘energy consumption’ the quantity ‘**final energy demand, expressed in primary units**’ should be applied. Final energy demand has a clear relationship with specific energy using activities. Split into heat and electricity (and feedstocks in some industrial sectors as well), it facilitates construction of more reliable reference consumption trends. Expressing energy consumption in primary units shows the ultimate burden on energy supply and environment. Both items are most important for electricity use, because of the difference in end-use quality for fuels and electricity, and because of the substantial losses in electricity production. The proposed approach enables calculation of energy savings owing to cogeneration at end-users site as well. The methods PME decomposition and reconstructed balances (MONIT) apply this approach. From a policy perspective the application of static primary units (calculated with base year conversion factors) is useful in presenting energy trends of end-use sectors including their saving performance. Dynamic primary units are needed to present the ultimate effect on energy system and environment, including

changes in energy supply. In the method reconstructed balances both results for quantities are presented.

Aggregation level and choice of reference variables

Analysis of energy consumption trends at lower aggregation levels provides for better saving figures. The first reason is that each part of energy consumption can be related to the most suitable reference variable (driving factor) when constructing reference trends. The second reason is that a greater part of structural changes in the socio-economic system can be taken hold of at lower aggregation level. Preferably, **bottom-up analysis** should be applied, where the aggregation level regards energy systems and saving options. At this level calculated energy savings are not mixed up with structure effects. The demand on data availability often seems prohibitive. However, statistical information in combination with survey results may provide good results, as the simulation method for households, presented here, shows.

Interaction to be dealt with

In decomposition analysis the change in total energy consumption is decomposed into a volume effect (GDP growth), structure effects and energy saving effects. These effects do not add up to total change, due to interaction between the various effects. Advanced decomposition methods can minimize the difference. However, they generally do not deal with **policy relevant interactions**, such as between cogeneration savings and power plant efficiency, and between two saving options in end-use sectors. In the reconstructed energy balances method (MONIT) cogeneration is defined as a separate saving category, and cogeneration savings can be calculated, including interaction effects. In bottom-up methods, such as energy trend simulation, interaction between saving options in end-use sectors can be analysed in detail.

Uncertainty in results

Most methods have to rely on a restricted set of, often unreliable, data at a too high aggregation level. Given these shortcomings, uncertainty analysis should be standard in calculating energy savings, but generally lacks in practice. The PME decomposition method calculates uncertainty margins in savings results, attributing margins to every input and to the constructed reference energy consumption, and applying a Monte-Carlo approach. The margin in national energy savings proves to be about 30%; the most important contribution to uncertainty proves to be application of inappropriate variables in constructing reference energy trends. Analysing at a lower aggregation level can partly lift this problem.

EU-directive demands

Most methods on calculating total savings cannot meet all evaluation needs of the new EU-directive on energy savings, for instance realised savings owing to policy measures. This could be accomplished though, using a method which supplies detailed information on implemented saving options, as well as the part of savings due to policy measures. The bottom-up energy trend simulation method presented here is thought to supply the information needed.

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Chapter 3 ENERGY AND EMISSION MONITORING FOR POLICY USE - Trend analysis with reconstructed energy balances[10]

Abstract

At the request of policy makers a new tool, called MONIT, has been developed for the presentation and analysis of historical energy use and emission trends. The tool is based on the concept of constructed energy balances. The system covers Dutch national and sectoral energy use and the accompanying CO_2 emissions, from 1982 onwards. In the presentation part the energy balance with statistical figures is corrected for disruptions in statistics and yearly climate variations. Next to time series for all energy variables and sectors, information is also available about the final demand for electricity or heat and about cogeneration, primary energy use as well as direct and indirect CO_2 emissions. In the analysis part the energy use developments are mapped with a step-by-step constructed set of energy balances, starting from the base year balance. In each step a supplementary explanatory factor is introduced and the effects are made into an updated balance. In this way the actual changes in energy use are unravelled into 14 explanatory factors, including four different energy-related structural changes, five saving factors, fuel mix changes and changes in export and import of energy. It is possible to reconstruct the actual energy balances within a small margin and most of the 14 contributing factors can be calculated with only a small uncertainty. The MONIT system offers policy makers an integrated set of monitoring results with different levels of information content: statistical data, time series, final and primary energy use, direct and indirect CO_2 emissions, intensities and policy relevant contributions to the actual changes in energy and emission variables.

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[10] Published in Energy Policy, Vol. 32 (2004) pp. 969-988.

3.1 Introduction

After a decade of intensified policies, aimed at energy savings and the reduction of CO_2 emissions, there is an increasing need for a better monitoring of national energy use and emission trends, to allow for a more mature emission mitigation policy. Monitoring has to start with the presentation of a set of reliable figures about energy use and related emissions of CO_2. Observed annual changes in energy use and emission trends need to be divided into contributions from explanatory factors, such as economic growth, energy savings, increased energy electricity imports, etc. Finally monitoring should be able to identify the effect of influencing factors, such as energy prices and government policies.

Monitoring results have been made available regularly, but according to Boonekamp (2003), not in an integrated manner. They do not cover all energy use or do not take into account the various contributions and influencing factors. Determining the effect of multiple influencing factors is also a major problem. The method presented here uses an integrated approach but deals only with the first two requirements mentioned. These are the depiction of national and sectoral trends in energy use and CO_2 emissions in a flexible and transparent way, and the unravelling of the changes in a consistent manner into policy relevant contributions.

Unravelling changes in energy use essentially boils down to the following question: what would the energy use figure have been if certain factors had not been present? To answer this question one or more ‘reference’ energy trends have to be calculated and compared with the actual statistical trend. The method of explaining changes in energy use by simulating or constructing reference energy trends is used extensively in the MONIT system, described in Boonekamp (1999). The new method has been applied to the Netherlands but is applicable to other countries too. Ample diagrams are given to illustrate which kind of policy relevant information could be provided.

3.2 General outline of the MONIT system

MONIT is an acronym for ‘Monitoring Of National energy use, Information and Trend analysis’. The system consists of a series of actual and constructed energy balance sheets, each containing the sectors and energy carriers used in energy statistics. The balance sheets also contain figures concerning final demand for heat and electricity, cogeneration, primary energy use and CO_2 emissions. The MONIT system is split into a presentation part and an analysis part (see Figure 3.1).

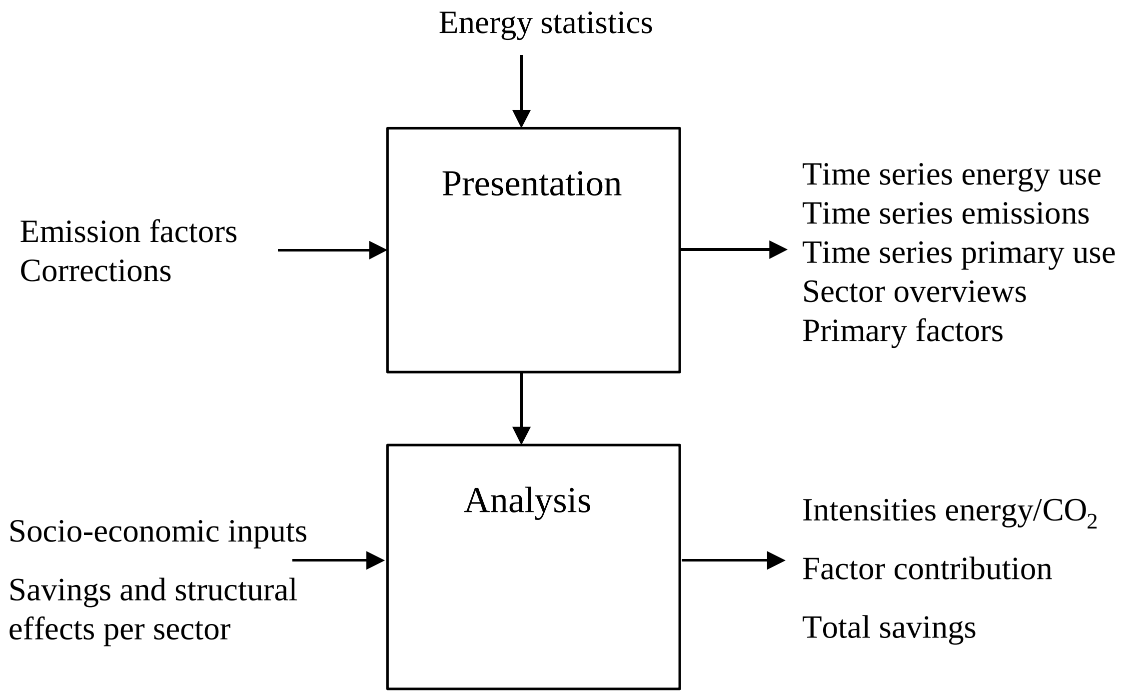

Figure 3.1 Outline of the MONIT system

Presentation part
The presentation part consists of three different annual balances. The first energy balance contains the original statistics from the Dutch Bureau of Statistics, specified per sector and energy carrier, and the figures for cogeneration. The second balance is a copy of the first, except where corrections were applied for trend breaks, etc. In the third balance these figures have also been corrected for yearly variations in outdoor temperature during the heating season, the so-called climate corrected figures.

When corrections have been made to certain figures for energy use, the effects in other parts of the balance system are calculated too. For instance a climate correction for household gas use leads to a correction for the amount of gas production and the amount used by the gas industry itself. All corrections, except shifts between sectors, are ultimately translated into changes in the amount of extracted or imported fuels. The energy use figures have been used to calculate final demand for heat, electricity and feedstocks, primary energy use, the direct CO_2 emissions from fuel use and the indirect emissions for electricity and heat (see Section 3.3).

Analysis part
The analysis of the trends in energy use is based on the corrected figures calculated in the presentation part. Starting from the energy balance for the base year, a number of balances have been constructed for a year t (see Figure 3.2). For the first balance one explanatory factor is used in the construction, for the second balance another factor is added, etc. The difference between the two consecutive balances is taken as the effect of the extra factor introduced

(see Figure 3.2). After the last step the final constructed balance should be equal to the actual figures for the year considered. However, in practice there are minor differences (see discussion about reconstruction error). The values of the variables in each balance are determined with up/down scaling or bookkeeping algorithms which make use of the base year values and the actual trends in external variables, e.g. GDP-growth, growth of physical production or transportation activity in person-km or ton-km. Inputs to run the MONIT system consist not only of statistical information about energy use and socio-economic variables, but also of corrections for trend breaks and yearly climate variations, CO_2 emission factors and sector-specific information (see Section 3.3, Analysis part).

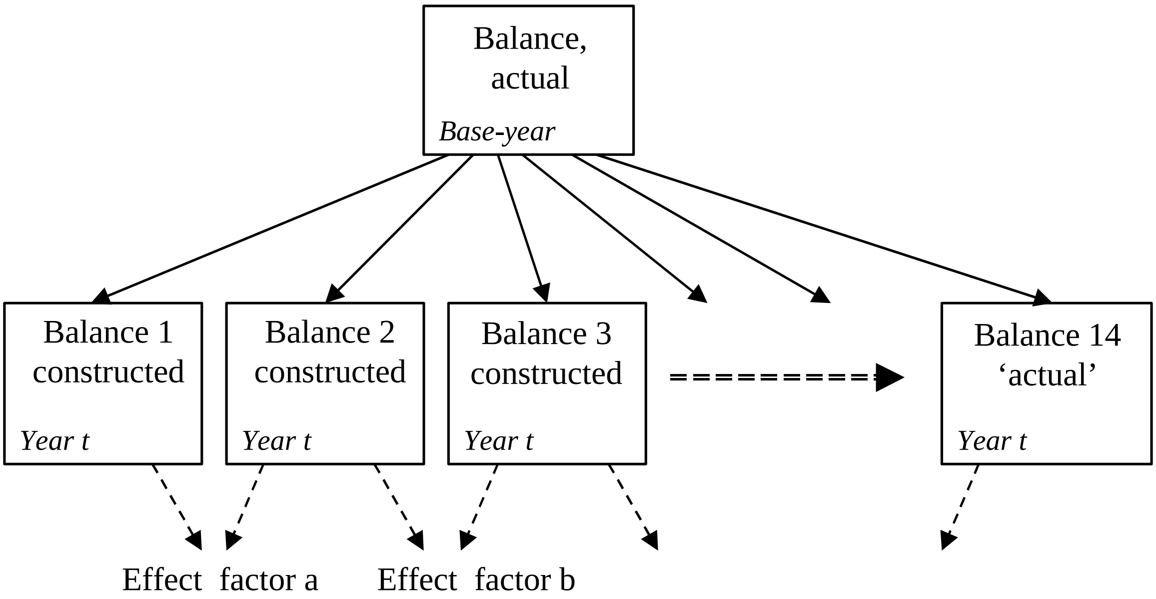

Figure 3.2 Consecutive construction of balances and resulting effects in the MONIT system

Analysis steps and explanatory factors

The number of steps used depends on the factors which analysts or policymakers want to consider in their analysis of the change in energy use. However, the amount of disaggregation often is limited by lack of sufficient data. The present MONIT system works with 14 steps i.e. explanatory factors, which are designed to satisfy the specific needs of the Dutch energy policy makers. These factors comprise not only the effects of economic growth, structural changes and energy savings in general, but also the specific contributions of cogeneration, fuel mix changes and energy imports or exports (see Section 3.3, Table 3.1). If more factors are needed, e.g. the contribution to a change in CO_2 emission from renewables or from fuels with less CO_2 emissions, the number of steps can be increased and another balance sheet constructed. For practical and conceptual reasons the factors are introduced in a fixed order during the reconstruction process (see discussion about sequence). Because whole energy balances are constructed it is possible to present the results of the analysis, i.e. the disaggregation of actual changes into 14 factors, for each energy or emission variable and each sector.

3.3 Construction of the balance sheets

The specific properties of the MONIT system are tied to the way in which the balances are constructed. Because each balance has its own feature, and the results are partly dependent on these features, the balances are described here one after another. Table 3.1 gives an overview of the balances described.

Standard balance sheets

Both in the presentation part and in the analysis part of MONIT a standard balance sheet format is used. The standard balance is composed as follows (see Figure 3.3):

- Columns: end-use sectors, energy sectors, total and sources.
- Rows: use of energy carriers, conversion/CHP, final energy demand, primary energy use and emissions.

Columns

The column ‘End-use sectors’ comprises four main sectors: households, industry (seven sectors), transportation and ‘miscellaneous’ (agriculture, construction, non-profit and commercial services). Energy sectors consist of refineries, power stations, waste incineration and ‘miscellaneous’ (coke factories, gas supply and distribution). The ‘Sources’ comprise import, extraction, export and bunkers and inventory changes. The ‘Total’ column shows the total primary energy requirement (TPE), which is equal to the sum of total energy use in all end-use and energy sectors. TPE is also equal to import plus extraction minus exports, bunkers and increase in inventories.

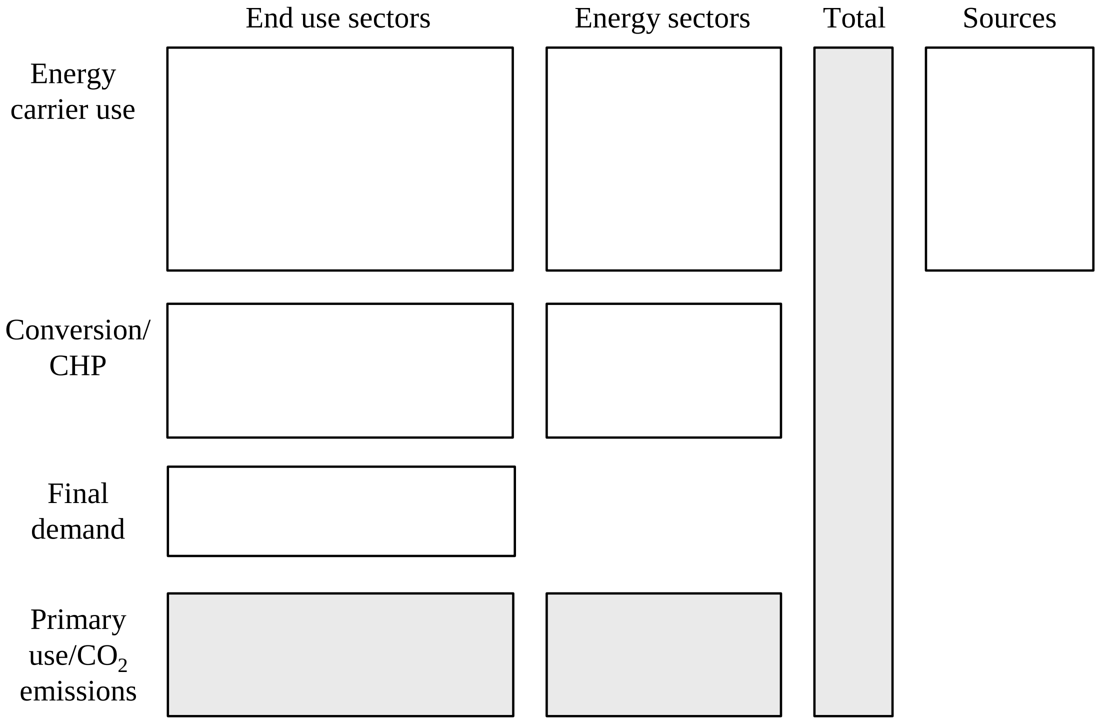

Figure 3.3 Standard energy and emission balance sheet in MONIT

Rows

The building block ‘Energy carrier use’ covers coal and cokes, oil and oil products, natural gas, secondary gases, heat, electricity and other energy carriers such as uranium, refuse/biogas and renewable inputs. The use of coal, oil products and gas is split into energy and non-energy applications. The block ‘Conversion/CHP’ contains inputs and outputs of cogeneration and other conversion processes and the production of renewable energy in the sectors themselves. The input of cogeneration is part of energy carrier use; the output figures are used to calculate final demand. ‘Final demand’ is split into electricity, heat and feedstocks (non-energy use); it is not specified for the energy sectors. Final demand of heat is the total of delivered heat (e.g. hot water from town heating systems), steam from own cogeneration plants and all the heat resulting from conversion of fuels. Final demand for electricity is the sum of electricity from the grid and own production, mainly with cogeneration. Final heat demand can be characterised also as ‘useful energy’, but this does not apply for electricity and transportation fuels. Therefore ‘final demand’ is used here instead of ‘useful energy’. In transportation there is a demand for mechanical energy for moving the vehicle. However, because it is difficult to separate the conversion of fuel from the total driving process the final demand in the transportation sector should be interpreted as the fuel used. The ‘Primary use and CO_2 emissions’ building block contains figures related to primary energy use and emissions. These figures are derived from the figures mentioned earlier. Also shown are figures for the energy savings resulting from cogeneration in each sector.

Presentation part balances

The presentation part consists of three yearly balances, called A, B and C.

Balance A, Energy statistics

Balance A contains the statistical information about energy use from 1982 onwards (see Figure 3.3, block ‘energy carrier use' and ‘conversion/CHP’). The final demand in end-use sectors (see ‘final demand’) is calculated. Final demand for heat is calculated from the use of fuels and the heat from CHP in the sector. Final demand for electricity is the sum of electricity use and CHP-production. If appropriate, also a final demand for feedstocks is calculated as the sum of the use of energy carriers for non-energy purposes. Primary energy use and CO_2 emissions are also calculated using the statistical figures from ‘energy carrier use’; this applies for all balances (see end of section).

Balance B, Corrected statistics

This balance is mainly a copy of balance A, but corrections have been made to certain statistical figures for one of more years. A major reason for corrections is the 1993 trend break in the statistical partition of energy users which caused shifts in the energy use per sector. Other reasons for corrections are missing figures for oil and heat use in non-industrial sectors and the availability of more detailed information about cogeneration in specific sectors. Finally there was a need to remove statistical differences, existing between total use originating from ‘sources’ and the total from sector aggregation. Corrections to final demand or cogeneration figures lead to subsequent adaptations of energy carrier use; in turn corrections applied to energy carrier use lead to adaptations of the final demand. The corrections for all end-use sectors together are translated into changes within the energy sectors and finally into changes for the sources (import or extraction). These changes take place where they are most plausible, e.g. increased electricity use is assumed to come from gas and coal power, extra gas use from extraction and extra oil use from imports. The resulting change in total energy use is not profound (<1%) because many of the corrections concern shifts between sectors. For individual sectors and years the difference between balance A and B is sometimes substantial (e.g. 10% for industry in 2000, see Figure 3.5).

Balance C, Climate corrected statistics

Balance C contains the corrected statistics from balance B plus corrections for yearly climate variations. Because the MONIT analysis is concerned solely with man-made trends and contributions, the disturbing influence of yearly climate variations has to be singled out. The climate corrections are applied to the final heat demand, mainly in the residential and service sector (see Figure 3.4). The fraction of heat used for space heating is corrected for yearly variations in outdoor temperature during the heating season. These variations are expressed in total heating degree hours in relation to the 1960-1990 mean, leading to a scaling factor ranging from 0.9 to 1.1. No climate correction has been applied yet to the final electricity demand. Corrections to the final demand are translated into changes in the use of specific energy carriers. Energy carriers used as a feedstock or exclusively for process heat are not corrected. The corrections made to the use of energy carriers are passed on to the energy sectors and ultimately to the sources (see description Balance B). The resulting climate correction for total energy use has been positive for most years from 1990 onwards, because mean outdoor temperatures have been above historical average. In 1990 and in recent years the climate corrections have amounted to 3% of total primary energy use.

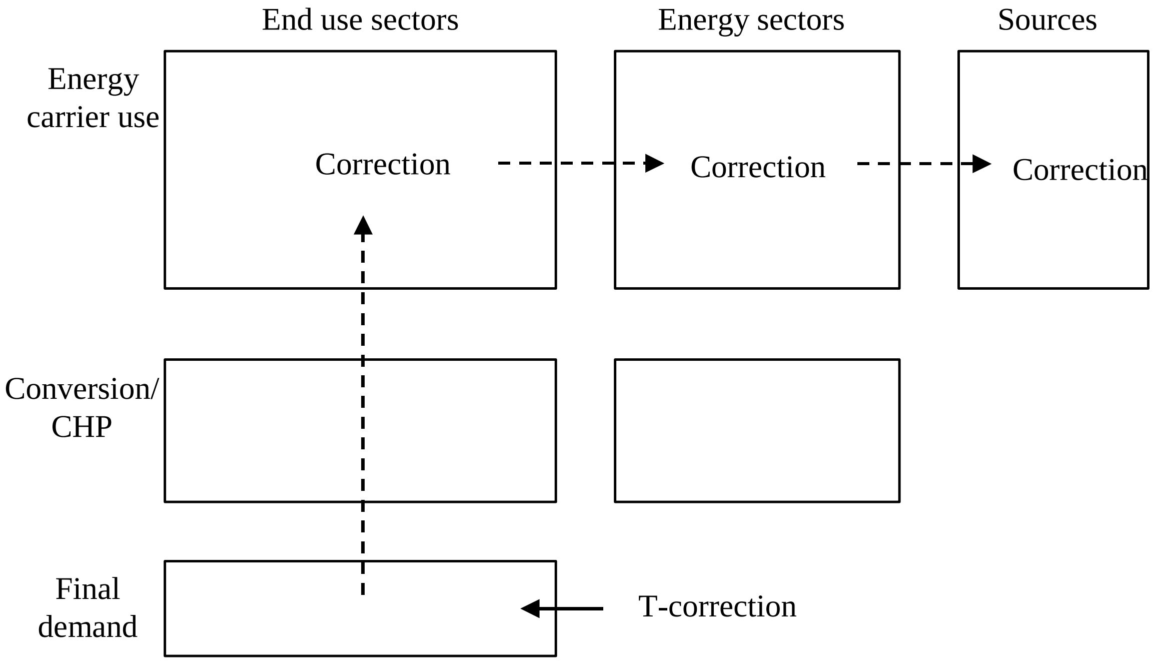

Figure 3.4 Calculation of balance C from balance B

Figure 3.5 shows an example of the results available from MONIT with figures for balance A (statistics), balance B (corrected) and balance C (climate-corrected). The difference between balance A and B, from 1993 onwards, is caused by the shift of cogeneration from the energy sectors to end-use sectors. After the climate correction the trend in gas use is far more stable than on the basis of statistics.

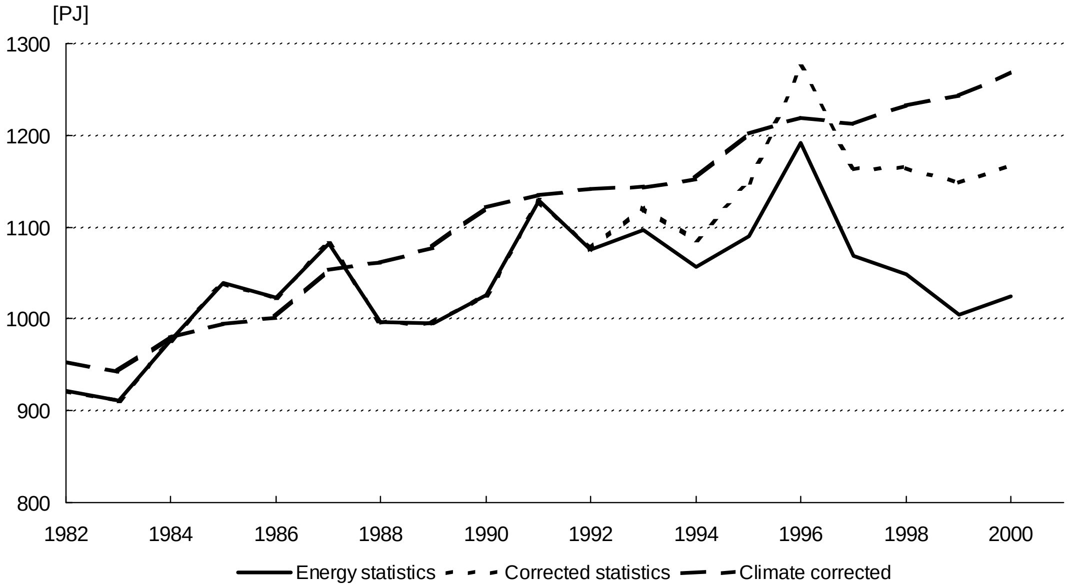

Figure 3.5 Use of gas by Dutch end-users: statistics, corrected and climate-corrected

Analysis part balances

The analysis part of MONIT consists of 14 balances, called D through Q, for each year. These balances are constructed one after the other, starting from balance C for the base year 1990 (see also Figure 3.2).

Principles used in constructing balances

Balance C for the base year is transformed in 14 steps into a replica of the actual balance for a chosen year. For each following balance one extra explanatory factor is introduced and added to the set of factors used in the previous balance. The stepwise reconstruction of the energy balance starts with the final demand and ends with the primary inputs (see also Figures 3.6, 3.7 and 3.8). If the values of certain energy use variables are adapted, the consequences for other parts of the energy balance system are determined as far as possible according to the situation in the base year. For instance, a change in the final demand leads to proportional changes in the base year use of each energy carrier involved. An increase in the total use of oil products of all end-use sectors leads to a proportional increase in all refinery figures for the base year. In some special cases values in the balance sheet are kept at the base year level, for practical reasons or in order to achieve a clearer presentation of effects. For instance, cogeneration is not updated following an up- or down-scaling of the final demand. The reason is that keeping cogeneration figures at the base year levels allows for a clear presentation of the cogeneration effect. In one dedicated step cogeneration figures change from the base year level to the actual level (see description ‘Balance J’). Table 3.1 gives an overview of each step in the reconstruction process: the explanatory factors, the inputs used, the balance from which the update starts and the status of the figures in different parts of the balance. The construction of balances, the explanatory factors used and the results can be described as follows.

Balance D, GDP growth
Balance D is first set equal to balance C for the base year (see Figure 3.6, ‘C-base year’). Then all final demand figures for end-users are scaled up in line with the national volume variable, the GDP growth between base year and year t. The use of energy carriers is updated to meet the new final demand and the changes are passed on to the energy sectors. The increase in electricity use is passed on to power stations, increased oil products use to refineries, coal products to coke factories and natural gas to the gas supply. Finally changes in total gas use lead to more or less extraction and changes in total use of oil and coal are passed on to imports. The explanatory factor for the differences between balance D and balance C (base year) is ‘GDP growth’ (see Table 3.1).

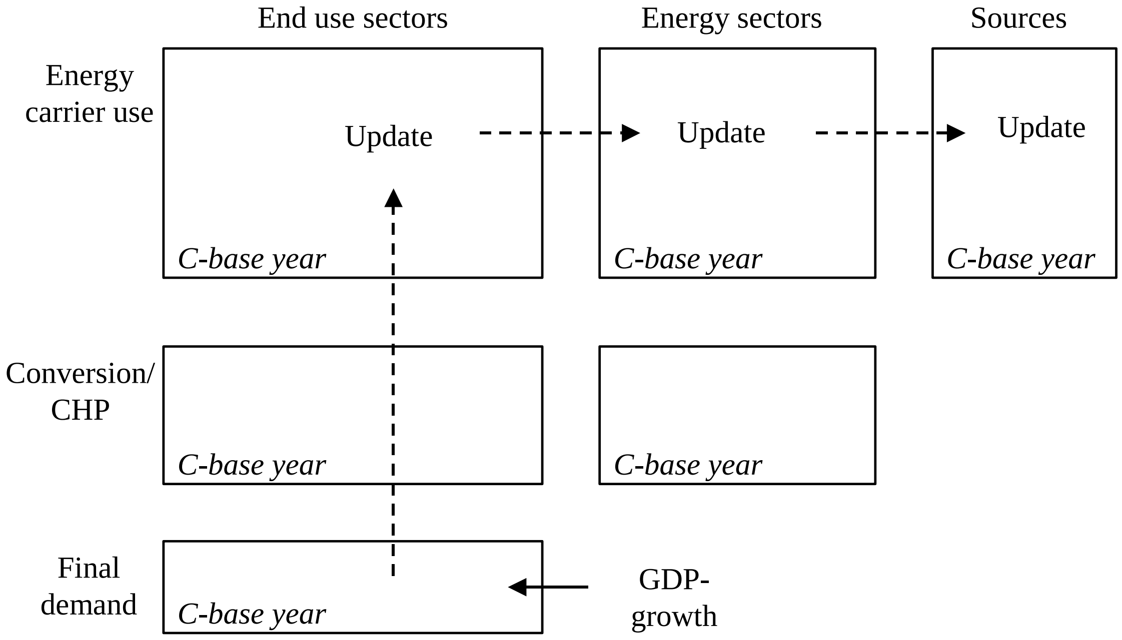

Figure 3.6 Construction of balance D from balance C-base year

Balance E, Structure main sectors
In balance E the final demand figures from balance C-base year are scaled up with the growth figure of the volume variable for each main sector: total Value Added for industry, number of households for households, total transport activity (person-km and ton-km) for transportation and total Value Added for ‘miscellaneous’. Further updates in other parts of the balance are executed in the same manner as with balance D. The differences between balances E and D

arise from volume developments in the main sectors which deviate from GDP growth; the explanatory factor is therefore called ‘Structure main sectors’.

Balance F, Structure subsectors
Here the final energy demand (from C-base year) in each separate subsector inside the main sectors industry and ‘miscellanous’is scaled up with the growth of its own volume variable. The differences between balances F and E are due to shifts in the relative economic importance of the seven industry subsectors and growth rates in the subsectors agriculture, construction, non-profit and commercial services, which deviate from the growth rate of the main sector ‘miscellaneous’.

Balance G, Structure final demand
The final demand in each sector is scaled with the sum of the growth rate (see Balance F) and a rate due to structural changes with respect to energy use within sectors, called the intra-sectoral effect. This scaling results in a so-called ‘reference use’, the development of final demand without savings. Where possible the growth in physical production variables is used to determine the reference use development. In that case the intra-sectoral effect represents the difference between economic and physical production trends. In other cases the results of bottom-up analyses have been used to estimate the reference energy use (see also discussion on uncertainty). The intra-sectoral effect is specified for electricity and heat separately (and in some sectors also for feedstocks) because developments differ substantially for these final demand categories.

Balance H, Savings final demand
The final demand figures in each sector (from C-base year) are scaled with the combined rates due to volume growth (see F), structural changes (see G) and realised savings on final demand. In MONIT this combined scaling effect is, by definition, equal to the actual change in the final demand between the base year and the chosen year. If the volume and structure effects are known, the saving effect follows from the change in final demand (see discussion on uncertainty). Therefore balance H contains the actual final demand figures for electricity, heat and (if appropriate) feedstocks.

Balance I, Conversion efficiency end-users
In this balance the use of fuels is calculated on the basis of the final demand for heat, taken from balance H, and the *actual* efficiencies for fuel to heat conversion in boilers, ovens, etc. In previous balances the fuel to heat end-use conversion efficiencies for the base year were used all the time. The separate presentation of conversion apart from savings on final demand (see G) provides for a reference conversion efficiency for heat production, which is needed to calculate the savings of cogeneration (see J). Moreover this avoids the inconsistency of summing up heat and fuels used for final demand. Changes in fuel to heat end-use conversion efficiency are present only in the ‘space heating’ sectors households, agriculture, non-profit and commercial services. Trends in conversion efficiencies are estimated on the basis of bottom-up analyses (see discussion on uncertainty). Efficiency changes for process heat in industry are assumed to be of minor importance. Therefore conversion efficiencies are kept at the same value for all years. Incidental conversion improvements will appear as part of savings on final demand for heat (see H). In transport final demand was defined here as demand for fuels and more efficient conversion is part of the savings on final demand.

Balance J, Cogeneration end-users
The inputs and outputs of cogeneration or CHP-production in each end-use sector, which till now have been kept at the base year level, are replaced by the actual amounts, from balance C for the chosen year (see Figure 3.7). Cogeneration in refineries or distribution companies is taken care of elsewhere (see N). The effects of an increase in cogeneration are less use of electricity from the grid, less fuel for conventional steam production, but more fuel for cogeneration. The effect on fuels for boilers is calculated with the actual boiler efficiencies introduced in balance I (see also savings from cogeneration). Note that the update no longer influences final demand figures (see ‘actual’ in Figure 3.7) and that the update of energy carrier use is applied to an already adapted part (see ‘I-update’).

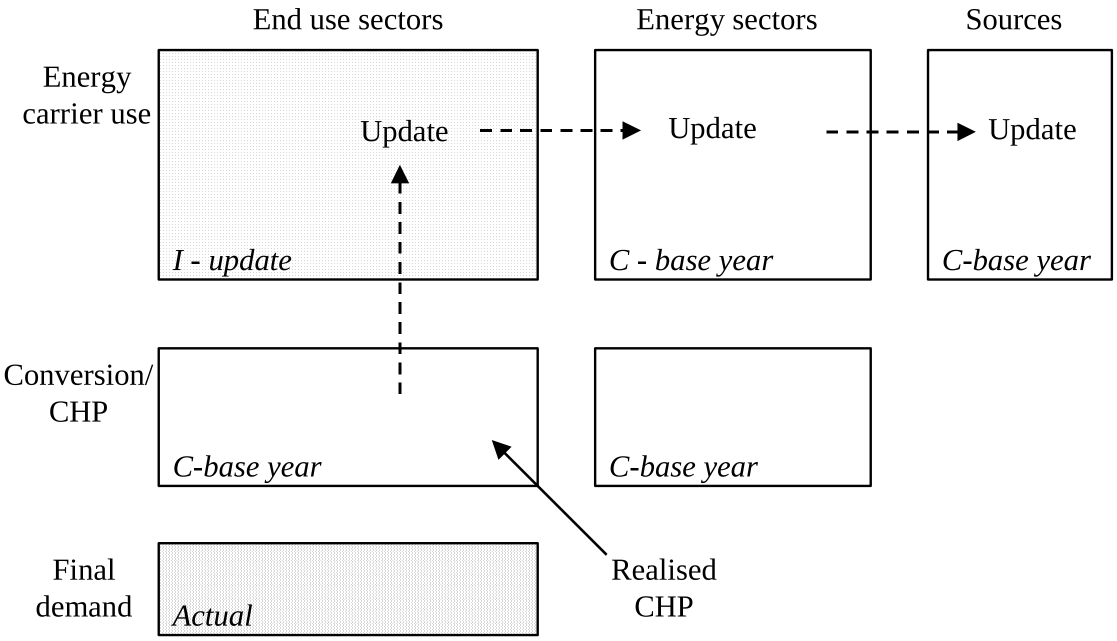

Figure 3.7 Construction of balance J from balance I

Balance K, Fuel mix end-users
Up to balance J all changes have been translated into proportional changes in the use of energy carriers for the base year. In this balance these constructed figures are replaced by the actual figures for each year (from balance C). Note that from now on all the figures for end-users do not change any more (see also Table 3.1).

Balance L, Export
Changes in the export of energy carriers influence the energy sectors in the same way as the changes in the end-use sectors. To show the influence of export changes the export figures from the base year are replaced by the actual figures (from balance C) in one dedicated step (see treatment of import and export).

Balance M, Structure energy sectors.

The change in total energy use of all energy sectors is due to shifts in the relative position of electricity production, refineries, gas supply, etc. and changes inside these different sectors. The first effect has been dealt with in balance D through L where the use of energy carriers by end-users and for export has been updated, leading to a different growth rate for energy use of each energy sector. At the level of the energy sector as a whole this can be seen as a structure-effect explaining why the growth of total energy sectors use deviates from that for all end users. Changes inside sectors comprise savings, structure and fuel mix; in balance M structure effects in different sectors are taken care of. Two important structural changes in the energy sectors are the more intensive processing of oil products in refineries (see Figure 3.8, block 'conversion/CHP'), and the increasing amount of gas use for both extraction and transportation of natural gas (see block 'energy carrier use'). In balance M the ratio 'own use/total output' for the base year is replaced by the actual ratio for each year. The actual ratio is calculated without the effects of efficiency gains after the base year. The new ratios for refineries and gas supply result in an update of the inputs of refineries and the own use of the gas supply system. Note that the resulting changes in the values for sources come on top of earlier adaptations (see Figure 3.8, 'L-update').

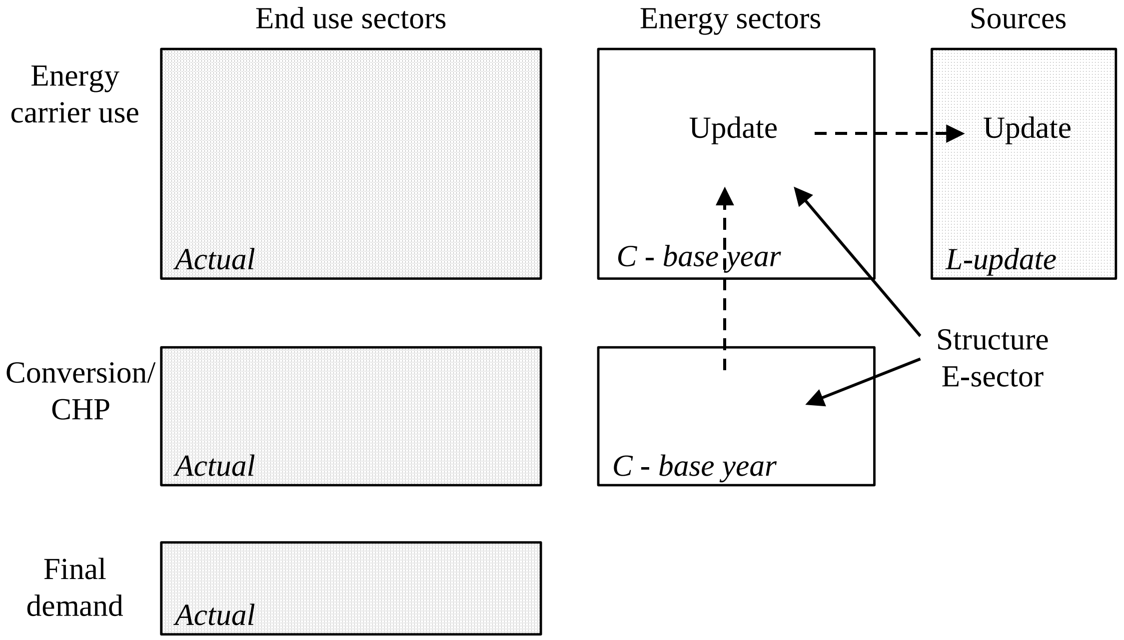

Figure 3.8 Construction of balance M from balance L

Balance N, Cogeneration energy sectors

The step taken with this balance is meant to show the energy savings brought about by extra cogeneration in the sectors refineries and electricity distribution. The cogeneration figures were kept at the base year level from balance D through M and are now replaced by the actual figures. The resulting increase in electricity production is compensated by a reverse change in the output of conventional power production (see also savings from cogeneration).

Balance O, Efficiency energy sectors

More efficient power plants and savings on the own energy use of refineries are also important saving options in the energy sectors. For the central electricity production the fuel input is calculated with the actual conversion factors per type of power station, instead of the factors for the base year. For refineries the ratio ‘own use/total output’ is decreased in accordance with the savings achieved in refineries.

Balance P, Import.

A separate balance with respect to changes in energy imports is introduced because some imports have been very important for recent trends in Dutch energy use. In this balance the figures for the import of gas, uranium and electricity are given the actual values. The changes in the import of electricity are translated into changes in central electricity production and the fuel inputs involved. The update of gas imports has been compensated by a change in extraction of gas. The update of uranium imports also leads to changes in other fuel inputs for electricity production. The import of coal (products) is not updated because there does not exist an alternative, such as extraction, to take care of further adaptations needed (see balance Q). Besides, changes in the import of coal hardly influence national energy use because the coal supply system itself has no conversion or distribution losses. The import of oil is not updated for the same reason; Dutch extraction of oil is limited in nature and imports must allow for further adaptations in the step-by-step analysis (see Q). To avoid a separate analysis step the extraction of crude oil is also updated in this balance. The trade off between import and extraction of crude oil has only a very small influence on total energy use.

Balance Q, Fuel mix energy sectors.

Up to balance Q all changes in the energy sectors were, as much as possible, in the form of proportional changes in the energy use figures. In the final step of reconstructing the energy balance the actual figures for the energy sectors are put in place. Two exceptions are the own use of heavy fuel oil in refineries and the gas use in central power production. The use of fuel oil is adapted to compensate for the changes with other refinery inputs (refinery gas and natural gas). Until balance Q these inputs were scaled according to the fractions in the base year. The use of natural gas has been calculated as a result of the updates of the values in all other variables. For instance inserting the actual figures for coal use in power stations changes the earlier calculated electricity production from coal. This leads to more or to less electricity production in gas power stations and thus gas use. This method also provides an opportunity to check the quality of reconstruction (see discussion).

Table 3.1 Overview of balances with explanatory factors, inputs and status of figures in the balance

	Name/explanatory factor	Inputs	Starting point	Status of figures during the reconstruction steps						
				End-users			E-sector		Export	Import (part)
				Final demand	CHP	Energy use	CHP	Energy use		
A	Energy statistics	Statistical figures	×							
B	Corrected statistics	Corrections for trend breaks, etc.	A							
C	Climate corrected	Degree-days and fraction room heating	B							
D	GDP growth	GDP growth rate	C-1990	Update	C-1990	Update	C-1990	Update	Update	Update
E	Structure, main sectors	Growth rate main sectors	C-1990	”	”	”	”	”	”	”
F	Structure, subsectors	Growth rate per subsector	C-1990	”	”	”	”	”	”	”
G	Structure, final demand	Reference final demand per subsector[1]	C-1990	”	”	”	”	”	”	”
H	Savings, final demand	Actual final heat/electricity demand	C-1990	C-year	”	”	”	”	”	”
I	Conversion efficiency end-users	Actual efficiency boilers, etc.	H	”	”	”	”	”	”	”
J	Cogeneration end-users	Actual CHP figures (end-users)	I	”	C-year	”	”	”	”	”
K	Fuel mix end-users	Actual energy use (end-users)	J	”	”	C-year	”	”	”	”
L	Export	Actual energy exports	K	”	”	”	”	”	C-year	”
M	Structure E-sectors	Reference use refineries/gas supply[1]	L	”	”	”	”	”	”	”
N	Cogeneration E-sectors	Actual CHP figures (E-sectors)	M	”	”	”	C-year	”	”	”
O	Efficiency E-sectors	Actual conversion efficiencies	N	”	”	”	”	”	”	”
P	Import	Actual energy imports (oil extraction)	O	”	”	”	”	”	”	C-year
Q	Fuel mix E-sectors	Actual energy use (E-sectors)	P	”	”	”	”	C-year	”	”

[1] Reference use is the actual energy use without savings, or the base year use scaled with the volume and structure effects

Calculation of primary energy use

The energy use of each end-use sector is the sum of fuels, electricity and heat, all of which are supplied by the energy sectors. However, the conversion losses incurred by supplying electricity and heat differ substantially from those for fuels. The primary energy use figure of a sector takes these differences into account and represents the real burden on energy supply. Primary energy use is calculated by multiplying the use of each energy carrier by a specific primary factor and then adding up the figures. The primary factor incorporates all the losses incurred by the delivery of the associated energy carrier. For electricity the primary factor is calculated as the ratio of total input, including electricity import, and total deliveries, including export. The same applies for input of refineries and oil products and for import/extraction of natural gas and gas deliveries. For coal/cokes the input and output of coke factories determine the ratio. For secondary gases a primary factor of 1 is taken. For grid-supplied heat the factor used is based on the marginal extra fuel used when heat is extracted from a power station. The fuel input for electricity has been corrected for this extra fuel use. The input of the energy sectors often consists of imported energy carriers, ready for delivery to end-use sectors. In MONIT no conversion losses are coupled to these inputs (see also discussion about treatment of imports). Primary factors can vary between sectors because of differences in the pattern of use, the volume of use or the point of delivery. Variable gas deliveries for space heating cause more losses than does continuous industrial use, and deliveries of oil products to petrol stations are less efficient than deliveries by pipeline to chemical industries. The electricity distribution losses range from 1% for big industrial users to 7% for small users out in the country. However, because of the minor effects on the analysis results, the same value for the primary factor is used for all end-use sectors.

Because primary factors are >1 (see also Table 3.2) the total primary energy use of a sector is greater than the total energy use. The sum of primary energy use for all end-use sectors is equal to total primary energy use because the use of the primary factors means that all energy use of the energy sectors is transferred to the end-use sectors.

Calculation of CO_2 emissions

The emissions of CO_2 are calculated using the energy use figures in the balances and the CO_2 emission factors per fuel type. The direct emissions follow from the multiplication of the use of fuels by the fuel specific CO_2 emission factors. Electricity and heat supplied to a sector have no direct emissions. For fuels used for non-energy use (feedstocks), the total use is corrected for the ‘fixed’ fraction, which does not cause emissions in the short run. So the total CO_2 emission per sector is equal to the direct emissions resulting from fuel use or the relevant fraction of non-energy use. For end-use sectors indirect CO_2 emissions are calculated in the same way as described earlier for primary energy use. The total CO_2 emission of electricity production is spread proportionally over all deliveries of electricity to end-users. The emissions of refineries are transferred to all oil product deliveries and the same applies for gas and coal. The sum of direct and indirect emissions by the end-use sectors, plus the indirect emissions connected to exports, is by definition equal to the total emission of CO_2 as calculated earlier.

Figure 3.9 applies to households and shows the direct emissions from fuel use, the indirect emission and the total emissions. The indirect emissions, which are coupled mainly to electricity, tend to increase more than direct emissions from fuel use because the relative importance of electricity has increased. However, the indirect emissions per unit of electricity have decreased in recent years because of the greater fraction of electricity import, which is considered to be CO_2 free. Therefore, the relatively fast increase in indirect emissions has recently stopped.

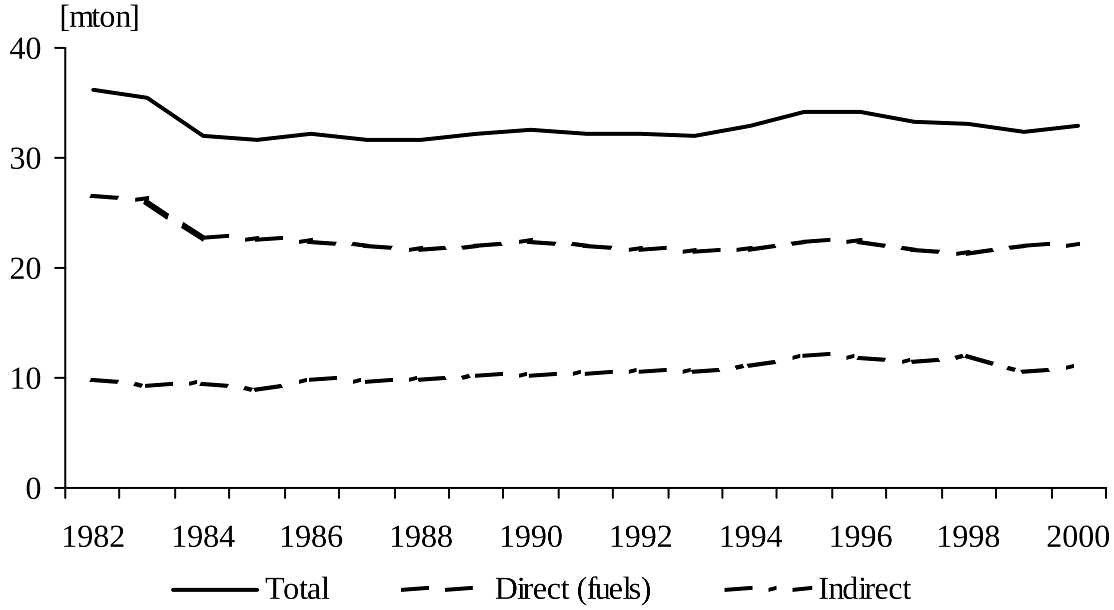

Figure 3.9 Total, direct and indirect CO_2 emissions from Households in the Netherlands

3.4 Results obtained with MONIT

In the following an overview is given of the results of both the presentation and the analysis part of MONIT. Results in the presentation part are generally given for all available years from 1982 onwards. The results derived in the analysis part are given only for the period 1990-1999 because these results have been verified in recent studies and the underlying statistical figures are more reliable than the figures for the period 1982-1989.

Time series for all variables

For up to 40 energy and more than 20 emission variables, and up to 28 sectors or aggregates, time series are available from 1982 onward. All figures are available in three versions: based on statistical figures, corrected for trend breaks, etc. and also corrected for yearly variations in the climate.

Intensities

The development of energy use and emission variables is related to that of socio-economic variables, used in the construction of balances E and F. This results in energy and emission-intensities. As an example, in Figure 3.10 the normalised trend in two final energy intensities is given for the Dutch agriculture sector. The electricity intensity (kWh per unit of value added) has increased strongly due to more artificial lighting in green houses. The heat intensity (MJ per unit of value added) has decreased thanks to energy savings and increased physical production of crops per m^2 of heated greenhouses. The following intensities are calculated:

- total primary energy use per unit of GDP or per capita,
- final demand of electricity or heat per capita or per household (sector households),
- final demand of electricity or motor fuel per unit of transport activity (person-km and ton-km),
- final demand of electricity or heat per full time employee (fte) in services,
- final demand of electricity, heat and feedstocks per unit value added (other sectors).

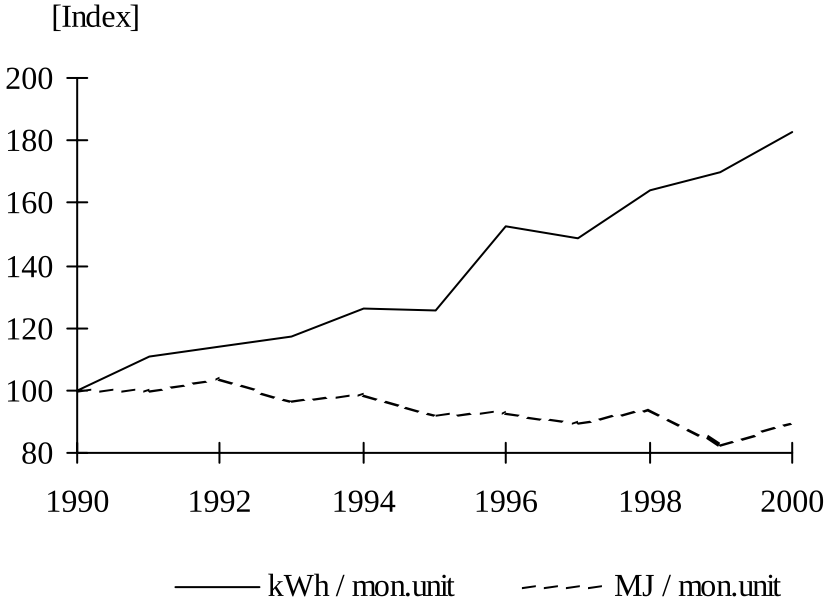

Figure 3.10 Electricity and heat intensities for Agriculture in the Netherlands (1990=100)

Primary energy factors and CO_2 factors

Table 3.2 shows primary energy factors for three years (based on the climate-corrected figures). The decrease for coal and cokes between 1995 and 2000 is due to the closure of one of the two coke factories. The profound decrease with electricity is due to more import, which is assumed to become available without conversion losses and therefore decreases mean energy use per kWh.

Table 3.2 Primary energy and CO_2 factors in different years in the Netherlands

	1990	1995	2000
Primary factors [-]			
Coal and cokes	1.062	1.064	1.034
Oil products	1.056	1.058	1.049
Natural gas	1.010	1.012	1.013
Electricity	2.47	2.46	2.21
CO_2 factor [gr. CO_2/MJ]			
Coal and cokes	106	106	103
Oil products	59	59	56
Natural gas	57	57	57
Electricity	166	164	135

For each energy carrier a CO_2 factor has been calculated which shows the sum of direct and indirect emissions per PJ used. For coal/cokes the commonly used CO_2 factor for direct emissions of 94 kg/GJ increases to 105; for natural gas the direct emission factor of 56 kg/GJ hardly changes. For oil products the direct emission factor is lower then the usual range of 60-75 kg/GJ in literature because of the substantial import of oil products which is supposed to be CO_2 free. Incorporating the indirect emissions, originating from refineries, leads to a 6% higher emission factor. For electricity the direct emission is zero and the value of the CO_2 factor depends solely on the indirect emissions from power stations. Here the development of the primary energy factor and the CO_2 factor can differ because of changes in the fuel mix for power stations, the fraction of (CO_2 free) imports in total deliveries, etc. The calculated CO_2 factor for electricity is also given in Table 3.2.

Primary energy use

Primary energy use figures can be given for all end-use sectors and for energy exports. Figure 3.11 shows both total energy use and total primary use for Services. Total primary energy use is growing faster than total energy use because of the increased share of electricity in total energy use and the relatively high conversion losses to deliver electricity.

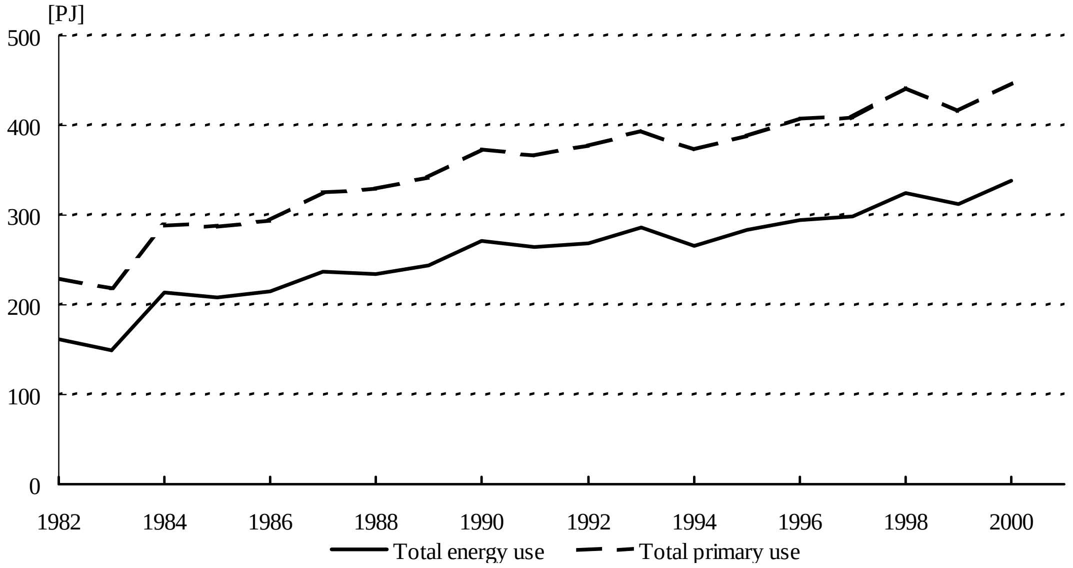

Figure 3.11 Total primary use and total energy use of Services in the Netherlands

CO_2 emissions

MONIT can deliver direct CO_2 emissions for all sectors. Total direct emissions are split into energetic and non-energetic use of fuels. Indirect CO_2 emissions are given only for end-use sectors and export. The sum of direct and indirect emissions is available too, split into energetic and non-energetic use (see also Figure 3.9).

Contributions to the change in energy use

The observed change in energy use over a period is attributed to the set of explanatory factors as listed in Table 3.1. The calculation of the contribution of each factor to the change in energy use is described in Section 3.3. For each energy/emission variable and sector figures about the contributions of the 14 factors are available. The 14 contributions to the change in total energy use in the Netherlands in the period 1990-1999 are shown in Figure 3.12.

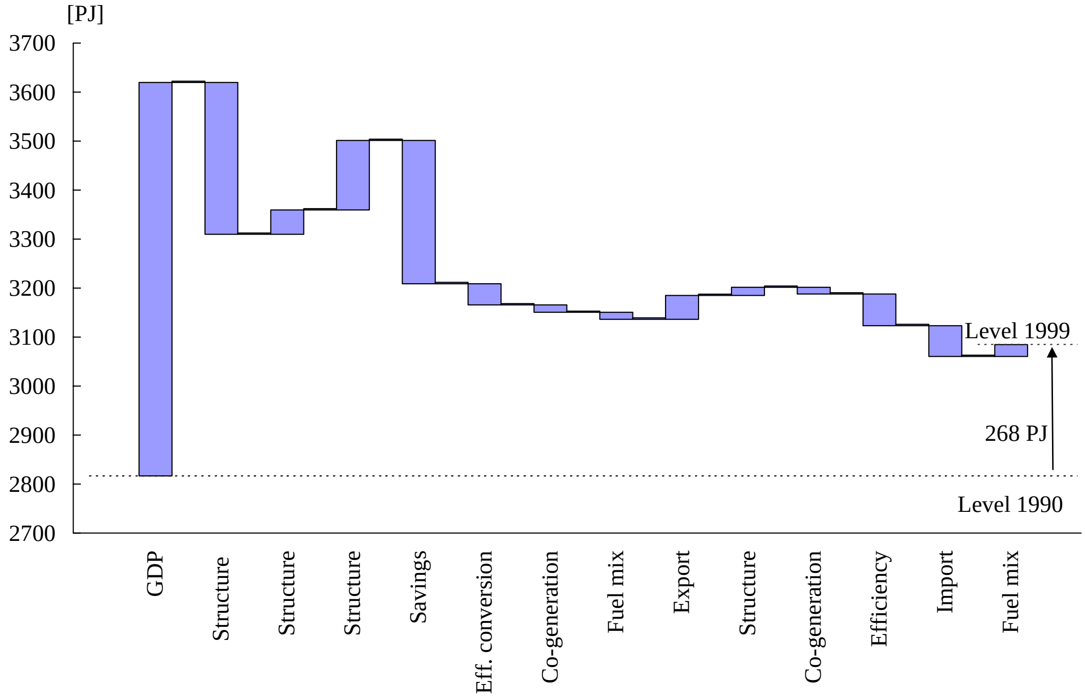

Figure 3.12 Contributions to the change in total energy use 1990-1999 in the Netherlands

The total change is the sum of increasing and decreasing contributions. The increase due to GDP growth is partly reduced by the relatively lower growth of the volumes in the main sectors: the number of households, person- and ton-km in transportation, employees in the Service sectors and Value Added in other sectors. Structural changes that will affect the final demand per sector, e.g. more appliances in households, more air conditioning in offices and larger cars in transport, cause an increase in total energy use. However, this is more than compensated for by the savings on final demand in the end-use sectors. Other contributions are related to the supply of energy, both in end-use sectors (efficient conversion in the residential, agricultural and service sectors, cogeneration and fuel mix) and in energy sectors (efficient power stations, cogeneration, structural changes in refineries and fuel mix). At last import and export are also responsible for part of the change in total energy use. In the period shown the substantial increase in electricity imports has decreased the growth in total energy use. As a result of all contributions, total energy use rose between 1990 and 1999 by 10%.

Contributions to a change in CO_2 emissions

The change in emissions is split into the same 14 contributions, as was the case with energy use. The relative importance of the contribution of each factor often is in line with that for energy. However, the contribution of fuel mix changes will be more profound because the fuel mix often is more decisive for CO_2 emissions than it will be for energy use.

In MONIT the period shown can be chosen at will, for instance two consecutive years. Figure 3.13 shows the change in total CO_2 emissions between 1998 and 1999. The contributions are based on the difference between the results for 1990-1998 and the results for 1990-

1999. The contributions in Figure 3.13 differ substantially from that depicted in Figure 3.12 because the chosen period is quite different. The contribution of changes in energy imports is substantial compared to the total increase in CO_2 emissions. This is caused mainly by the fast increase in electricity imports, coupled to market liberalisation, and the alleged CO_2 free character of imports. The negative reduction from cogeneration is not due to a decrease in capacity but to detoriation of the CHP-efficiency, probably caused by a statistical trend break.

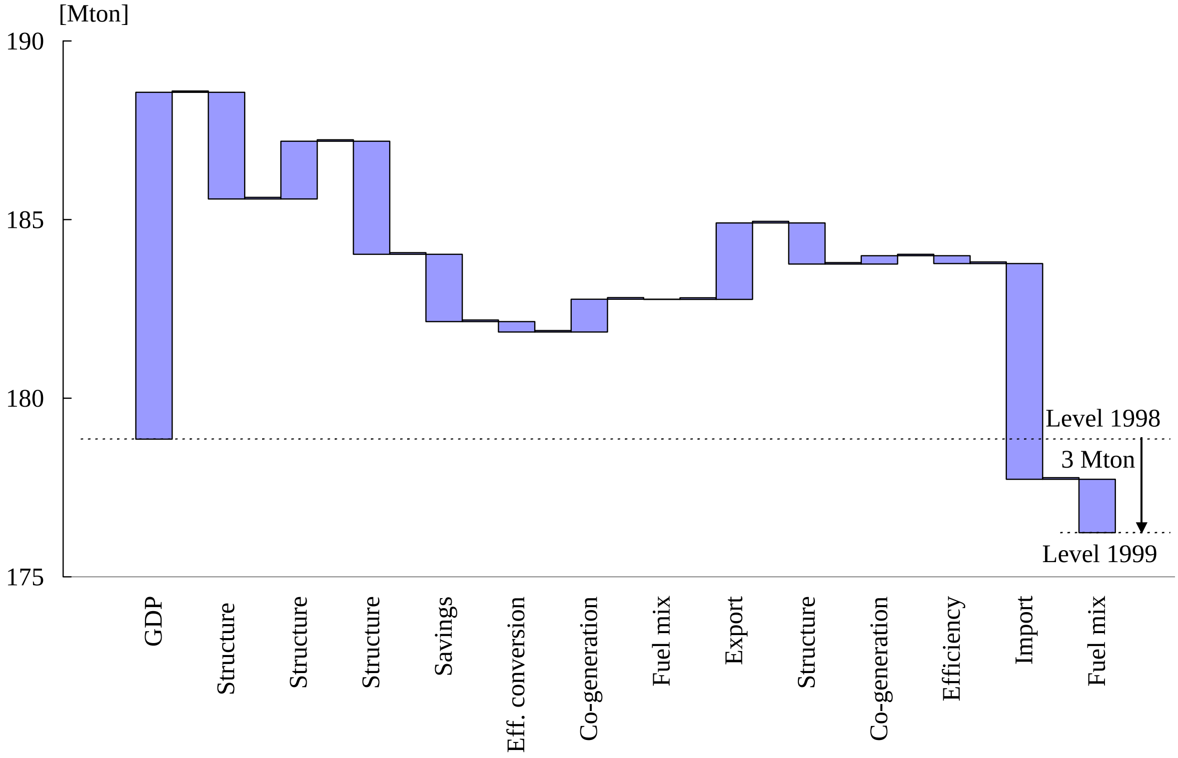

Figure 3.13 Contributions to the change in total CO_2 emissions 1998-1999 in the Netherlands

Volume, structure and saving effects

The 14 contributions to changes in total energy use can be aggregated into three general effects: volume, structure and savings. The volume effect is equal to the contribution of GDP growth and the saving effect is taken as the sum of the contributions ‘savings final demand’, ‘conversion efficiency’ and ‘cogeneration’ for the end-use sectors and ‘efficiency’ and ‘cogeneration’ for the energy sectors (see also Table 3.1). The structure effect must contain the other contributions: various structural changes in end-use and energy sectors, import and export changes, and fuel mix changes for end-users or power stations. In Table 3.3 the values for the three general effects are given for Dutch energy use in the period 1990-1999.

Table 3.3 Aggregated results for the development of total energy use in the Netherlands between 1990 and 1999

	1990 [PJ]	1999 [PJ]	Change/year [%]
Total primary energy	2817	3078	+1.1
Effects:			
Volume (GDP)	×	+542(3620)	+2.8
Structure	×	-113(3507)	-0.4
Savings	×	-429	-1.4

GDP growth should have driven energy use up by 2.8% per year, all other relations kept unchanged in this period. The structure effect, consisting of positive and negative contributions (see Figure 3.12), mitigates this growth induced increase. It should be pointed out that this structure effect is defined here in a broader sense than is usually the case in studies of energy-use developments. The energy savings have, by definition, a mitigating effect. The result of the three general effects together is an increase in energy use of 1.1% per year. The rounded figures conceal the fact that the sum of the three effects is not exactly equal to the change in total energy use between 1990 and 1999. This is due to small reconstruction errors (see discussion).

Savings from cogeneration

The application of cogeneration by energy users decreases the use of electricity from the grid and reduces conventional heat production, but it increases fuel use. As a result, total energy use increases on the site. However, taking into account the lower conversion losses in power stations, more cogeneration leads to energy savings at the national level. The amount of savings is dependent on the reference systems used for heat and electricity. The electricity alternative chosen is particularly important in this respect. This is illustrated with the 14-step MONIT analysis of savings from cogeneration in industry in the period 1990-1998 (see Figure 3.14). The savings derived from extra cogeneration have been defined as fuel saved in boilers and power stations minus the fuel used in cogeneration. The savings have been calculated in each of the 14 constructed balances and the changes from one balance to another are presented in Figure 3.14. During the first six analysis steps the amount of cogeneration is kept at the base year level and therefore no extra savings appear. From balance I to J (see Section 3.3) the cogeneration figures of the base year are replaced by the higher figures for the year 1998. This leads to the so-called initial savings shown for ‘Cogeneration end-users’. These savings are calculated using the efficiency of power stations in the base year 1990. These initial savings decrease in the following steps, when efficiency increases in the energy sectors enter the calculations (in balance N, ‘Cogeneration E-sectors’ and balance O, ‘Efficiency E-sectors’). Savings decrease further when the higher 1998 import figure replaces the 1990 electricity import. In all these cases the calculated savings decrease because the amount of fuel saved by not using electricity from the grid decreases. On the other hand the modest change in the power station fuel mix (more refuse incineration and less gas) lowers the mean efficiency of electricity production. Therefore the calculated savings increase in the balances where these developments are taken into account. Ultimately, ending with the actual electricity system of 1998, about half of calculated initial savings remain, presenting the de-facto savings derived from extra cogeneration in end-use sectors.

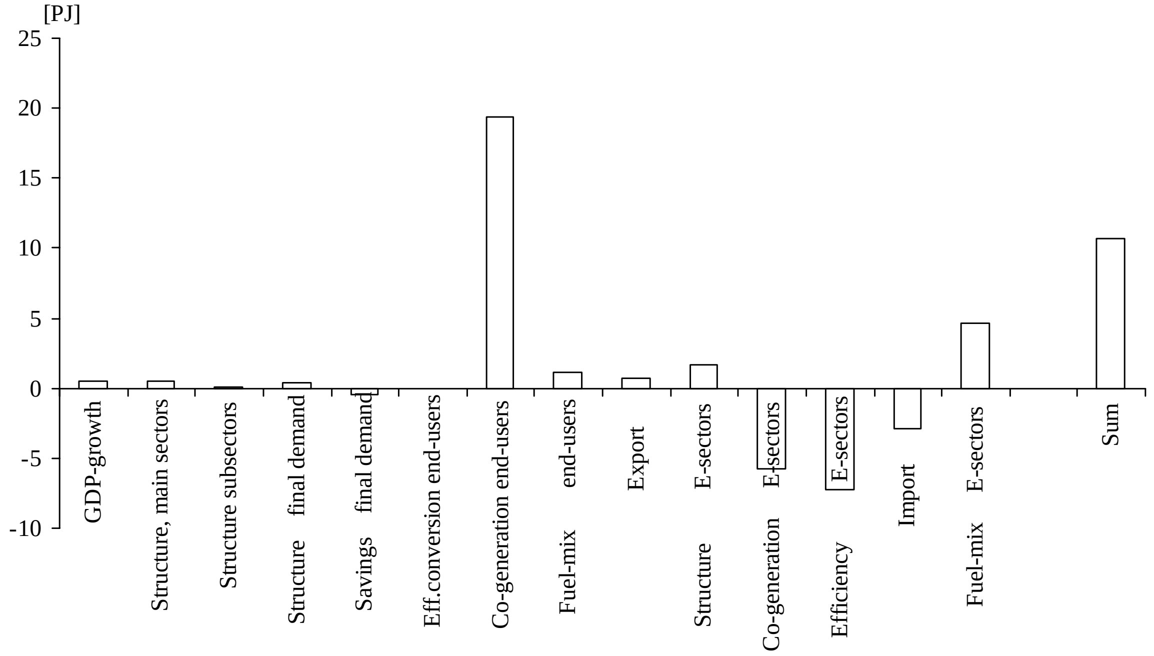

Figure 3.14 Disaggregation of energy savings by Dutch industrial cogeneration 1990-1998

Trend analysis with static primary energy use

In Section 3.3 the definition of primary energy use and the reason for using this variable, in stead of energy use itself, have been described. Another reason is the fact that it proves to be difficult to understand trends in energy use if the PJ electricity and PJ fuel use are just added. Because electricity often is used for quite different purposes than fuels or heat, the two developments diverge (see also Figure 3.10). Also, electricity undergoes fewer conversion losses than fuels in meeting the same final demand. A change from fuel to electricity can lower total energy use, and that can be wrongly interpreted as savings on energy use. However, using primary energy use has also disadvantages because the changes are not only the result of developments in end-use sectors but also of trends in the energy sectors. These two causes for changes appear at the same time and make it difficult to analyse properly the changes in energy use. This is why it is convenient to use ‘static primary energy use’ in the analysis. Static stands for constant primary factors, based on the energy supply system of the base year. Therefore the development of static primary energy use is determined only by the changes in the end-use sectors. So, static primary energy use provides a true picture of the sector developments without the drawbacks of using total energy use.

In the MONIT analysis of sector developments the concept of static primary energy use is used too. In Figure 3.15 the change in total primary energy use for the sector Households has been unravelled into 12 contributing factors (the factors ‘GDP growth’, ’structure, main’ and ‘structure, subsectors’ have been combined). In the first six analysis steps the factors, which influence household energy trends are mapped. In each step the total primary energy use is calculated with primary factors, which are based on the current configuration of the energy sectors. The energy sectors are scaled proportionally with changes in total deliveries but remain unchanged with regard to efficiency or fuel mix. This means that the primary factors are the same in these balances. In fact the calculated primary energy use is of a static nature and therefore the effects shown in the left part of the diagram can be ascribed entirely to changes within the sector Households. In the right part of the diagram the opposite effect is the case. Household energy use itself remains the same and all changes in primary energy use are the result of developments in energy supply. Thus the MONIT analysis of primary energy use in end-use sectors provides both information about the sector developments itself and information of system-wide indirect effects on sector use. This approach ensures that the information needs of the policymakers are optimally fulfilled.

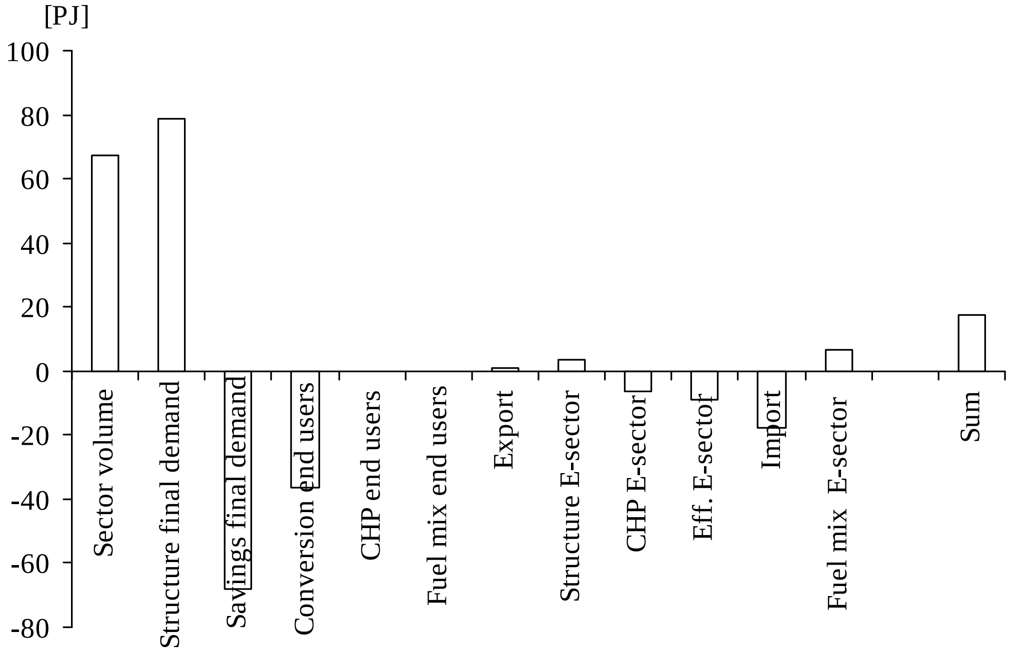

Figure 3.15 Analysis of primary energy use for Households in the Netherlands 1990-1999

3.5 Discussion

Quality of the reconstruction

The quality of reconstruction is defined here as the difference between the finally constructed balance Q and balance C with the actual figures. With respect to total primary energy use the (absolute) difference is less than 0.3% in each year of the period 1990-1999. The main reason for these relatively small differences is the fit between constructed and actual figures, which is made during the construction of the 14 balances (see Figure 3.16). After the first five steps, in balance H the constructed final demand figures are set equal to the actual figures. Possible errors in constructed final demand figures in the previous balances do not work their way to balance H and the following balances. After four more steps, in balance L a ‘perfect fit’ is again reached for all the energy use figures of the end-use sectors and export. From this point on only construction errors in the energy sectors can cause a difference between the ultimately constructed total use and the actual total use. During the further reconstruction of the supply side more and more energy use figures in the energy sectors are fitted ‘perfectly’ to the actual figures (in balances M through P). Finally, in balance Q only a few energy variables have a value as a result of the reconstruction, and only these values may differ from the actual figures. The resulting reconstruction error is caused by some simplifications in the way the updates in the energy sectors are passed on to import or extraction. It should be noticed that the small error found for total energy use does not mean that all constructed variables in each intermediate balance are of the same quality as total energy use (see beyond).

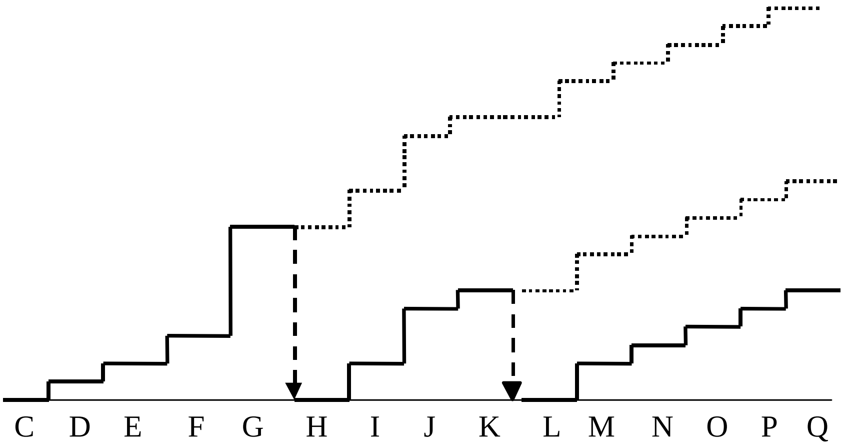

Figure 3.16 Cumulative error during the stepwise reconstruction of total primary energy use

Uncertainty in the calculated 14 contributions

Generally speaking, the uncertainty in the contributions, as shown in Figure 3.12 and 3.13, depends on the quality of the energy statistics, especially the figures for the base year, and on the quality of the explanatory variables used to scale the energy use figures. In the Netherlands this poses no real problem, although in some sectors the figures are less reliable. Therefore, most (9 out of 14) contributions can be calculated as well as the statistical information will allow. However, to determine the other five contributions another kind of information is needed. The change in conversion efficiencies of power stations, needed to calculate part of the contribution of the factor ‘efficiency E-sectors’, can be determined reasonably well with the statistics regarding the input and output for the different types of power stations. To calculate the contribution of the factor ‘efficient conversion end-users’ the fuel to heat conversion efficiencies are needed. For the sectors Households and Services bottom-up information about more efficient boilers, etc. is used to calculate these efficiency changes. For industry, incidental improvements in conversion are part of the savings on final demand (see Section 3.3, balance I). In transport, more efficient conversion is also part of the savings on final demand. Actually the contribution of the second factor can be calculated also reasonably well. A great deal of uncertainty remains with respect to the contributions of the factors:

- ‘structure final demand’
- ‘savings final demand’
- ‘structure energy sectors’
- part of ‘efficiency energy sectors’ (refineries).

The contributions of ‘structure final demand’ and ‘savings final demand’ are defined for both electricity and heat in each sector. The sum of both contributions is by definition equal to the change in the final intensities of electricity and heat, which can be calculated from statistical data. Once the contribution of savings is known the contribution of structure is known too, and vice versa. The same reasoning applies for the contributions of ‘structure energy sectors’ and part of ‘efficiency energy sectors’. These two factors together cover the change in the ‘own use/output’ ratio for refineries, gas supply and coke factories. The change in these ratios can be calculated on the basis of statistics. In fact only two contributions have to be determined, not four.

In MONIT the contributions of savings and structure have been estimated on the basis of another more detailed analysis in Boonekamp (2002) per sector for 1990-2000. For industry an evaluation of the results of a long-term voluntary agreement for energy savings in the period 1989-2000, in Rietbergen and Blok (1999), has also been used as a source of information. The same applies for the energy sector refineries. For households results from a more detailed analysis of historical use in Boonekamp (1997) were used. For transport a more disaggregated approach in Bleijenberg (1997) was used, with a distinction being made between transport of persons and freight and accounting for modal split changes. For services however, only changes in specific energy use per employee per sub-sector can be used as a proxy for actual energy savings. The uncertainties about the contribution of savings on final demand range from minor for industry and refineries to probably large for services. This raises questions about uncertainty in the total contribution of the factor ‘savings final demand’, as shown in Figure 3.12. In a recent study Boonekamp (2001) about defining and calculating energy savings it is concluded that national savings (in % per year) can actually be one third lower or one quarter higher than the calculated value. The contribution of savings on final demand outweighs the other ‘saving’ factors (see Figure 3.12). Therefore the margin found elsewhere for total savings provides a good impression for the uncertainty in ‘savings final demand’. The margins in the contribution of ‘structure final demand’ follow directly because the sum of the two effects is known more or less exactly from statistics.

Sequence of stepwise reconstruction

As described earlier in Section 3.2, the explanatory factors are introduced in a fixed order during the reconstruction of the actual balance for a year. This means that the effect of the first factors introduced is determined in another way than the effect of factors introduced later. For instance, savings on final demand in a sector are calculated in MONIT using the conversion efficiencies of the *base* year. This final demand after savings is then used to calculate the savings by more efficient conversion in the sector. If this order should be reversed the savings by efficient conversion will be higher because the calculation is based on the final demand without savings. But the savings on final demand will become lower because the calculation is based on the higher efficiencies of the chosen year. In principle the contributing factors can be chosen in any order in the analysis, but each choice can lead to (minor) shifts between the contributions of the factors. This problem of order, or how to split up the combined effects of two or more factors, is to a certain extent solved by the use of decomposition methods, described in Ang (1995). In MONIT the choice of order is dictated by the stepwise reconstruction process which proceeds from final demand to primary sources. From the point of view of calculation algorithms this order is much easier to implement than the reversed order. However, MONIT can be adapted to a different order of the factors conversion, CHP and fuel mix. Presently, on considerations about the presentation of the contributions, cogeneration in the energy sectors (balance N) is updated, before the change in efficiencies of power stations (balance O) and fuel mix (balance Q) are introduced. The savings of cogeneration are thus calculated on the basis of the base year characteristics of the central power system; this is in line with Dutch policy evaluation of cogeneration. However, as Figure 3.14 shows the ultimate savings of cogeneration will be substantially lower if the changes in central power production are accounted for.

Treatment of import and export

Imports of secondary energy carriers, like electricity or oil products, enter the energy balance on the basis of their energy content, not the energy inputs needed to produce and deliver them. Also no indirect CO_2 emissions are regarded for import. Therefore, the substantial and increasing imports of electricity in the last decade have led to lower losses and emissions per kWh delivered to end-users. Exports are considered here to be a (special) end-use sector, and a proportional part of the losses of the energy sectors is allocated to this ‘sector’. The same applies for the allocation of CO_2 emissions of the energy sectors to export. However, to keep up consistency with the treatment of import, the losses and indirect emissions connected with energy exports are tied to the inland energy sectors. This treatment of emissions is consistent with the IPCC rules for green house gas accounting in IPCC (1997). However, this standard method of treating import and export does not show the real pressure of national activities on energy supply and the environment. Two alternative methods are proposed:

- Determine the true inputs abroad, used to deliver the imported secondary energy carriers.
- Set the conversion losses made for imports equal to the losses in inland production.

In both cases the losses due to import are added to those of inland production and then allocated proportionally to the inland users and export of energy carriers. The first method accounts for the differences in primary energy sources and conversion efficiencies in the different countries from which electricity or other energy carriers are imported. The method delivers realistic figures about losses but it proves very difficult to gather the information needed. The second method is easy to implement because the losses in inland production are already known. However, results are less accurate because the Dutch supply system differs from the supply system of other countries. For practical reasons the second method has been chosen. For all imports of (semi) finished energy products the primary factor, valid for inland production, has been used to calculate the amount of imports in primary energy terms. From the corrected import figures and the losses in the energy sectors new primary factors have been calculated in MONIT (see Table 3.4, Import equivalent to domestic production).

When these corrected primary figures are used to calculate primary energy use for each end-use sector the total for 1990 proves to be 2.4% lower than total primary energy use from statistics. The extra burden of losses abroad, mainly for the import of electricity, is more than compensated by diverting a great deal of the energy use of refineries to the export of oil products. Because more than two-thirds of the refinery output is exported the same fraction of refinery energy use, some 120 PJ or 4% of TPE, can be subtracted from national energy use. Due to increasing electricity imports the difference between both primary figures decreases to less than 1% in 2000.

Table 3.4 Primary energy and CO_2 factors and import of energy (1990)

	Import without losses	Import equivalent to domestic production
Primary factors [-]		
Coal products	1.062	1.074
Oil products	1.056	1.082
Natural gas	1.010	1.011
Electricity	2.47	2.72
CO_2 factor [gr. CO_2/MJ_e]		
Electricity	166	193

3.6 Conclusions and observations

General conclusions are drawn and observations made about the way in which the MONIT approach contributes to a policy relevant analysis of historical energy and emission trends. In this evaluation only few comparisons are made with alternative methods because this was not the main goal of this publication.

Meeting monitoring needs

The goal of MONIT activities can be defined as:

- Present relevant figures about energy use and related emissions of CO_2.
- Unravel the observed changes in energy use into contributions by the explanatory factors.

The first task is accomplished fully with the MONIT system described here. Statistical energy figures and related variables are processed in a clear manner in order to deliver useful time series for analysing purposes, and all figures are readily accessible via a retrieval system. The second goal is met to a large extent; the actual change in all the usual energy and emission variables and sectors is disaggregated into contributions by 14 factors which are relevant for policy makers. The detailed results per variable and sector are aggregated to provide the same information at the sector and national level. One negative point is the uncertainty in the figures for some contributory factors, such as savings on final demand. However, this problem is probably also the case in other commonly used methods, such as Farla and Blok (1997), Uyterlinde (2000) and Schipper (2001).

User-oriented analysis structure

Most analyses of energy trends presented in literature are based on the data structure available and on the specific method chosen. However, if results are to be really useful it is also important to look at the needs of the potential users. Sometimes they are particularly interested in rather small but sensitive energy-use effects, such as electricity imports or cogeneration. Often users prefer an aggregation level that fits to a certain policy instrument over the statistically dictated aggregation levels. The analysis structure in MONIT has been designed in answer to concrete questions posed by policy makers. To meet this demand 14 policy relevant factors have been defined and the changes in energy use or emissions were split into contributions for these factors. The choice of the (sub)sectors is also based on policy demands, despite the fact that sometimes extra statistical data had to be found. With respect to energy variables, not only the usual energy carriers but also CHP variables and energy related CO_2 emissions are part of the analysis system. In this way it was possible to meet the information needs of potential users. This is illustrated by the use of the MONIT results for CO_2 (see Figure 3.15) in a government white paper VROM (2002), in the energy report in Dougle (1998) and in the recently published energy and environment outlook, Ybema (2002) respectively Wijngaart (2002). The flexible analysis framework also makes it possible to meet new information needs, for instance with regard to the contribution of energy carriers with a lower CO_2 content. The number of sectors, variables or explanatory factors can be increased rather easily.

Coupling results to data sources

The results of trend analysis often are questioned because of discussions about the data used. The users' confidence in the results decreases because the data shown do not match with their own knowledge or recognised sources of information. It is of vital importance in any monitoring exercise that the users of the results can access and check the data used. The MONIT system is designed to meet these demands because it incorporates a menu-based presentation of all the source data and the adaptations made to them. The users' confidence is increased because the data are presented in the form of energy balances, with sectors and energy carriers, a form that is familiar to most users of the results. Also the presentation part and the analysis part are fully integrated. Updates to the data are therefore automatically and consistently translated into new results. The difference between old and new results can be traced back to the differences in inputs.

Different levels of information content

Generally speaking understanding and interpreting the results of trend analysis proves difficult for policy makers and other non-skilled users of the results. Therefore it is necessary to present the results at different levels of information content and in a user-friendly form. In MONIT the results are presented first in the form of simple time series and indices normalised to the base year. The next level contains indicators (energy intensities) and time series of related variables, such as final demand for heat and (direct) CO_2 emissions. Then there follow calculated variables, such as primary energy use, savings from cogeneration or the indirect CO_2 emissions of fuel, electricity and heat delivered. Finally, at the highest level of information content the contributions to an observed change in energy use of emissions by the explanatory factors are presented. Every user can choose the appropriate level with regard to the needs. Moreover the simple information at the lower levels can help with the interpretation of the intricate results at a higher level.

Methodological evaluation

The MONIT approach differs from decomposition techniques in Ang (1995), but one purpose is the same: to determine how diverging socio-economic developments at a lower aggregation level influence the development of energy use at a higher level. This is accomplished by coupling energy use to socio-economic trends at the national, the main sector and the subsector level and analyse the different resulting energy trends. However decomposition techniques work with total energy use, where MONIT uses either final demand, split into electricity and heat, or primary energy use. Final demand (see definition in Section 3.3) is thought to be a more suitable variable than energy use to analyse the relation with socio-economic trends. Primary energy use provides a better indication of the real burden of energy use on energy supply and environment. Decomposition schemes distinguish only between energy use and energy supply. In MONIT also a supply section is present in the end-use sectors, namely cogeneration and other conversions. Therefore it is possible to distinguish between the effect of ‘own’ supply changes in the end-use sectors and the effect of supply changes in the energy sectors.

It has proved possible to reconstruct the actual energy balances for each year from a base year balance with a limited set of inputs. The reconstruction error is kept quite low because it is possible to fit intermediate results to actual values, which prevents the accumulation of errors (see Figure 3.16). Differences in total energy use between the finally constructed balance and the actual balance are less than 0.3% of the actual value. Therefore the sum of the effects of all 14 contributing factors is almost equal to the actual total change in energy use.

The 14 contributions to a change in energy use or emissions cannot be calculated with the same margin of uncertainty. Nine of the contributions can be calculated quite accurately, two reasonably exactly and three with a substantial margin of uncertainty. The latter is due to rather fundamental data problems that make it difficult to split changes in final demand intensities into saving and structural effects. A comparison with other methods is difficult because in literature hardly anything is said about uncertainties in the contributions of factors. In decomposition studies the effect of volume changes and some structural changes is determined; all other developments are assigned to a third factor, often called ‘efficiency improvement’, without an indication of the amount of non-efficiency influences.

In MONIT the order in which explanatory factors are dealt with is determined by arithmetical reasons. The analysis starts with the factors related to changes with final demand and ends with the factors related to supply and the sources. Sometimes the order follows from the usual way in which policy makers evaluate developments, e.g. the calculation of cogeneration savings with the base year efficiencies of power stations. This fixed order determines to a certain extent the results because the contribution of the explanatory factors sometimes depends on the sequence of steps in the analysis.

For a country with an open economy and energy supply system the treatment of import and export of energy carriers can have a great influence on trends in energy use and emissions. In the treatment according to the IPCC no losses or emissions are attached to imports or to exports. In an alternative treatment the losses made for the import of secondary energy carriers are set equal to that of inland production and part of the total conversion losses is diverted to users abroad. Both methods are applicable in the MONIT system.

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Chapter 4 MONITORING THE ENERGY USE OF HOUSEHOULDS USING A SIMULATION MODEL[11]

Abstract

In a bottom-up model for simulation of future energy use of households, called SAVE households, a great number of saving options are analysed in conjunction with growth of the number of inhabitants, dwellings, households and other structural changes which influence energy use before savings. The calculated change in energy use from the base year level is presented in the form of so-called volume, structure and saving effects. This model has been adapted to serve as a monitoring tool. In 1996 it has been used for the first time, for the official yearly monitoring exercise of environmental trends in the Netherlands, as a tool to analyse changes in household energy use in the period 1990-1995.

If sufficient information on a detailed level is available the approach based on the adapted simulation model has a number of advantages above other methods, e.g. the energy intensity analysis methods using disaggregation of energy use. The model offers a very flexible structure with regard to the preferred definition of saving options and structural changes. Further on, the adapted model is capable of handling the interdependency between structural changes and saving options and the substitution between different energy carriers. Also very complex changes with regard to energy use, such as smaller household sizes or a higher fraction of dwellings with district heating, can be easily analysed.

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[11] Published in Energy Policy, Vol. 25, No.7-9 (1997), pp. 781-787.

4.1 Introduction

For energy policy analysis in the Netherlands a bottom-up model of future energy use called SAVE (Simulation and Analysis of energy Use in Energy scenarios) is available. The model has been used for drafting the third White Paper on Energy Policy (EZ (1995)). Given the diversity in driving forces within sectors four different modules are used: Households, Industry, Services and Transportation. In these modules all saving options are analysed in conjunction with growth of the activities (production, consumption or transport) and with all structural changes, which influence sectoral energy use. The results encompass the change in future energy use from the base year level; this change is presented in the form of so-called volume, structure and saving effects. In this paper the focus is on the SAVE-module for households.

In the last few years the environmental trends in the Netherlands have been monitored annually for policy purposes in the so-called Environmental Balance. The growth of greenhouse gas emissions forms an important issue; in this respect an analysis of historical changes in energy use is of great relevance. In particular the changes related to policy measures for energy savings receive special attention. In the 1996 monitoring exercise, the SAVE-module for Households, as described in Boonekamp (1994), has been used for the first time to analyse recent changes in household energy use.

In the following a description is given of the global structure of the Households module, the special features which are needed for the monitoring function and the inputs required (Section 4.2). Then some monitoring results are presented for the period 1990-1995 in Section 4.3 and 4.4. An analysis of complex changes in household energy consumption is given in Section 4.5. The paper also focuses on the differences between this method of analysis and existing methods that are based on energy intensity analysis (Section 4.6).

4.2 The SAVE households module

Main characteristics of the model are a functional approach, the incorporation of demographic and life style impacts, an explicit modelling of all energy using technologies and the separation of the effects of technical efficiency and structural changes. The energy use of households (excluding transportation) is split up in seven so-called energy functions: space heating, hot water, washing/drying, cooking, cooling, lighting and other appliances. For space heating the dwelling/heating systems are divided according to age, type and local/central heating; for the other energy functions three household types are distinguished (one-, two- and more person families). First the energy use, excluding savings, for each function is calculated from a number of input variables and a set of rather simple relationships. Different kinds of scenario inputs are used: demographic figures, future expenditures, number and type of (new) houses, life style changes such as the amount of time spent at home, etc. Further inputs comprise the number of already existing dwellings, heating installations and appliances.

Given the energy use without savings a number of saving options attached to each function can decrease energy use. The penetration of the saving options is based on the cost/benefit ratio (except in some cases, e.g. regulated insulation of new houses). Benefits equal the saved amount of energy times the price per unit. Costs comprise the annualized investment costs and other yearly costs, and sometimes the costs of another energy carrier, which is needed to realise the saving option. The technical-economic specifications have been derived by translating the ICARUS data on saving options in de Beer (1994) to the SAVE format. From the cost/benefit ratio a penetration level for each saving option is calculated with a specific S-curve based on historical experience. When more competing options are present, ‘market shares’ are calculated for each option. Important inputs with respect to the penetration of saving options are the energy prices (gas, electricity and district heat) and government policy measures for energy savings (subsidies on investments, levies/taxes on energy carriers, information campaigns, performance targets for energy use of new houses, etc.).

Most saving options can only be implemented when an energy using system (dwelling, hot water installation or electric appliance) has to be replaced. To model the time restricted penetration of more efficient alternatives, a vintage approach is applied to each energy-using system and the alternatives. For the base year 1990 and the case years 1995, 2000, ..., 2020 the stocks of dwellings, installations and appliances are modelled, including the alternatives. The results comprise, next to the energy use figures, also the cost/benefit ratios and penetration levels of each saving option. For all households together a complete financial picture is given as well: total investments, total yearly expenditures for energy carriers and connection to the grid and the yearly costs and benefits of all energy saving activities in each case year.

Volume, structure and saving effect

A feature of the model, which is very useful for policy analysis, is the possibility of strictly separating volumetric, structural and saving impacts on energy demand. After a calculation is completed the total change in (primary) energy use between 1990 and a case year can be analysed further. A volume-variable, here the number of inhabitants, is chosen as the main deciding factor for the future level of energy use (excluding savings). All other factors that influence energy use, but are not saving options, are defined as structural changes. Every structural change variable can be set back at 1990 levels in the model. E.g. the future fraction of houses with local heating can be kept at the 1990 level of 20%, instead of decreasing slowly to 3% in 2020. The same is true for penetration levels of a (group of) saving options. E.g. the level of insulation of new houses, built after 1990, equals that of houses built in the eighties instead of following new standards. In this way the specific effect of each structural change or saving option can be calculated. In the present SAVE households model the effect on energy use of about 30 structural changes and more than 80 saving options can be analysed separately.

It is also possible to show the effects of all structural changes and saving options together. This is done by omitting one by one the structural changes or (group of) saving options from the base case calculation and then registering the change in total energy use. Since the effects of saving options and structural changes are sometimes interrelated, the omitting is done in a cumulative manner (see also Savings in a dynamic situation). The sum of all separate changes should equal the difference between the already calculated energy use and the value according to the volume effect (i.e. the increase in the number of inhabitants). However, not all structural changes can be cancelled fully; e.g. keeping the fraction of houses with local heating systems constant would imply part of the newly built houses after the base year to have local heating, which leads to a very unrealistic reference case.

Model adaptations for monitoring purposes

The future energy use is calculated in SAVE with a number of so-called exogenous and intermediate variables. For monitoring purposes the value of all exogenous variables should be in line with the actual realisations in the case year of interest, here the year 1995. The calculated values of the intermediate variables, e.g. the penetration level of the saving options, must also be compared to reality. Further on the calculated energy use results must be compared to the real figures. All this leads to a need for a double representation of 1995 variables in the model: one set of figures for the realisations and one set for model values. Another need for model adaptation arises because the model only describes energy use developments for ‘normal’ climatic conditions, i.e. the medium values for temperature and sunshine hours over a period of 30 years. The statistical energy use figures for 1990 have already been corrected for deviations from this normal climate to obtain a good base year for scenario calculations. Now for the monitoring exercise the calculated ‘normalized’ 1995-results have to be corrected back, to be comparable with the actual energy use figures. This leads, where relevant, to a third set of energy use figures, valid for the ‘actual’ climate in 1995. Further ‘bookkeeping’ adaptations, e.g. aggregation of model output, are sometimes needed to use other information sources than common in scenario studies.

The presentation of the results often demands further adaptations because the way in which the change in energy use is accounted for has to fit the wishes of the user of the monitoring results. One can prefer a different volume-variable, e.g. the number of households, instead of the number of inhabitants. Moreover, the opinions about the definition of savings differ: sometimes one wishes to incorporate energy saving structural changes such as the decreased presence of people at home. Sometimes the savings due to more district heating have to be attributed to other parties than households. In SAVE it is possible to adapt the analysis framework to each way of looking at savings. Finally one has to choose an appropriate ranking when constructing a picture of the contribution of each structural change and saving option to the total change in energy use. The contribution sometimes depends on the order in which the structural changes and saving options have their turn in the analysis (see Savings in a dynamic situation).

4.3 Analysing the 1990-1995 change in energy use

After applying the described adaptations to the model structure, the realisations for 1995 have been inserted: the exact figures for the number of inhabitants, families, jobs and houses and energy prices from Dutch Energy Statistics. The penetration of energy using installations and appliances and the penetration of energy saving options for 1995 have been extracted from a yearly survey, on respectively gas and electricity use in households, from EnergieNed. Based on these inputs a first calculation has been executed. For some cases the results for intermediate variables, such as penetration levels of saving options, differed from the realised values. In these cases specific parameters in the model have been calibrated to fit the calculated value to the statistical figure. In this way the calibrated model delivers a perfect 'prediction' of the value of intermediate variables in 1995. Further information from life style studies has been used to estimate the developments with some structural change variables, such as the mean water temperature for clothes washing.

After this calibration procedure the model has been run for the second time and the resulting energy use for 1995 has been compared to the statistical figures. For that purpose the statistical energy use figures for 1995 and the correction factors related to the 1995 climate (degree-days with respect to the 30-year mean value) have been put into the model as well. The first results showed that the model could not explain totally the realised change in energy use between 1990 and 1995; in particular for gas the calculated value was lower than the realised value. Apart from a number of uncertain inputs one possible explanation was a change in the behaviour concerning room heating. A better fit could be obtained with a (very modest) correction for higher thermostat settings after 1990 based on spotted trends in the literature. After this additional correction the whole change between 1990 and 1995 was accounted for.

General results

The many different factors causing the change in (primary) energy use between 1990 and 1995 have been aggregated to the main factors 'volume effect' (number of inhabitants), 'structure effect' and 'saving effect' (see Table 4.1). All statistical figures are corrected for deviations from the standard number of degree-days. The table shows that the increases due to volume effect and structural changes more than offset the savings, causing an increase in primary energy use of households.

Table 4.1 also presents the use of gas and electricity (the minor use of oil products and heat from the grid has been omitted here). The developments of gas and electricity use differ substantially. The structural changes lead to a much greater increase for electricity than for gas (27 resp. 7% of the 1995 volume-level); the relative savings differ less (13% resp. 9% of the amount excluding savings). One cause for the strong difference in structural change is the substitution of electricity for gas in hot water production and cooking.

Table 4.1 Main results of monitoring Dutch households energy use 1990-1995

	Primary energy [PJ]	Gas [PJ]	Electricity [PJ_e]
1990-standard climate	541	381	61
Volume effect	(+19)	(+14)	(+2)
1995-volume	560	395	63
Structure effect	(+69)	(+27)	(+17)
1995-without savings	629	422	80
Saving effect	(-61)	(-36)	(-10)
1995-realisation(standard climate)	568	386	70
Change 1990-1995	+27	+5	+9
Relative change	5%	1%	15%

Structural changes

The contributions of different structural changes modelled in SAVE are shown in Figure 4.1. At the horizontal axis the structural changes are denoted by their number (see also list in the appendix). At the far right one finds the primary energy use for 1995 without any structural changes; this value is equal to the 1990 value (541 PJ) times the growth of the number of inhabitants. Going from right to left the structural changes enter the calculation one by one and the accompanying energy use is registered and presented in the figure.

The figure shows that the structure effect is built up almost entirely from structural changes, which increase energy use. One of the few saving structural changes (no.4: -10 PJ) is the lower heating demand because of decreased presence at home, due to more jobs per household. Important dis-saving structural changes are:

- lower number of persons per household, leading to an extra need for dwellings, heat and light (no.3: +19 PJ),
- increased use of hot water per person (no.18: +15 PJ),
- more central heating instead of local heating and larger houses (no.12/14: +6 PJ),
- higher thermostat-settings (no.17: +10 PJ),
- more electric drying (no.25: +6 PJ),
- more cooling/freezing (no.31-33: +9 PJ),
- higher penetration rate of other appliances (no.36: +14 PJ).

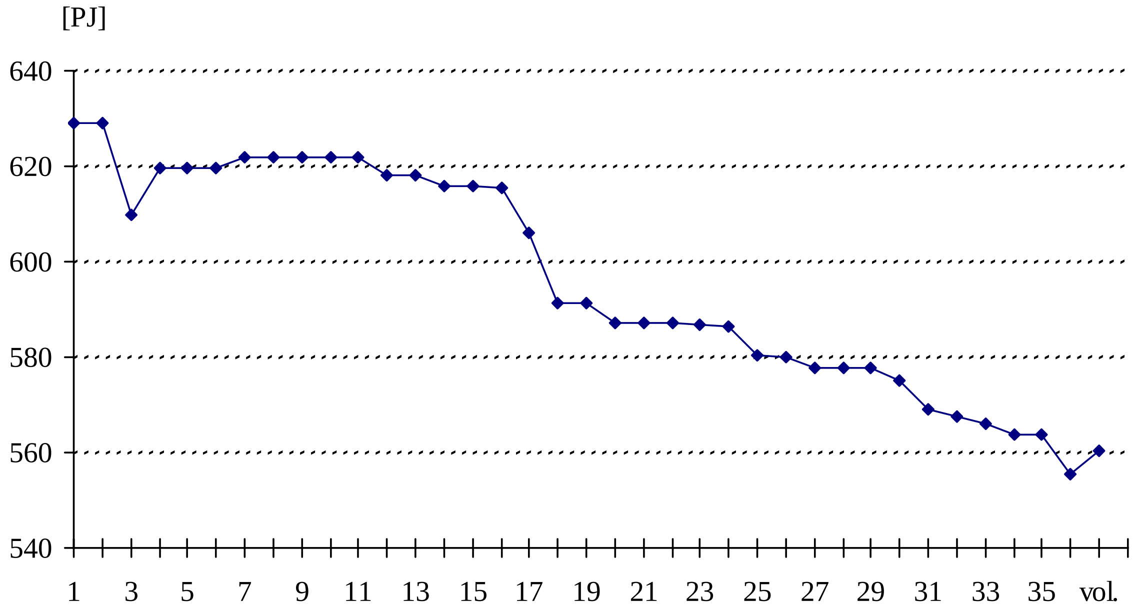

Figure 4.1 Effect of structural changes on primary energy consumption of Households 1990-1995

The last three items are the most important ones with respect to the structural change in electricity demand; the other structural changes mentioned lead to an increase in the use of gas.

Savings per option

The disaggregation of total savings is given in Figure 4.2. For practical reasons the 80 saving options are aggregated into about 30 groups, denoted by the numbers at the horizontal axis (see list in the appendix). To the right in the diagram the calculated primary energy use in 1995 is shown including all structural changes, but without all the saving options (this value equals that in Figure 4.1, at the far left). From right to left primary energy use decreases when the saving options enter the calculation, each on top of the previous one. The trend line is by definition of a non-increasing nature (contrary to the case of structural changes where both increases and decreases are possible). The figure shows that the most important option is the set of insulation options (no.3: -22 PJ). Other substantial contributions come from efficient boilers for space heating (no.6: -6 PJ), savings on hot water use and more efficient hot water preparation (no.13/16: both -4 PJ), more efficient cooling appliances (no.26: -8 PJ), more efficient lighting (no.27: -3 PJ) and more efficient other appliances (no.30: -4 PJ). Because the figures express primary energy use, the changing conversion efficiencies of district heat and electricity production can influence the total change in primary energy use between 1990 and 1995. These effects are shown at the far right end of the diagram as additional saving options (no.31/32). However, as conversion efficiencies did not increase much between 1990 and 1995, contrary to the past, there is hardly any effect to be seen on primary energy use.

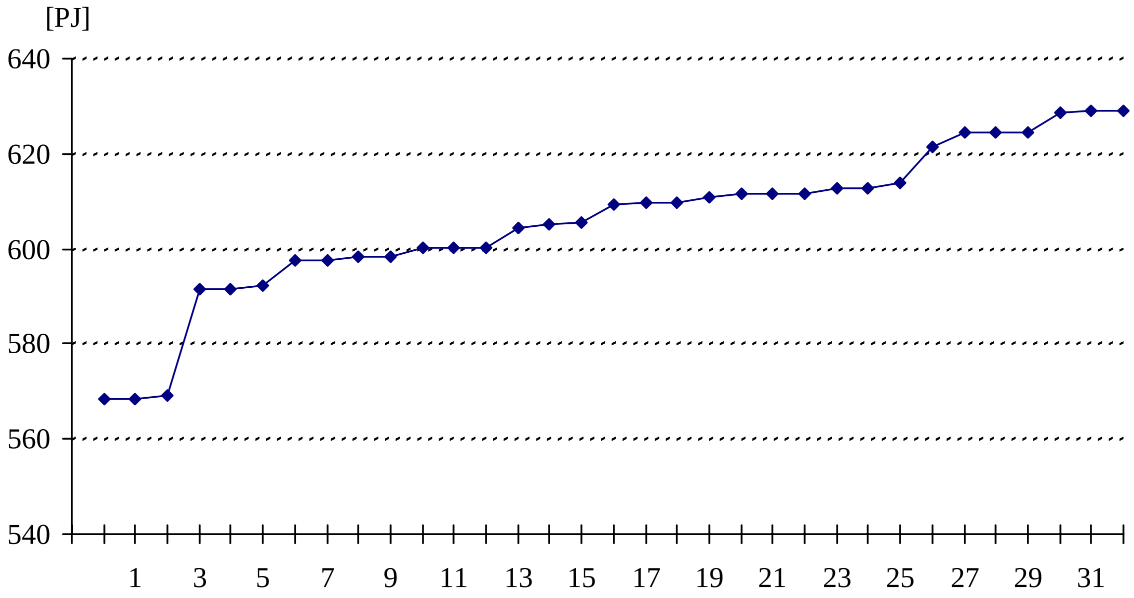

Figure 4.2 Effect of saving options on primary energy consumption of Households 1990-1995

4.4 Savings in a dynamic situation

An often confusing issue in analysing the effect of saving options is the definition of the reference situation, especially when structural changes or other saving options influence the reference situation. A good example is the calculation of the savings due to the penetration of efficient boilers; it can be calculated with or without further insulation of the dwellings, a changing stock of dwellings, higher thermostat settings, etc.

In order to highlight the importance of this choice, the savings of more efficient boilers have been calculated for five different situations (see Table 4.2). The standard calculation (a) of the savings supposes that all structural changes and penetration of other saving options with respect to the demand for space heating have been taken care of first. In case b without further insulation measures after 1990 the savings of efficient boilers increase because the heat demand reaches a higher level. In case c the structural changes after 1990, such as the trend to central heating instead of local heating and higher thermostat-setting, are omitted. Since there is less room for efficient boilers and less demand per dwelling the total savings of efficient boilers are smaller. The savings for the combination of both cases are given in case d. This shows that the combined effect is somewhere between the effects of the two separate cases. Finally case e shows the maximum amount of savings when applying only the structural changes and other saving options in favour of the savings of efficient boilers. The results show that, depending on the reference situation, the savings of this option can differ by a factor of 1.5 or more.

Table 4.2 The savings due to efficient boilers for different reference situations

	Gas [PJ]	Electricity [PJ$_e$]	Primary energy [PJ]
a. Standard	4.8	0.1	4.9
b. Without other savings	5.9	0.3	6.6
c. Without structural changes	4.0	0.1	4.1
d. Combination b and c	4.8	0.3	5.5
e. Maximum	6.3	0.3	7.0

4.5 Monitoring of system wide structural changes or saving options

Another point for discussion in monitoring studies is the exact effect of structural changes or saving options which have many different influences on household energy use at the same time. An example from the set of structural changes is ‘smaller households’. In the monitoring case the number of persons per family and dwelling decreases from 2.42 in 1990 to 2.33 in 1995. A selection of different results is presented in Table 4.3 (case ‘smaller’). In the table the same set of results is shown in case of households and dwellings growing at the same rate as inhabitants (case ‘constant’ with the 2.42 persons per household in 1995).

The results show that energy use figures **per household** often decrease a little due to the smaller number of persons. Consequently rooms are used less intensively, saving heat and light, less hot water is needed and less use is made of appliances. The extra houses needed in this case use relatively little gas because of stringent standards for new houses with a relatively small floor space. However, because of the extra dwellings and households, total energy use is increasing as a result of smaller families.

Table 4.3 Various effects of household size change in 1990-1995

Case	Unit	Constant	Smaller	Change
Number of dwellings	(×1000)	6106	6369	+263
Local heating	[%]	15	14	-1
Gas for central heating	[m^3/dwelling]	1657	1626	-21
Total heat demand	[PJ]	234	241	+7
Space heating energy	[PJ]	305	313	+8
Gas for hot water	[m^3/household]	464	450	-14
Hot water energy	[PJ]	87	88	+1
Electricity for washing	[kWh/household]	192	187	-5
Energy for washing	[PJ_e]	9.9	10.2	+0.3
Energy for lighting	[PJ_e]	10.6	10.9	+0.3
Total electricity use	[PJ_e]	68.1	70.1	+2.0
Total gas use	[PJ]	377	386	+9
Total primary energy	[PJ]	554	568	+14

An example from the set of saving options is the increase in number of houses connected to a district heating system (saving options 1 and 2 in Figure 4.2). Total savings of extra district heating is composed of a number of positive and negative side effects: the extra fuel to produce the district heat, the saved gas for space heat, the saved gas or electricity for hot water, the extra electricity for cooking (instead of gas) and, in cases with hot fill options, the substituted electricity for washing and dish washing. In Table 4.4 a comparison is made between the monitoring case, called ‘extra’ (about 20% increase in dwellings connected to a district heating system), and a case ‘constant’ without a further increase after 1990.

The value of each side effect (see under ‘change’) is dependent on the type of dwelling connected to the grid (insulated or not), the kind of boilers for space heating (efficient or not), the substituted hot water appliances (gas or electricity, efficient or not), the efficiency of electrical and gas cooking and finally the conversion efficiencies for the production of district heat and electricity. If each one of these other developments changes, the figures in the table will change too. This illustrates how complicated it is to calculate ‘by hand’ the real saving effect of more district heating in a dynamic environment.

Table 4.4 Various effects of more district heating on household energy use

Case		Constant	Extra	Change
Dwellings with district heating	(×1000)	169	206	+37
Efficient boilers	(×1000)	1822	1796	-26
Space heating	[PJ]			
Heat use		5.6	6.5	+0.9
Gas use		298.2	297.1	-1.1
Hot water	[PJ]			
Heat use		1.2	1.5	+0.3
Gas use		79.1	78.8	-0.3
Electric cooking	[%]	14	15	+1
Gas for cooking	[PJ]	10.2	10.1	-0.1
Total heat use	[PJ]	6.9	8.0	+1.1
Total gas use	[PJ]	388	386	-1.4
Total primary energy	[PJ]	569	568	-0.8

4.6 SAVE as a monitoring tool

A common approach in monitoring energy developments is the use of statistical figures on energy and related variables to analyse energy intensity trends, i.e. the relationship between economic and energy variables. By means of a disaggregation of energy use and the introduction of intermediate variables (physical production, person-km driven, etc.), which are more directly coupled to energy use, it is possible to ascribe part of the intensity change to structural changes. The other part of the intensity change is then accounted for by savings.

However, if sufficient information is available, the simulation approach offers a number of advantages compared to this method. This is especially valid for energy use of households. By using a simulation model all factors which are thought to be influencing future energy use are also used to analyse the past. Especially the various structural changes, each delivering a modest contribution to the change in energy use, are taken care of. In energy intensity analysis this is, for practical reasons, not always the case. This can lead to an underestimation of the (dis-saving) effect of structural changes and consequently an underestimated saving effect.

The composition of the total savings, which is of special interest for policy makers, is not yet clear in intensity studies. As stated earlier it is difficult to calculate a consistent picture of all the contributions to total savings ‘by hand’. In the simulation approach the total saving effect can be analysed, in a flexible and yet consistent manner, at the level of individual options.

In reality many different types of interaction exist between structural changes and saving options. The simplest type is the multiplicative relationship where, for a chosen saving option, the total saving effect is the product of the proportion of total demand respectively the fraction saved on this part of demand (in extreme cases good saving options can render no savings when relevant parts of energy use would disappear). Savings are sometimes influenced in a non-linear way by structural changes because the penetration level itself is dependent on a level of energy use, which in turn is a result of a structural change. When hot water demand of families increases it will automatically become more attractive to install a more efficient boiler. So, if a reference case is constructed without this kind of structural change, the amount of more efficient boilers should be changed too. Then, if the effect of more efficient boilers is calculated, by comparing with the situation in the base year, this effect will have been influenced by the increasing hot water demand.

For some combinations of saving options the same kind of interaction exists, e.g. between more insulation and the penetration of more efficient boilers. These interactions cannot be easily handled in a statistically oriented method based on the (disaggregation of energy use, where the developments of the parts are supposed to be independent from each other.

In most energy intensity studies the analysis is done separately for electricity and fuel (including heat). If that is the case, a substitution between energy carriers distorts the true picture of the trends; for instance in the case of a (policy based) substitution of electric hot water boilers by gas heated systems. In a simulation approach the savings by means of substitution can easily be separated from the savings on one particular energy carrier.

The preferred definition of the volume, structure or saving effect varies with the use(r) of the results; a very flexible analysis instrument is needed to deliver the results in a suitable format. In the SAVE approach, the relevant figures can be produced by labelling all the different contributions to the total change in energy use, and then introducing them one by one in the calculations. As stated earlier the order of introducing the different contributions sometimes influences the magnitude of the specific contribution (see also Table 4.2).

For the sectors Industry and Services the use of a simulation model as a monitoring tool seems less useful. One reason is the lack of detailed figures needed; the other reason is the absence of interactions between energy use trends in different parts of these sectors. In that case a disaggregation approach can be useful too as a monitoring method. For the sector Transportation the amount of interactions between different structural changes and saving options is comparable with households; not yet clear is the amount of information available to run the SAVE-Transport model as a monitoring tool.

A general advantage of using a simulation model is that it can be used to detect the most important ‘white spots’ in the information still needed for good monitoring results. With a sensitivity analysis it is possible to investigate the effect of uncertainty in data, i.e. the margin in the total calculated change in energy use. Finally, using a simulation model for monitoring enables one to regularly validate the simulation model. The monitoring results can be used directly to update the models for scenario studies.

Appendix

List of structural changes and energy saving options in SAVE households

Structural changes (Figure 4.1)

1. Household income
2. Number of inhabitants
3. Number and type of households
4. Number of jobs/presence at home
5. n.a.
6. Dwelling type per household type
7. Number of special dwelling forms
8. Demolition rate of old dwellings
9. Non-occupation of dwellings
10. Type of new dwellings
11. Fraction of jointly heated houses
12. Fraction of local heating systems
13. Rented vs own dwellings
14. Floor space
15. Fraction of dwellings centrally heated with oil
16. Closed boilers with forced ventilation of combustion air
17. Thermostat-setting room-temperature
18. Hot water use
19. Fraction of hot water systems on oil
20. Fraction of combined space heat and hot water boiler
21. Penetration of auxiliary electric kitchen boilers
22. Electricity use electric kitchen boiler
23. Washing/drying activity level
24. Penetration of washing machines
25. Penetration of clothes dryers
26. Dish washing activity level
27. Penetration of dishwashers
28. Cooking activity level
29. Households cooking on electricity (100%)
30. Penetration of cooking equipment
31. Refrigerated volumes for food
32. Penetration of refrigerator equipment
33. Penetration of freezers
34. Use of lighting equipment
35. Fraction of halogen bulbs
36. Penetration of other electric appliances

n.a. = structural change effect removed from model

Saving options (Figure 4.2)

1. Fraction of district heating with existing dwellings
2. Fraction of district heating with new dwellings (after 1990)
3. Various insulation measures
4. n.a..
5. Fraction of improved efficiency boilers
6. Fraction of high efficiency boilers
7. Fraction of advanced gas heating systems (heat pumps)
8. Fraction of more efficient stoves
9. Fraction of advanced electric heating systems (heat pumps)
10. Fraction of more efficient pumps for central heating systems
11. Penetration of ventilation heat recovery systems
12. Effect of hot water saving behaviour
13. Penetration of water saving showers, taps, etc.
14. Substitution of electric hot water boilers (to gas)
15. More efficient electric hot water boilers
16. More efficient hot water systems on gas
17. Effect of saving behaviour for washing (lower temperature)
18. Effect of saving behaviour with clothes drying
19. More efficient washing machines
20. More efficient clothes dryers
21. Penetration of hot-fill washing machines
22. Penetration of gas heated clothes dryers
23. More efficient dishwasher
24. Penetration of hot-fill dishwashers
25. More efficient cooking appliances
26. More efficient refrigerators and freezers
27. Penetration of compact fluorescent light bulbs (CFL)
28. More efficient lighting systems
29. Effect of saving behaviour with other electric appliances
30. More efficient other electric appliances
31. Mean efficiency of electricity production
32. Mean efficiency of district heat production/distribution

n.a. = options removed from model

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Chapter 5 ACTUAL INTERACTION EFFECTS BETWEEN POLICY MEASURES FOR ENERGY EFFICIENCY - A qualitative matrix method and quantitative simulation results for housholds[12]

Abstract

Starting from the conditions for a successful implementation of saving options a general framework has been developed to investigate possible interaction effects in sets of energy policy measures. Interaction regards the influence of one measure on the saving effect of another measure. The method delivers a matrix for all combinations of measures, with each cell containing qualitative information on the strength and type of interaction: overlapping, reinforcing, or independent of each other. Results are presented for the set of measures on household energy efficiency in the Netherlands for 1990-2003. The second part regards a quantitative analysis of the interaction effects between three major measures: a regulatory energy tax, investment subsidies and regulation of gas use for space heating. Using a detailed bottom-up model, household energy use in the period 1990-2000 was simulated with and without these measures. The results indicate that combinations of two or three policy measures yield 13-30% less effect than the sum of the effects of the separate measures.

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[12] An adapted version has been submitted to Energy - The International Journal.

5.1 Introduction

The need to evaluate past energy trends and policy results has increased after more than a decade of intensified policies on energy efficiency and reduction of CO_2 emissions, due to the Kyoto agreements. However, when trying to evaluate the effect of the different policy measures one should take care of interaction. Interaction can occur when different policy measures aim at the same energy saving options and one measure influences the saving effect of a second measure. Then the contribution of each measure apart cannot be summed up because of overlapping effects. On the other hand the combined effect can be higher than the sum of the separate effects as well.

Remarks on (possible) policy interaction are dutifully made in ex-post evaluations, e.g. Vermeulen (1994), or discussed for specific cases in Gunningham and Grabosky (1998) or Jacobsen (1998). In ex-ante evaluations the possible interaction between specific combinations of policy measures is analysed too. Recently this subject has attracted new interest because of the set up of an European emission trading system. The interaction mechanism with national policy is extensively analysed in Sorell (2001). However, a general and quantitative method to investigate possible interaction effects is missing so far. The methodological problem of unravelling the effects of different policy measures, which simultaneously influence energy consumption, has not been solved yet. According to Sorrell (2001) the analysis of interaction still asks for a systematic approach. In contrast with ex-post evaluations many scenario studies use energy models that can cope with a combination of policy measures, e.g. PRIMES of Capros (1998) and the model of Verbruggen and Goetghebuer (2001). But here too the interaction effects between different policy measures are hardly treated explicitly.

From a policy viewpoint there is a pressing need to look at actual interaction effects. In most developed countries a large number of policy measures for energy savings was introduced in the nineties. In Europe not only national governments but the EU as well became more and more active in this field as can be seen in the policy measures database MURE (2003). With more measures deployed, interaction between measures can very well become stronger too. If interaction effects become more and more negative, i.e. the total effect is less than the sum of the separate effects, one could say that energy policy as a whole is becoming less effective. New methods to investigate possible interaction effects in sets of policy measures are needed, both in a qualitative and a quantitative sense

Regarding the issue at stake a number of research questions can be formulated. What is the mechanism that causes interaction effects for different policy measures aimed at energy savings? Which combination of measures will show strong interaction and which will show hardly any interaction? And how often do interaction effects show up in actual sets of policy measures? Finally it is of interest to quantify interaction effects for the measures that are thought to interact strongly and to have substantial energy saving effects. In this paper these research questions will be addressed, focused on policy measures to reduce energy consumption of households in the Netherlands.

In Section 5.2 the mechanisms underlying interaction effects of policy measures for energy savings are analysed. In Section 5.3 a method to map possible interaction effects qualitatively for a general set of policy measures is presented. In Section 5.4 the method is applied to the set of actual policy measures for households in the Netherlands, regarding the period 1990-2003. The next sections are devoted to the quantification of the interaction effects. The focus lies on the three most important ones: a regulatory tax on energy consumption, investment subsidies on saving options and regulation of energy use for space heating. In Section 5.5 the key features of the applied bottom-up household simulation model are described. The quantitative interaction results are presented in Section 5.6 for the period 1990-2000. After discussion of the results in Section 5.7 conclusions and policy observations follow.

5.2 Application of saving options using policy measures

In the following analysis it is assumed that the various policy measures try to realise energy savings by stimulating the application of so-called saving options that either reduce energy demand or increase the conversion efficiency. Most measures focus on the implementation of these saving options, but some measures regard a proper utilization of the energy system present. Behavioural savings will be left aside, unless they influence the technical savings. The general framework developed here is applicable to the end-use sectors households, industry, transport and services.

Conditions for a successful implementation of saving options

In literature, e.g. Blok et al (2002), Greene (2003), Hennicke and Ramesohl (1998), Jochem (2000) or Velthuijsen (1995), many factors on the implementation of saving options are mentioned. Here the realisation is assumed to be dependent on the following set of conditions:

1. The saving option must be available for application.
2. The option must be sufficiently known to appliers.
3. Restrictions that prevent a choice for the saving option must be lifted.
4. The decision maker must become motivated to take a positive investment decision.

As illustrated in Figure 5.1, all four conditions have to be met before the saving option will actually be implemented.

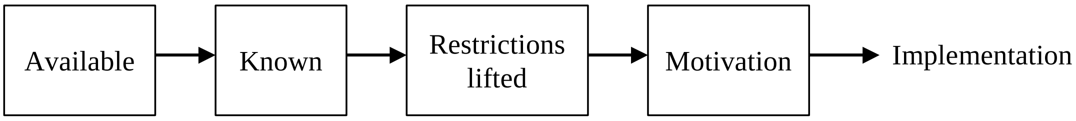

Figure 5.1 Conditions for a successful implementation of a saving option

For proven saving options **availability** is hardly an issue; however, when demand is growing very fast the supply of the efficient systems can pose a (temporally) problem. For new options ‘availability’ can have different meanings. The first one, the proof of the concept after fundamental research, is not what is meant here. The saving option should be technically grown up and provide the energy function in (almost) the same manner as the reference system it replaces. However, it need not serve all possible applications from the start. Often it suffices to supply a niche market; for instance, in case of an electrical heat pump, only new dwellings that have no connection to the gas grid. Thus availability of new saving options regards market ready saving options, at least for some applications.

Sufficient knowledge of the existence and properties of a saving option normally is a prerequisite to make a choice for a more efficient energy system. Only if the choice is obligatory, because of legislation, this knowledge is not essential. In other cases an important issue concerns **who** must obtain the knowledge: the user of the more efficient system, the investor in the system, the actual decision maker, the fitter/installer of the system, the architect or all parties involved? Insulation of rented houses asks for a coordinated information process towards all parties involved. In small enterprises the technical staff and management have to be informed both. In large energy intensive enterprises an organisational structure will be available to continuously obtain, disseminate and evaluate the information on saving options. The same applies for a well functioning energy service market where experts decide about the choosing of options.

An important **restriction** for current energy applications is the remaining lifetime of the existing energy using systems. Normally decisions on implementing a more energy efficient system are taken at the ‘natural moment’ only, when old equipment must be replaced. In Velthuijsen (1995) this is one of the often mentioned barriers for energy savings, as the earlier investment is not yet depreciated. However, retrofit options can be installed at any time. Another restriction can be the split between ownership/investment and utilization/benefits. In the case with rented office buildings or shop malls this hinders costly investments in energy savings. Finally a number of specific restrictions can be present, such as lack of space for the system, scarcity of investment money or lack of personnel resources (see Velthuijsen (1995)).

Unless legal pressure forces the implementation of saving options, the decision maker should **become motivated** to choose the more efficient system. The most often cited motivation is the financial benefit resulting from the implementation of the saving option. This motivation can be enhanced by introducing a tax on energy consumption; the higher financial value of energy saved shortens the pay back time. Another possibility is lowering the investment costs by providing investment subsidies. However, strengthening non-economic motives is also possible, for instance by increasing the general awareness of the greenhouse problem and its relation with energy use. Another way is the creation of social pressure by public campaigns. Hennicke and Ramesohl (1998) mention the role of regional networks and the behaviour of the peer group. Sometimes a saving option creates its own investment motive, as is the case with the extra living comfort that is achieved by installing double-glazing.

Next to the four conditions for implementation, the **proper utilization** of installed energy systems forms a fifth condition for realising energy savings. This regards daily use as meant in the system design, without sacrificing the energy services needed. Meeting this condition is especially important in case of new saving options because it makes sure that the promised saving effect is realised. For instance, regular maintenance of heat recovery systems is needed to keep the savings at the original level. Proper utilization asks for continued action, from a yearly inspection to a weekly feedback on energy consumption. Actually this condition can be translated into the same conditions as used with implementation: knowledge, restrictions and motivation (availability is not relevant here). However, due to the limited importance of proper utilization in this interaction analysis, this has been omitted.

Influence of policy measures on the conditions

Various policy measure types are used to stimulate the application of saving options. Overviews are given in Gunningham and Grabosky (1998), Oosterhuis (1998), WRR (1992) and Vermeulen (1994). In Table 5.1 the policy measure types according to MURE (2001) are presented; this set represents common measures in European countries. These policy measures can be split up into different types, from very pressing (legislation on implementation) to no engagement whatsoever (public campaigns on behaviour). The measures of an obligatory nature, such as (performance) standards, often focus on the investment decision. But some of these measures focus at the later utilization phase (obligatory maintenance) or the preceding phase when information is needed (mandatory labels). Financial measures consist of energy taxes, investment subsidies or other types of financial support, such as tax deductions or low interest rates. Information measures range from client specific advice and education of fitters to TV-campaigns to raise awareness on the subject of energy savings. Agreements between government and energy users or other parties generally do not focus at specific saving options but at total energy use in a sector. The obligatory character depends on the formulation of the agreement and country specific habits. Procurement focuses on coordinated action of the various parties involved with respect to a specific saving option. Both agreements and procurement are often used in combination with other measures. Stimulation of research and development (R&D) was added to the list of MURE-measures; it must be stressed that this regards not fundamental research but demonstration projects or additional development to provide a market ready product. Finally the policy measure emission trading, recently introduced in the EU, was added to the list of policy measures.

The columns in Table 5.1 represent the conditions; the contribution of each measure to comply with the conditions is indicated with crosses. A general observation, which can be drawn from the table, is that most common policy measures are designed to influence investment decisions, especially motivation. Also it is clear that there are few measures that influence both implementation (first four conditions) and utilization (fifth condition). Only energy taxes will by nature influence both. The effect of measures on each condition will now be highlighted into more detail.

Table 5.1 Contribution of measure types with respect to the conditions for implementation and utilization of saving options

	Implementation				Proper utilization
	Available	Known	No restrictions	Motivation	
Measure type:					
Legislation					
Implementation	×	×	×	×	
Utilization					×
Labels		×		×	
Taxes				×	×
Support					
Financial		×		×	
Audits		×			
Information					
Options		×		×	
Utilization					×
Agreements		×	×	×	
Procurement	×	×		×	
R&D-facilities	×		×	×	
Emission trading				×	

The **availability** of new market ready saving options is often dependent on additional R&D to deliver a marketable option. In the latter stages of development, legislation (e.g. standards) can speed up the development process too according to Newell (1998). Financial measures can stimulate the creation of marketable options too, provided that they are considered to last over a long period. With the exception of high taxes on transport fuels, sustained for decades in various countries, this has not been the case for energy taxes in general. As Newell (1998) shows, even the very high energy prices due to the oil crises were only partly responsible for increased energy efficiency. Finally procurement can speed up actual availability. The **knowledge** of saving options, not only about the concept but also about the actual performance, is most effectively increased by dedicated information, such as mandatory labels. Other possibilities are free information on specific saving options. Audits, agreements and procurement combine the search for saving opportunities with the provision of information on saving options. Vermeulen (1994) and Blok et al (2002) state that subsidies often focus attention of energy users to saving options and thus serve as an information source too. Regional and branch networks of entrepreneurs are a means to provide knowledge as well, as parties often imitate each other's decisions (see Hennicke and Ramesohl (1998)). The level of implementation already achieved contributes to knowledge of other users too. Actually all measures that stimulate the take-off of a new option contribute to it becoming more widely known. Finally, as stated earlier, legislation on the implementation of the saving option is an alternative as it cancels the need for information. **Restrictions** that hamper the implementation of saving options often are of a non-economic nature; therefore they cannot be lifted easily by financial measures according to Vermeulen (1994). Restrictions on performance can be overcome partly by adaptations to the saving option with additional R&D. For instance the development of a high efficiency boiler with ‘closed air circulation’ has diminished the problems of placement to a great extent. Restrictions with respect to the decision making process sometimes can be circumvented with tailored policy measures. For rented dwellings this can be an agreement between housing associations, representatives of occupants and the government on the division of costs and benefits. But hardly any measure is able to influence the replacement moment that provides the opportunity to realise energy savings. Even legislation on more efficient systems does not influence directly the actual lifetime of the old systems (see policy descriptions in MURE (2003). Almost all measures can contribute to the **motivation** to invest in new saving options. Some provide an economic motivation, such as subsidies or taxes. Other measures, such as information campaigns and voluntary agreements, can create a social motivation. Legislation creates by definition the strongest ‘motivation’. In the longer run this can be accomplished too in an indirect way, by some other measures that lead to the disappearance of less efficient options altogether. Influencing the proper **utilization** of energy systems asks for continuous action, as opposed to the one time investment decision. Moreover, the users of the systems are more difficult to reach. In practice relatively few measures are available to ensure a proper utilization, for instance legislation on maintenance and monitoring of performance. Regular feedback can lead to savings for space heating according to Jensen (2003), but for practical applications feedback costs have to be low. Groot (1998) states that energy taxes lead to limited energy savings on daily energy use given the rather low short term price elasticities.

As Sorrell (2001) shows, it must be pointed out that the influence of policy measures does not just regard government and the energy users but other actors in an implementation network as well. Shop owners that are pressed to sell more efficient appliances to their customers form an example of these other actors. The network of researchers, suppliers of technologies, energy advisers, user associations, public interest groups and subsidizing agencies, each with their own interests, defines the relationship between policy measures and implementation too. This means that the different conditions for realising saving options are not tied to the same actor. For instance the condition ‘availability’ often will be associated with the manufacturing of new appliances or systems, while the condition ‘motivation’ mostly regards the energy user. In this analysis the role of these other parties is taken into account when analysing possible interaction between policy measures.

Optimal combinations of policy measure types

Looking to the rows in Table 5.1 it is clear that most policy measures do not cover all conditions. The influence of taxes is limited to only one of the implementation conditions; information and subsidies cover two implementation conditions. Legislation can influence all conditions for implementation but is not always acceptable or applicable. Therefore a combination of policy measures seems necessary to comply with all conditions. However, the importance of each condition differs per saving option. For instance, if a saving option is readily available and restrictions are minor, financial and information measures alone can do the job. On the other hand, not all types of policy measures present are applicable to each saving option. In energy policy formulation many other factors play a role when choosing a policy measure type. For instance, regulation demands extensive ex-ante knowledge about the appropriateness of the regulated saving option; this knowledge is not always easy to provide. Subsidies often affect actors not belonging to the target group; too much free riders diminish the effectiveness of the measure (see Blok et al (2002) and Vermeulen (1994)). From the foregoing it follows that the optimal set of policy measures is dependent on the type of saving option.

With respect to the application of saving options one can formulate general rules to reach an optimal set of policy measures. From the preceding analysis the following general criteria for an optimal set follow:

- The optimal set should cover all, if relevant, conditions.
- Measure types should complement each other, not overlap.
- A measure type should influence more than one condition.
- Measures should be introduced in the right order.

An optimal combination of different measure types meets all conditions for a successful implementation of saving options. Preferably it enhances the proper utilization of the energy systems as well. The policy measures in an optimal combination complement each other with respect to meeting the five conditions. Because the conditions often are coupled to different actors, an optimal set should also regard all relevant actors as well. To limit the number of policy measure types deployed, it is important that the measures influence more conditions at the same time. The last criterion concerns the timing of different measures; it has obviously no use to increase the motivation to buy a saving option at a time when the option is not yet market ready. This last criterion is not elaborated on further as it does not play a role in the following analysis.

5.3 Interaction matrices for a set of policy measures

The theoretical approach from Section 5.2 is translated into a method that estimates, for any set of policy measures, the interaction effect between two measures. To this end the concept of optimal combinations is used to formulate a qualitative rating of the possible interaction effect between two measures.

Qualitative rating of the possible interaction effect between two measures

In this analysis, the interaction effect regards the direct influence of one policy measure on the saving effect of another measure. With direct is meant (i) in the same period of analysis, (ii) first order effects only and (iii) no indirect influences of other policy. Measures from an earlier period, such as R&D-programmes, can still influence the effect of present policy measures but are not taken into account. Next to first order effects due to the direct interaction between measures also second, and even third, order effects are possible. A second order example regards past agreements on industrial energy efficiency that provide for a structure that is beneficial to a new measure, such as benchmarking. A third order effect could be a slow down of industrial activity, due to restrictive policy measures, that in turn decreases the scope for other saving measures. Point (iii) regards for instance policy on traffic safety where a lower maximum driving speed for safety reasons also saves fuel. This influence of non-energy policy is not regarded in this analysis.

The qualitative rating of the possible interaction effect proceeds as follows. The more two measures exert influence at the same condition(s) for implementation, the more they mitigate each other's effect. Depending on the specific situation this results in a relative rating: marginal, modest or strong mitigating ('-', '- -' or '- - - '). The last rating can be characterised as 'too much of the same kind'. An example is the combination 'standards and subsidies' that provides more motivation to invest into a saving option than is actually needed. Their combined effect is less than the sum of the separate effects of both measures apart. In the extreme opposite case two measures complement each other in such a way that the combined effect is much greater than the total effect of both measures apart. This synergetic combination is rated as strong reinforcing ('+++'). A Dutch example is the label system for appliances and the energy premium scheme. In Ybema (2002) it is shown that this combination has led, in a few years only, to shops offering efficient or very efficient appliances only. If the mutual reinforcement of two measures is less optimal, the rating is modest or marginal reinforcing ('++'or '+'). In cases where it can be reasoned that one measure does not influence the saving effect of the other the rating '0' is given.

The interaction cases for two measures A and B are illustrated in Figure 5.2. For the mitigating combination the total saving effect is less than the sum of both effects; for the reinforcing combination this is the other way around. A neutral combination provides (almost) the same total savings as the sum of both measures. In literature the interaction effect is not always described in this way. Gunningham and Grabosky (1998) present the fact that the saving effect of a measure is enhanced by another measure as positive. However the figure shows that an increase in savings is valid for all three combinations described; even mitigating combinations will deliver more savings than measure A or measure B alone. The question is: how relates the combined effect to the sum of the effects of both measures on their own?

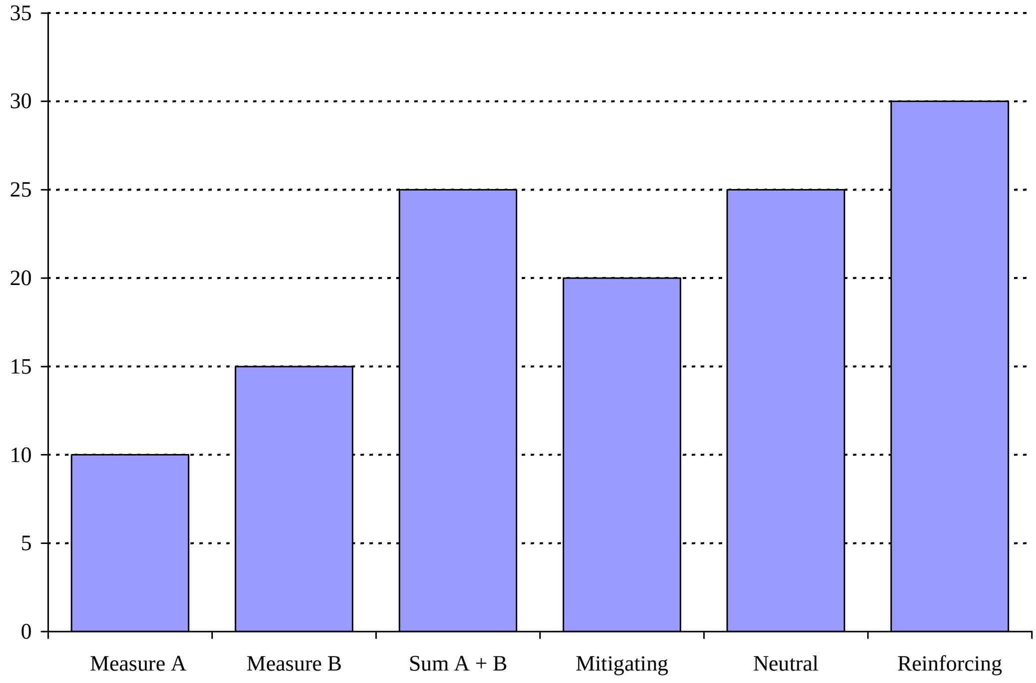

Figure 5.2 Cases for the saving effect of two measures with interaction (example)

Interaction matrix for a general set of measures

For the set of measures from Section 5.2 the matrix of possible interaction effects has been constructed (see Figure 5.3). Strong reinforcing combinations (value '+++') are 'support application & legislation information' and 'information on use & regulatory tax'. These combinations provide for the knowledge of the saving possibilities and the motivation to realise them. A practical example of the first case is the combination of subsidies and mandatory labels for electric appliances that was mentioned earlier. An example of the second case regards regular feedback on daily energy use; according to Jensen (2003) it enhances the effect of higher energy prices due to a tax substantially. In case the market readiness of saving options poses a problem, the combination 'R&D-promotion & support application' can create a strong reinforcing combination. Temporary subsidies can create a firm position for the market ready option. However concrete examples have not emerged in recent years in the Netherlands. Strongly overlapping (value '- - - ') combinations are legislation on investment decisions and other measure types: (financial) support, information, negotiated agreements or procurement. In these cases actors are already forced to choose an option, so other policy measures are not needed. Subsidies for saving options that are used in new dwellings with an energy performance standard as well are an example of such an overlap. Labels that promote appliances that are hardly more efficient than the prescribed minimum level form another example. Combinations of mandatory information and free information measures are more of the same, and therefore also mitigating. Substantial prices to be paid for emission rights in an emission trading system provide a financial motivation for energy efficiency. Therefore the interaction effect with a CO_2 tax, that has the same influence, will show a strong overlap, as Sijm (2004) concludes too.

	Legislation on:			Regul.	Support via:		Information:		Agree-	Procu-	R&D-	Tra-
Measure	applic.	use	inform.	tax	applic.	audits	applic.	use	ments	rement	prom.	ding
Legislation application												
Legislation use	-											
Legislation information	- - -	0										
Regulatory taxes	- -	- -	+									
Support application	- - -	-	+++	- -								
Support audits	- - -	- -	- -	+	+							
Information application	- - -	0	- - -	+	+	- - -						
Information on use	-	- - -	0	+++	0	-	0					
Agreements	- - -	-	-	-	+	-	-	-				
Procurement	- - -	0	+	+	+	+	-	0	-			
R & D-promotion	-	0	0	++	+++	0	+	0	0	++		
Emission trading	- -	- -	0	- - -	- -	-	+	++	-	0	+	

Mitigating: - - - = strong / - - = modest / - = marginal, 0 = no interaction,
Reinforcing: +++ = strong / ++ = modest / + = marginal,.

Figure 5.3 Relative ratings of the possible interaction effect between general policy measures for implementation of saving options

Modest reinforcing combinations of measures (value '++') are R&D-promotion with a (high) tax or with procurement. Modest overlapping/mitigating combinations (value '- -') are composed of six possible combinations of subsidies/mandatory options/mandatory maintenance and regulatory tax/emission trading. An actual example is the combination of subsidies and tax that provides ‘too much of the same kind’ for motivation. However, subsidies provide information on saving options as well, and sometimes both are needed to make a break through for an expensive new option. Therefore the combination is rated here as modest mitigating instead of strong mitigating. Legislation and tax can be rated as strongly mitigating as the tax-enhanced motivation is not really needed. However, legislation directed at profitable saving options often causes a rebound effect (by spending of the saved money on products that demand extra energy use). A tax can keep the energy budget at the same level and prevent the rebound effect; therefore the combination is rated as modest mitigating only.

The remaining combinations are rated as marginally mitigating (-), reinforcing (+) or even neutral (0) because the two policy measures neither lead to much overlap nor full coverage of the conditions for implementation. With respect to emission trading the interaction ratings resemble that of a regulatory tax (see Figure 5.3). However, in some cases there are slight differences because the price signal from a regulatory tax, that seldom decreases, is thought to be more robust.

Non-existing interactions

When the rating method is applied to actual sets of policy measures, often there are cases where no interaction effect can exist between two policy measures because:

- The two measures aim at different sectors, energy applications or target groups.
- The two measures do not overlap in time.

Applications and target groups can be defined in such a way that most of the measures regard just one application or target group. This facilitates the recognition of non-existing interactions between two measures. As will be shown later the exclusion of non-existing combinations of measures restricts the amount of analysing work to a great extent, in particular when a substantial number of measures must be analysed. If measures do not overlap in time it is obvious that no interaction effect exists. Sometimes measures hardly overlap in time, compared to the length of the period of observation. In that case the rating is downscaled for the time when there cannot exist an interaction effect.

Post- and pre-implementation interaction effects

In a few cases measures interact at another point than the implementation of saving options or the stimulation of a proper utilization. Post-implementation effects regard interaction between the resulting saving effects of two measures. E.g. insulation decreases heat demand; this lowers the benefits of installing a more efficient boiler, which is detrimental to the success of a policy measure directed at efficient boilers (see also Sezgen (2001)). Pre-implementation interaction regards a measure that influences another measure’s potential to realise energy efficiency. For instance, Johannsen (2002) finds that voluntary agreements have the (implicit) goal to forestall other policy measures, such as a CO_2 tax. Therefore the combination with a tax measure will touch the content of the agreement. The combination will deliver less effect than can be determined from the original content of both measures. In the few relevant cases the rating in the matrix is corrected for these effects.

Summary of the rating method

With respect to the rating of possible interaction effects in a set of policy measures, the possible ratings can now be defined as:

- mitigating: (-), (- -) or (- - -),
- reinforcing: (+), (++) or (+++),
- neutral: (0),
- not possible (×).

Finally it must be stressed that the interaction analysis regards only the common scope of two measures, e.g. in case of appliance standards and subsidies only the part of the subsidy scheme that is devoted to appliances is taken into observation. The rating does not speak out on the effect between the subsidy measure in general and the standards. The rules to construct an interaction matrix can be summarised as follows:

1. Define the different measure types.
2. Define (mutually excluding) applications for te sector that is analysed.
3. Attach to every policy measure the type, the application and year-in/year-out.
4. If necessary split measures with a broad scope into different applications.
5. If necessary split broadly defined measures into different types.
6. Determine the matrix-cells with no overlap in time for the measures.
7. Determine cells where measures focus on different applications or actors.
8. Rate the possible interaction effect, taking into account the relevant conditions for successful implementation or proper utilization, the influence of both measures on these conditions and the overlap or synergy.
9. Correct for the fraction of the period when one of the measures is not present.
10. Correct for post-implementation interaction: the overlap in the resulting savings.
11. Take account of pre-implementation interaction: one measure changes the content of another measure partly or wholly.

5.4 Interaction effects in a set of actual policy measures for Dutch households

The method has been applied to a set of policy measures to promote energy efficiency in households in the Netherlands. In Table 5.2 all measures in the period from 1990 on, and with a non-trivial saving effect, are presented. Some measures regard local initiatives as well (climate campaign) or regard EU-wide legislation (mandatory appliance labels), but most measures are part of national energy policy. A description of these measures is given in MURE (2003) and, into more detail for some measures, in Oosterhuis (1998). The MURE-measure types ‘legislation on use’ and ‘procurement’ (see Table 5.1) are not used for households in the Netherlands. The first ten measures aim at three specific applications: new dwellings (measures 1-6), existing dwellings (7-9) and appliances (10). The other measures (12-15) relate to various or all applications; this category ‘General’ encompasses taxes, agreements and general subsidy schemes. The Environmental Action Plan (MAP) of energy distributors forms a special case because of its very broad scope. This measure has been split into three segments, directed at new dwellings (11a), existing dwellings (11b) and appliances (11c), to provide for a much easier analysis of interaction effects.

Table 5.2 Overview of policy measures for household energy efficiency in the Netherlands 1990-2003

	Policy measure	Application	Target group
1	Building code insulation 1992	New dwelling	Builders
2	Energy Performance New dwelling (EPN)	” ”	Builders
3	Sustainable building options (DUBO)	” ”	Builders
4	Optimal Energy Infrastructure (EPL/OEI)	” ”	Builders
5	Novem demonstration programmes	” ”	Builders
6	Building code insulation 2002	” ”	Builders
7	Renovation/saving subsidies	Old dwelling	Housing association
8	Retrofitting rented houses	” ”	Housing association
9	Energy Performance Advice (EPA)	” ”	Owner/Association
10	Energy efficiency labels	Appliances	Consumers
11	Action Plan distribution sector (MAP)	Various	All parties
12	Regulatory Energy Tax (REB)	General	Consumer/Owner
13	Climate Campaign ‘21	”	Consumers/Municipality
14	Agreement housing corporations (LTA)	”	Housing association
15	Energy Premium Scheme (EPR)	”	Consumer/Owner

For each measure one or more target groups can be specified. The table shows that policy measures for the specific applications aim for the greater part at only one target group. For ‘new dwellings’ the target group consists of the ‘builders’: developers, public housing associations and the local authorities that decide on new building sites. The target group for existing dwellings (‘old dwelling’) often regards housing associations only; for appliances the consumers are the primary target group. The measures for the applications ‘various’ and ’general’ often regard more parties involved.

In Figure 5.4 the matrix of possible interaction effects is shown, with the measures grouped according to application. The total number of combinations of two measures is (15+2)*(14+2)/2 = 136. The two extra measures in the formula originate from splitting the MAP-measure into three sub-measures. The division by two is because only one half of the matrix should be specified. First attention is paid to the cells of the matrix where interaction is not possible because of different applications (dark shaded, with x). These cells encompass all combinations of measures for new versus old dwellings (columns {1-6,11a} & rows {7-9,11b}), for new dwellings versus appliances (columns {1-6,11a} & rows {10,11c}) or for old dwellings versus appliances (columns {7-9,11b} & rows {10,11c}). Secondly there are cells where interaction is not possible because measures do not overlap in time (light shaded, with ×). For instance all measures starting after 1996 cannot interact with measure 7 ending in 1996. It shows that 57 cells (42%) of the matrix are not relevant with regard to interaction between policy measures.

	Active period Start	End	1 **BD-1991**	2 **EPN**	3 **DuBo**	4 **OEI**	5 **Demon. progr.**	6 **BD-2002**	11a **MAP new**	7 **Reno-vation**	8 **Retro-fit**	9 **EPA**	11b **MAP old**	11c **MAP appl.**	10 **Label**	12 **REB**	13 **Clim. camp.**	14 **LTA**	15 **EPR**
1	1992	2001																	
2	1996		- - -																
3	1995		- -	- - -															
4	1997		0	- -	0														
5	1985		+	+	+	-													
6	2002		×	- - -	- - -	0	+												
11a	1991	*2000*	0	- -	0	0	+	×											
7	1993	1996	×	×	×	×	×	×	×										
8	1994	2000	×	×	×	×	×	×	×	+++									
9	2000		×	×	×	×	×	×	×	×	-								
11b	1991	2000	×	×	×	×	×	×	×	0	++	+							
11c	1991	2000	×	×	×	×	×	×	×	×	×	×	×						
10	1996		×	×	×	×	×	×	×	×	×	×	×	+					
12	1996		-	- - -	-	+	+	0	+++	0	+	+	- -	- -	+ +				
13	1991		0	0	0	0	0	0	0	×	0	- -	+	+	+	++			
14	1998	2000	0	0	-	-	+	×	0	×	- - -	- - -	- -	0	0	-	0		
15	2000	2003	0	-	0	0	+ +	0	0	×	0	+++	0	0	+++	- - -	+	-	

Mitigating: - - - = strong / - - = modest / - = marginal, 0 = no interaction,
Reinforcing: +++ = strong / ++ = modest / + = marginal, × = non-existing.

Figure 5.4 Relative ratings of possible interaction effect between 15 policy measures for savings in households in the Netherlands 1990-2003

The cells, for which an interaction effect was specified, can be split up into groups. The upper left part of the matrix is devoted to mutual interaction between measures that are all directed at **new dwellings**. Here strong mitigating interaction effects exist between:

- old or new building code and energy performance standard (column 1 & row 2, column 2 & row 6),
- new building code and the sustainable building options DUBO (column 3 & row 6),
- the performance standard EPN and the sustainable building code (column 2 & row 3).

In these cases two measures are of the same type, aim at the same actors, or focus on the same conditions for implementation of saving options. Therefore these interaction effects are rated as mitigating. There also is a mitigating interaction effect between MAP activities for advanced options in new dwellings and the performance standard EPN. Due to the limited period of overlap this effect is rated as modest. This is true for the old building code and the DUBO options as well.

For **existing dwellings** only four specific measures are present and subsequently the number of possible interaction effects is limited. A strong reinforcing effect exists between the retrofitting programme, providing the organisational structure, and the subsidies for renovation, that provide the motivation (column 7 & row 8). For **appliances** there is one interaction effect only. Because there were no substantial MAP-subsidies on appliances, and most labels only started at the end of the MAP-period, the interaction effect is rated small anyhow.

The lower far right part of the matrix contains the interaction effects for combinations of two general measures. The most important mitigating effect exists between the energy premiums (EPR) and the energy tax REB (column 12 & row 15) that together provide (too much) motivation. The REB modestly reinforces the effect of the Climate campaign as motivation and information are combined (column 12 & row 13).

The last and greatest part of the matrix concerns the interaction effects between general measures and the measures focused on specific applications. The broadly defined general measures interact easily with dedicated measures. A strong mitigating effect exists between the performance standard and the energy tax (column 2 & row 12); the tax is not needed as motivation when building standards already force to save energy. A second example is the agreement with the housing associations on existing dwellings that overlaps with the earlier started retrofit-programme (columns 8 & row 14). Further, subsidized energy advices (EPA) are devoted to dwellings of housing associations that have already agreed to take action; again this creates a strong mitigating effect (column 9 & row 14). Strong reinforcing interaction effects are present between advice and subsidies (column 9 & row 15), or labels and subsidies (column 10 & row 15), because of the combination of motivation and information.

Top six interacting combinations

The preceding analysis shows 12 strong interacting combinations (9% of all combinations). However, a strong interaction effect between two measures is not always of the same importance. When both measures only have a very limited saving effect, the combination will not be decisive for the effectiveness of saving policy. From Table 5.2 the most important measures were selected, based on various evaluation studies, such as Berenschot (2001), IBO (2001), Jeeninga (2002), Berkhout (2001), Das (1996) and Oudshof (1997). These measures are:

- building codes (version 1991 and 2002) for insulation,
- energy performance standard (EPN), started in 1995,
- MAP-subsidies (period 1992 -1999),
- regulatory energy tax (REB), started in 1996,
- labels for various appliances, introduced between 1996 and 2002,
- energy premium scheme (EPR), started in 2000,
- energy advice (EPA), started in 2000.

The strong interaction effects between these measures are given in Table 5.3; three combinations are rated as mitigating and three combinations as reinforcing.

Table 5.3 Strong interaction effects between important policy measures in Dutch households

	First measure	Second measure	Type of interaction
A	Building codes	EPN-standard	Mitigating
B	EPN-standard	REB-tax	Mitigating
C	MAP-subsidies	REB-tax	Reinforcing
D	REB-tax	EPR-subsidies	Mitigating
E	EPA-advice	EPR-subsidies	Reinforcing
F	Labels	EPR-subsidies	Reinforcing

In case A the performance standard EPN comes on top of the building codes that define minimum specifications for the different technical measures. The overlap is a deliberate choice of policy makers; the EPN assures that energy efficiency can be realised at the lowest costs. But the building codes restrict the EPN-choices with respect to insulation, because the consequences stretch very long into the future. This deliberate choice is not true for case B with EPN and energy tax (REB). Given the strong EPN-demands, the REB does not lead to extra energy efficiency measures in new dwellings; however it is practically impossible to exclude occupiers of new dwellings from paying the REB-tax. In case C the combination of MAP-subsidies and REB-tax reinforces the total effect for saving options (in new dwellings) that are not yet proved and rather expensive. Subsidies focus the attention of the users at specific saving options as well; this task cannot be accomplished by the REB-tax alone according to Daamen (2000). For case D, again with subsidies and tax, the interaction effect was rated as mitigating. This differs from case C because the EPR-subsidy was submitted from the start to proven saving options, especially appliances. Moreover the level of the tax was much higher than at the time of the MAP-subsidies. The ineffective spending of EPR-money can be justified with the argument that the subsidies facilitated the acceptance of the ever-higher REB-tax. People were given the opportunity to avoid part of the high tax by investing in (subsidized) saving options. In Menkveld (2002) an analysis was made of an EPR restricted to the options that save the most and being relatively expensive. With regard to the reinforcing cases E and F one would expect lasting support of energy policy; especially the reinforcing combination of labels and EPR-subsidy was found to be very successful. This combination led to such a rapid transformation of the appliance market that, in a few years, a great part of appliances for sale consisted of high efficiency appliances. However, due to budget constraints the EPR has been cancelled in 2004 for most saving options. According to Boonekamp (2004) this will diminish the saving effect of labels and (still subsidized) EPA-advice to a great extent.

5.5 Quantitative analysis of interaction effects with a simulation model

The forgoing qualitative analysis was based on the characteristics of the implementation process, on reported effectiveness of combinations of measures in practice, and on experience in scenario studies. For practical policy purposes it is important to gain some quantitative insight into interaction effects in the past. The most important interaction effects found earlier should be quantified as to their influence on total efficiency gains. Here interactions are analysed between:

- energy tax (REB),
- all subsidies (EPR, MAP, renovation),
- regulation of gas use for space heating (building code, EPN and agreement with housing associations).

As mentioned in the first section, the models used in policy scenario studies often are designed to cope with interaction between policy measures. Therefore it seems beneficial to use such a model to investigate interaction effects between historic policy measures. To this end an adapted version of such a model, described in Boonekamp (1997) and used earlier for national scenario studies such as NEO (1998), was applied to quantify the interaction effects.

For practical reasons this analysis was not done for the period until 2003 but for 1990-2000 only. First the key properties of the model, that are important for interaction analysis, are presented. Then the model adaptations are summarised and some background results are given for the analysis that is described in Section 5.6.

Main structure of the simulation model

In Figure 5.5 the broad design of the household energy model is presented. Demographic, social, economic and life style trends are the driving factors that determine the demand for so-called energy functions, for instance the heating and lighting of dwellings, cleaning, cooking, etc. This demand is met with a number of appliances and other energy using systems (boilers, etc.). Energy prices, technological developments and policy measures affect energy use of these systems and appliances.

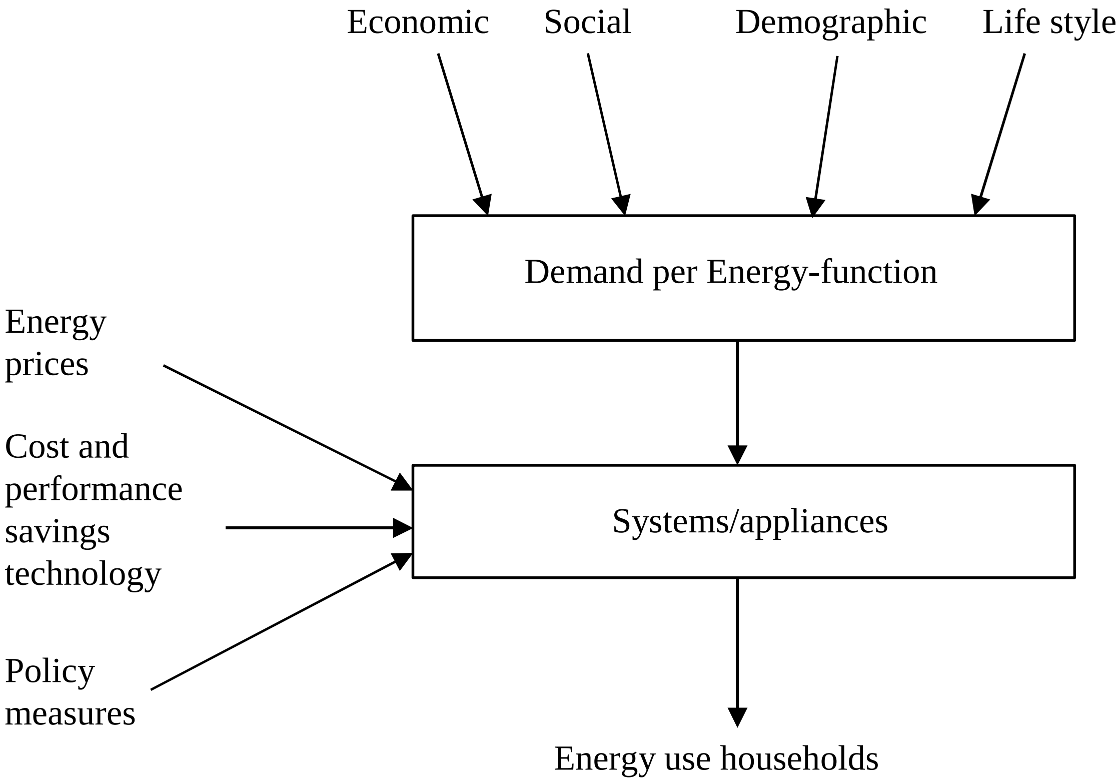

Figure 5.5 Set up of the simulation model of household energy consumption

Determination of energy consumption developments

The model contains a detailed description of energy consumption in the base year. Total energy consumption from statistics is first disaggregated to the level of energy functions (e.g. space heating or lighting) and than to the energy input of all adjoining systems or appliances. When appropriate, also a distinction between type of dwelling and type of household is made. Most details are based on extensive information from surveys by EnergieNed as to electricity and (natural) gas consumption. Energy consumption over time for each of the systems or appliances is determined by three factors:

- the (change in) total number of a specific system/appliance,
- the (change in) intensity of use,
- the (change in) efficiency of energy consumption.

The **total number of systems or appliances** is equal to number of households/dwellings times the ownership rate, i.e. the fraction of households that use the system or appliance. For 'standard' appliances such as washing machines the number is dependent on the number of households only. For dishwashers and dryers the number is also dependent on socio-demographic-economic trends. The second factor, **intensity of use**, is mainly dependent on socio-demographic trends (see Weber (2000)). For instance a higher fraction of households with two jobs, an important trend in the Netherlands in the nineties, has decreased the occupation rate of dwellings and thus space heating demand. But it has increased the demand for cooled food storage. The third factor, **change in energy efficiency**, is dependent on quite different factors. It is supposed that energy efficiency is realised by purchasing systems or appliances having higher conversion efficiencies, or by application of demand reducing technologies such as wall insulation (see also discussion). This decision is restricted by the fixed gradual replacement of the existing stock of appliances or energy using systems.

Calculation of change in energy efficiency

For each system or appliance one or more energy saving options have been defined in addition to the reference version. For the system 'dwelling' different insulation measures can lower heat demand for space heating. All these possibilities constitute so-called saving options. A cost/benefit formula is applied to model the choice for more efficient systems and appliances or the decision to insulate dwellings. Costs arise from additional investments for saving options; the benefits are equal to yearly saved energy times average price. The cost/benefit ratio (CBR) is calculated as follows:

$$\text{CBR} = [(\text{Inv} - \text{Subs}) \times \text{Ann} + \text{O\&M}] / [\text{Saving} \times (\text{Price} + \text{Tax})] \tag{1}$$

Inv = Investment in saving option [€]
Subs = Subsidy on saving option [€]
Ann = Fixed annuity factor to calculate yearly investment costs
O&M = Yearly operation & maintenance costs (if present)
Saving = Annual savings realised with option [GJ]
Price = Price of energy excluding tax [€/GJ]
Tax = Tax on energy [€/GJ]

The relation between the penetration of saving options and the cost/benefit ratio is modelled in the form of an S-shaped curve (see Figure 5.6). The S-curve prohibits an 'all-or-nothing' decision for a CBR-value near 1. It allows for different investment decisions at the same CBR because actual circumstances differ per household: greatly varying intensities of use, varying costs of saving options, etcetera. The relationship is defined such that in 50% of the decision cases the saving option will be chosen, provided that the cost/benefit-ratio is equal to the 'acceptable' ratio (see Equation 2).

$$P = 1 - 1 / \{1 + \mathrm{Exp}\,[-Stp \times (CBR - CBR50)]\} \quad (2)$$

P = Penetration level saving option (fraction of replaced systems),
Stp = Steepness of S-curve,
CBR50 = Acceptable cost/benefit ratio.

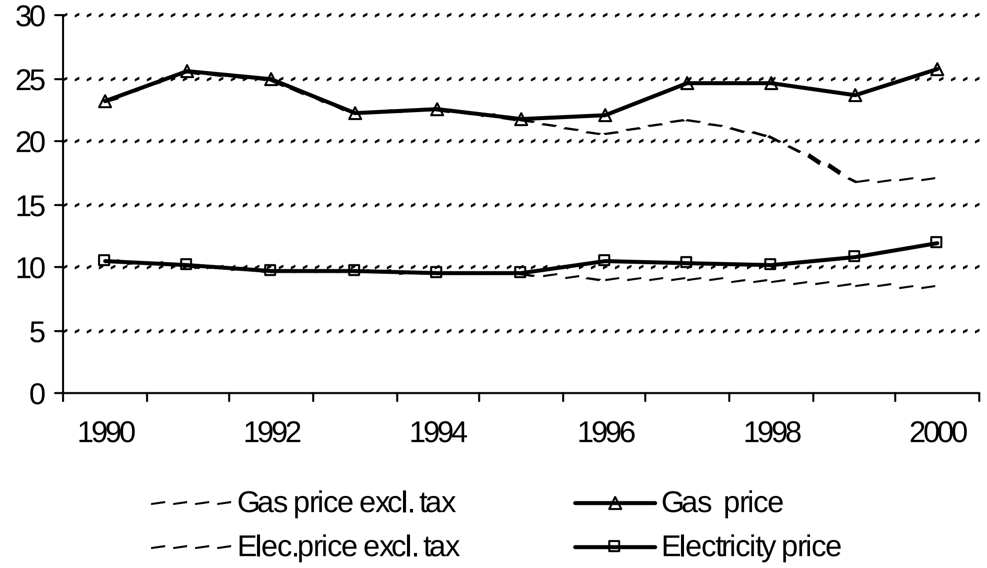

Figure 5.6 Relationship between cost/benefit ratio and penetration level for saving options (example)

For households the value of the acceptable ratio often is dependent on non-economic factors in the decision making process. Sometimes the acceptable ratio is less then 1, for instance with water saving showerheads where the reduced amount of hot water forms a non-economic burden. For double-glazing however the 50% penetration point will be found at a cost/benefit ratio above 1 because of the non-economic benefit of extra living comfort. The acceptable cost/benefit ratio has been estimated for each saving options apart on basis of perceived penetration trends (see next section).

Model adaptations and inputs used to simulate past energy use

The simulation model describes the developments for 1990-2000 with 5-year intervals from the base year 1990. For the years 1995 and 2000 the model was expanded to contain two values for each variable, the calculated value and the actual value. In this manner a comparison of model results and actual developments can be made at each level of detail. Further adaptations enabled the calculation of energy consumption in the absence of selected policy measures (see next section). Finally the parameters of the model have been adjusted, as to fit model outcomes to the known energy developments in the period 1990-2000. This was achieved in a number of steps:

- Replacement of all scenario inputs by historical values for 1990-2000.
- Fitting calculated penetration levels of saving options to known historical levels by adjusting the parameters of the S-curve equations. Most of this work regarded the determination of the acceptable cost/benefit ratio CBR50 for every saving option. Values found are shown in Table A.2 in Boonekamp (2005).
- Correcting the resulting energy consumption per energy function by adjusting the activity levels (time devoted to cooking, number of showers per day, etc.) to the actual levels from surveys.
- Correcting total energy consumption by adjusting the general parameter ‘average indoor temperature for space heating’ to estimated historic patterns.

Inputs used in the historic simulation can be split into:
- socio-demographic and life style trends,
- penetration rates for energy systems or appliances,
- energy prices,
- policy measures.

The historical economic inputs are incorporated into the other inputs and are therefore not presented here (see discussion in Boonekamp (2005)). The development of main socio-demographic trends and penetration of important energy using systems or appliances are given in Table 5.4.

Table 5.4 Development of main input variables for simulation of households energy trends

Model variable	Unit	1990	1995	2000
Households (index, 1990=100)	index	100	108	114
Persons per household		2,45	2,34	2,30
Jobs per household		1,06	1,04	1,13
Number of dwellings	x 1000	5802	6192	6590
Newly build after 1990	x 1000	×	434	867
With local heating	[%]	23	16	11
With hot water combi-boiler	[%]	27	45	59
With clothes dryers	[%]	28	49	59
With dish washer	[%]	10	21	39
With electric cooking	[%]	12	14	20

In Figure 5.7 gas and electricity prices for households are given for the period 1990-2000. The total gas and electricity prices increase; however without the regulatory tax after 1996 the prices would have been substantially lower in 2000 than in 1990. The policy measures are described in Section 5.6.

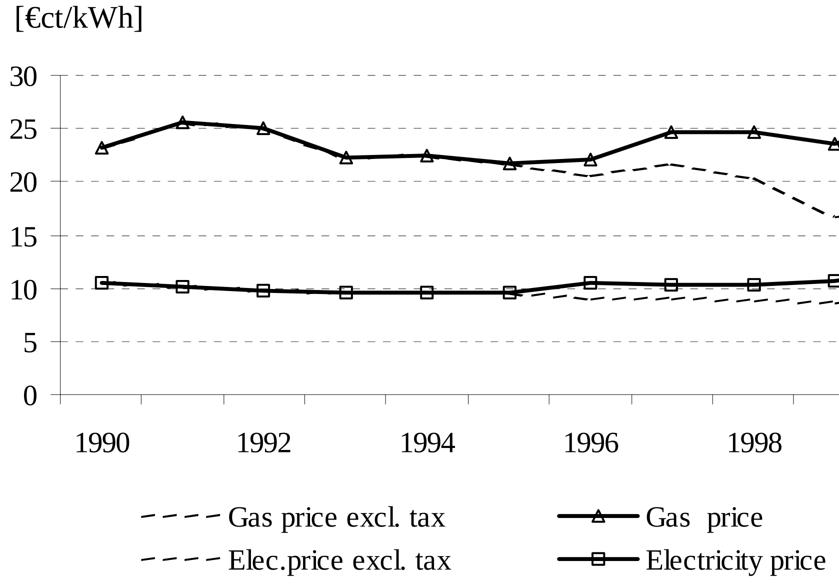

Figure 5.7 Gas and electricity prices and regulatory tax for households 1990-2000
Note: €ct$_{1990}$ per m^3 or kWh

Overall results for household energy consumption
Table 5.5 shows the actual energy consumption of households in 1990 (first row) and in 2000 (last row). Total electricity consumption increases by one-third, but total gas consumption, being 97% of total fuel use, proves to be quite stable. The 'consumption excluding savings' in 2000, or 'frozen technology consumption', has been determined by stalling, from 1990 on, all improvement of conversion efficiencies or insulation levels in the model (see for methodology Boonekamp (1997)). The difference with observed consumption in 2000 is equal to total savings in the period 1990-2000. These total savings are the result of either policy measures or other developments such as price-induced savings or autonomous efficiency improvements. The difference with the 1990-level, called the 'Growth 1990-2000' effect, is the result of more households, higher ownership rates for appliances, more consumption of hot water, etc.

Table 5.5 Overview of household energy consumption developments 1990-2000[1]

	Fuel [PJ]	Electricity [PJ$_e$]
Actual energy consumption 1990	394	60.3
Growth effect 1990-2000	+77	+44.4
Consumption excluding savings 2000	471	104.7
Total saving effect	-78	-25.2
Actual energy consumption 2000	393	79.5

[1] Corrected for yearly variations in temperature during the heating season

5.6 Energy savings from combinations of policy measures

The simulation model described reproduces past energy trends using the relationship between different policy measures and the penetration of saving options. This approach enables the analysis of alternative developments for deviating policy inputs. These alternatives describe a (theoretical) past trend for another set of policy measures. First a so-called 'base case' trend has been simulated, without the three policy measures of interest: regulatory tax, investment subsidies and regulation of saving options. In this base case the level of fuel and electricity consumption is higher than the observed energy consumption, meaning that the policy measures save energy. However, the base case consumption is lower than the 'consumption excluding savings' level from Table 5.5. Only 50% of all fuel savings and 15% of all electricity savings can be attributed to these three measures. Starting from this base case the efficiency gains have been determined for each of three policy measures, followed by all combinations of these measures.

Saving effect of the energy tax

The regulatory tax increases the benefits of energy saved and thus lowers the cost/benefit-ratio for investments in saving options (see Equation 1 in Section 5.5); this in turn leads to lower energy consumption. The regulatory tax on fuels and electricity (REB) was gradually introduced from 1996 on. In 2000 the REB amounted to 36% of the total gas price and 32% of the total electricity price (see also Figure 5.7). Because of the five-year interval an average value for 1996-2000 was used to determine the total saving effect in 2000 (16-18% of the total energy price). In Table 5.6 the difference with base case energy use is shown as the saving effect for 'tax only'. The REB decreases the base case consumption in 2000 by 2.0% for gas and 1.9% for electricity. Because the energy tax has been introduced after 1995 there is no effect in 1995.

Table 5.6 Energy savings due to a regulatory tax, investment subsidies, regulation, and the combination for 1995 and 2000

	1995		2000	
	Gas [PJ]	Electricity [PJe]	Gas [PJ]	Electricity [PJe]
Policy measures:				
Tax only	0.0	0.0	8.5	1.6
Subsidies only	10.1	1.5	18.1	2.7
Regulation only	6.1	0.0	19.3	0.0
(sum)	(16.2)	(1.5)	(45.9)	(4.3)
Tax & subsidies & regulation	15.3	1.5	41.5	4.2

Saving effect of investment subsidies

Subsidies decrease the additional investment for the saving options, and therefore the cost/benefit-ratio, which results in lower energy consumption. Investment subsidies (MAP, renovation subsidies and EPR, see Section 5.4) were available in the entire period 1990-2000 for all important saving options, such as various insulation measures, high efficiency boilers or heat pumps. Subsidies often amounted to 20-25% of the extra investments into more energy efficient options. The simulation run with subsidies shows that gas and electricity consumption decrease compared to the base case (see Table 5.6, ‘subsidies only’). In 2000 gas use is 4.3% lower and electricity consumption decreases with 3.2%

Saving effect of regulation

In the period 1990-2000 regulation has mainly focused on fuel use in new dwellings. Until 1995 the building code defined minimum insulation levels for wall, roof, floor and windows. From 1996 on the energy performance standard (EPN) limited total energy consumption of new dwellings. The choice of saving measures, additional to the building codes, was left to the builder. However, the builder had to prove beforehand, by means of a prescribed calculation method, that the EPN-standard was met. The yearly surveys by EnergieNed provided information on the saving options actually applied. The total number of new dwellings with regulation of gas use amounted to 13% of the total housing stock in 2000. In the model runs with regulation the actually chosen EPN-options have been forced into the simulation by replacing the calculated cost/benefit-ratio with a very low fixed ratio.

Regulation of gas use in existing dwellings regarded the agreement with social housing associations on the realisation of saving options in their dwellings. Social housing stock regards 35% of all dwellings. A great part of these rented dwellings were already partly insulated in the eighties due to the National Insulation Plan. Therefore the agreement was restricted to the remaining saving options. In the simulation runs with regulation it has been supposed that the extra saving options were coupled to the fixed yearly number of renovated dwellings.

For the case without regulation the usual cost/benefit formula (see Section 5.5) has been used to calculate penetration rates of the saving options concerned. For new dwellings the regulated saving options were often not economically attractive. But for the existing dwellings of housing associations the simulations without regulation showed almost the same amount of saving options in most cases. After introducing regulation in the base case, the gas consumption decreased with 4.6% in 2000; the electricity consumption was not affected (see Table 5.6).

Combined effect of three policy measures

In the previous analysis only one policy measure at a time was introduced in the historic simulation. With all three measures present one can expect the sum of the three effects given earlier. However, from Table 5.6 it follows that the combined effect often is lower than the sum of the three effects and only in one case equal. This means that there is an overlap in the effects of the three measures, up to a maximum of 10% for gas in the period 1990-2000. However, before drawing conclusions, an analysis is made of the interaction effects between each combination of two measures.

Combined effect of two policy measures

With three different measures at hand there are three possible combinations of two measures. For each of these combinations a simulation run with the model has been made. In Figure 5.8a results are presented for gas and in Figure 5.8b for electricity. Results are given for the period 1995-2000 only because all three measures have been active in this period only. All changes are given as a percentage of total gas or electricity consumption in the base case.

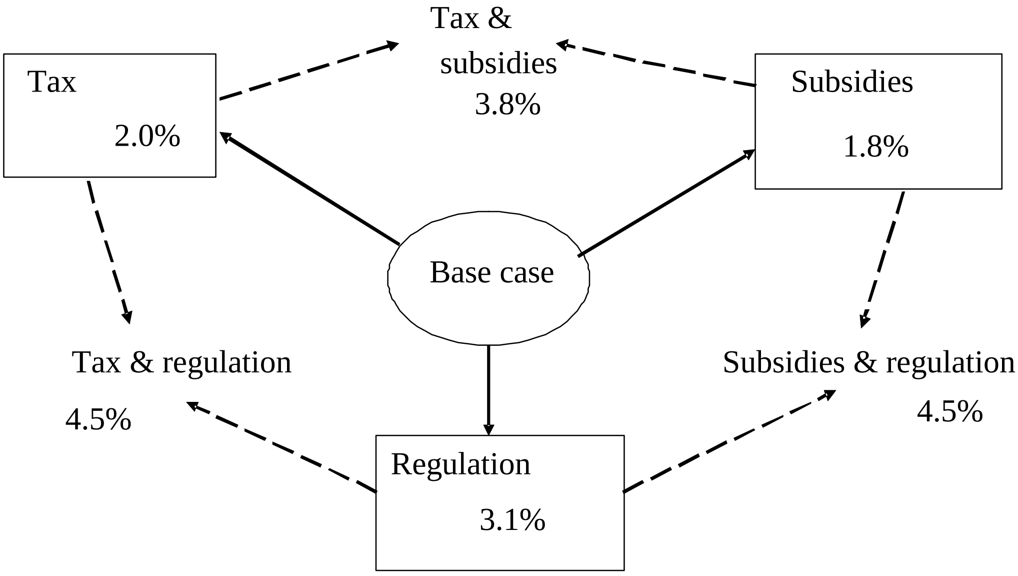

Figure 5.8a Savings on gas 1995-2000 for combinations of policy measures (% of base case consumption)

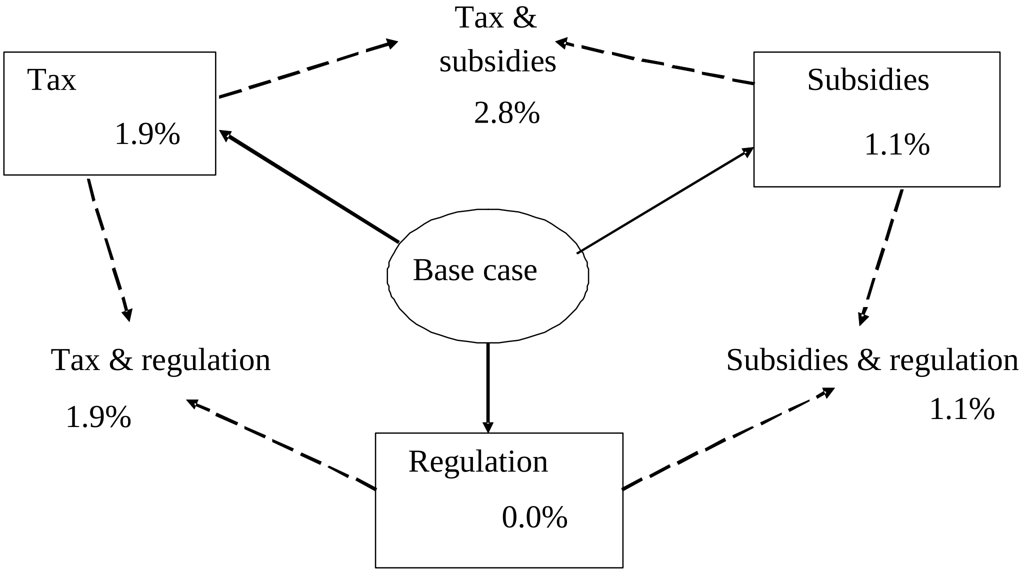

Figure 5.8b Savings on electricity 1995-2000 for combinations of policy measures (% of base case consumption)

The results for a single policy measure are shown in the rectangles. These values correspond to the 'tax-only', etc. cases in Table 5.6; the increase in savings from 1995 to 2000 translates into the percentages given. Combined saving effects for two measures are shown between the rectangles in Figure 5.8. These saving effects are larger than that of each of the corresponding single measures. This is because two policy measures will have more influence than one. However, in case of electricity the savings of 'tax & regulation' are equal to that of 'tax' because the electricity savings due to regulation are practically zero. The same is valid for 'subsidies & regulation' and 'subsidies'.

The qualitative results presented in Section 5.4 show mainly mitigating combinations of the three policy measures. Therefore one may expect that the combined saving effect of two measures often is lower than the sum of the separate savings; the two policy measures will overlap with regard to their influence on saving options. For instance, in the case of both regulation and tax, the extra effect of the tax on top of regulation will be negligible. This is confirmed in Figure 5.8a: the combined effect of 'tax & regulation' is -4.5% against -5.1% for the sum of the two effects. Thus the amount of overlap between these measures is almost 13%. For the combination 'subsidies & regulation' the amount of overlap is less profound (8%). From Figure 5.8b it follows that for electricity the overlap for 'tax & subsidies' is 4%.

However, in the case of gas and 'tax & subsidies' the combined effect is **not** lower than the sum of the two separate effects. This combination proves to be of a reinforcing nature. Probably this due to the fact that in the period 1995-2000 part of the subsidies is given to new, still expensive, saving options. In these cases the combined financial stimulation of the two measures was needed to force the start of the implementation process. The other part of the subsidies has been spent on proven options, leading to a mitigating combined effect. This case resembles the reinforcing and mitigating combinations C and D described in Section 5.4.

The overlap for the three measures together is more than 13% for gas and 4% for electricity. The 4% figure is equal to that found earlier for the combination 'tax & subsidies'. Because the other combinations of two measures show no overlap, the three-measure overlap is equal to the only existing two-measure overlap. For gas the three-measure overlap is slightly greater than the overlap for the two-measure combination 'tax & regulation'. The other overlap for 'subsidies & regulation' does hardly provide an extra contribution to the total overlap for three measures. One of the rare cases to compare the results with is provided by Vaisanen (2004) for energy savings in the Finnish industry. The overlap of about 20% for the combination of audits, subsidies and voluntary agreements has the same order of magnitude as found here.

5.7 Discussion on interaction results

Effect of measures not regarded

Besides the measures used in the preceding analysis a number of other policy measures were present in the period 1990-2000 (see Table 5.2):

- OEI (optimal energy infrastructure),
- DuBo (sustainable building options),
- EPA (enery advice),
- energy efficiency labels for appliances.

The infrastructural measures (OEI) have contributed to a 50% increase for the number of dwellings connected to a town-heating system. However, this type of dwellings still regards only 3% of the total number in 2000. DUBO-standards related to energy use can be ignored too as they overlap to a very great extent with the insulation standards that have been taken care of already in the preceding analysis. In Section 5.4 the EPA has been mentioned as an important measure in the qualitative analysis of possible interaction for 1990-2003. However, it was introduced in the last year of the simulation period only. The effect of labelling was substantial in the Netherlands according to Winward (1998). Moreover the combination of labels and subsidies (EPR) has been mentioned as an important combination. However, most MAP-subsidies did not coincide with labels, and the consecutive EPR-subsidy was introduced in the last year of the simulation period. This is not true for labelling and the REB-tax that both have been introduced step by step after 1996. Although this combination is rated less reinforcing than that of labelling and subsidies (see Figure 5.4) a synergetic effect cannot be excluded. However, possible effects regard electricity consumption only. Given these notes it is concluded that the measures that were not selected in the quantitative analysis for 1990-2000 are of limited importance with respect to the overall results.

Contribution of substitution between gas and electricity

In this paper results have been presented separately for the main energy carriers gas and electricity. However, substitution between the two carriers can take place due to changes in the penetration rate of electric heat pumps, electric kitchen boilers, hot-fill (water using) appliances, gas heated dryers and electric cooking. This substitution could have influenced the results of the preceding analysis on interaction between saving measures. An investigation into changes for the energy systems mentioned earlier reveals that substitution did not affect the results on overlap at all.

Interaction effects in the longer term

As the three policy measures analysed have been continued after 2000 it can be expected that the interaction effect have increased further. More and more new dwellings will have been constructed according to regulation that mitigates the potential saving effect of the REB-tax on new dwellings. The same is true for the combination ‘tax & subsidies’ or ‘subsidies & regulation’, at least if lowered subsidies in 2004 rise again in the future. However, an analysis with simulation runs for the period 2000-2005 is not possible as realisations for 2005 are not available yet. To provide some raw estimate about the further increase in the size of interaction effects, past household energy use was simulated with artificially enforced measures. The tax level for 1995-2000 was doubled, bringing the average value at 30-35% of the total energy price. Investment subsidies were doubled too, and the scope of regulation for new dwellings was expanded according to current policy. The effects on total energy use were calculated for the three enhanced measures and for the combination. The results for intensified policy show 25-30% lower savings for the combination of three measures compared to the sum of effects for each measure apart. The overlap is more than two times higher than that found earlier for three measures (see Table 5.6).

Interaction effects between subsets of more than two measures
Interaction between policy measures is not restricted to combinations of two measures. However, the number of permutations for subsets of three or more measures is such that the analysis becomes very cumbersome. Moreover the presentation of the results in the form of a simple matrix is not possible anymore. A more practical approach seems to be to select the most important measures with regard to both their saving effect and amount of interaction with one other measure. For this restricted number of measures the interaction effect for three or more measures can be analysed. In fact, this has been done in the quantitative analysis presented in the second part of this article.

5.8 Conclusions and observations

New framework for investigating possible interaction effects between measures
The possible interaction effect between two policy measures can be rated by investigating how these policy measures affect a number of conditions for a successful implementation of saving options. For a set of policy measures this approach results in a matrix with ratings of the possible interaction effect for all combinations of two measures. If two measures complement each other with respect to the conditions for implementation, the interaction effect is reinforcing. The combined effect is greater than the sum of both effects apart. In the opposite case the interaction effect is mitigating. The rating ‘neutral’ applies when the measures do not interact. For a set of actual policy measures the matrix will also show non-existing interactions because policy measures aim at different energy applications or do not overlap in time.

Qualitative interaction results for actual saving measures in households
The method has been applied to the actual set of 15 policy measures on energy efficiency for households in the Netherlands, in the period 1990-2003. The matrix of possible interaction effects shows that for over 40% of all measure combinations interaction is non-existing. Only 9% can be rated as strongly interacting, of which the greater part mitigating. Taking into account measures with a substantial saving effect only, the important interaction effects are between:

- building codes and energy performance standard (EPN),
- EPN and regulatory tax (REB),
- MAP-subsidies and REB-tax,
- REB-tax and energy premiums (EPR),
- energy advice (EPA) and EPR-subsidy,
- appliance labels and EPR-subsidy.

Quantitative interaction results for the most important policy measures

The interaction effect was quantified for the policy measures regulatory tax, investment subsidies for saving options and regulation of gas use for space heating (in new dwellings or renovated social housing), using a simulation model of household energy use in the period 1990-2000. In the absence of the two other measures the effect of a tax, starting in 1996 and amounting to one-third of the total price in 2000, is a 2% decrease in energy consumption in 2000. Subsidies of 20-30% of the extra investments into more efficient options lead to 3% lower electricity consumption and 4% lower gas consumption. Regulation substantially reduces the gas consumption of new dwellings; including the effect for social housing renovation the saving effect on gas is 4 to 5%.

In the period 1995-2000 the combination 'tax & regulation' delivered 13% less gas savings than the sum of both measures apart. For all three measures the loss of effectiveness was slightly higher. The combination 'tax & subsidies' showed no overlap for gas. This is probably the result of both overlapping and reinforcing processes with respect to different saving options. For electricity only one combination 'tax & subsidies' showed an overlap of 4%. Here the effects were rather small because, up to the end of the decade, regulation of electricity use was minimal. According to calculations with an artificially enhanced intensity of the three measures, representing the ongoing interaction process after 2000, the amount of overlap could further increase to 30%.

Observations for optimal policy

The analysis offers some general insights to reach an optimal set of policies as well. The most obvious way is to direct individual policy measures to specific energy applications. A second way is a better tuning of two measures for the same application. For instance, standards can be used to assure a minimum efficiency level and subsidies to stimulate the most efficient options only. A third way to prevent loss of effectiveness is a good timing. The reinforcing combination of subsidies and regulatory tax is effective in the difficult 'take-off' phase of a new saving option but not in the grown-up phase. Finally the choice of measure types should be based on the characteristics of the implementation process. For instance, both tax and subsidy provide a motivation to choose a more efficient option, but subsidies focus the attention of the users at specific saving options as well.

The matrix-method has been applied to sets of policy measures for EU-15 countries. From Odyssee (2005) it can be concluded that the method offers a quick overview of possible interaction effects in actual sets of policy measures. In case of a structural and extensive use of many types of policy measures the matrix-method can be useful to avoid the overlapping effects of different policy measures. Moreover, the analysis can show opportunities for reinforcing combinations of measures. However, some interaction effects have to be accepted for practical reasons, e.g. the part of energy use that is influenced by standards cannot be exempted from taxation. Moreover other criteria influence the choice of policy measures, for instance the policy expenditures or public acceptance.

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Chapter 6 PRICE ELASTICITIES, POLICY MEASURES AND ACTUAL DEVELOPMENTS IN HOUSEHOLD ENERGY CONSUMPTION - A bottom-up analysis for the Netherlands[13]

Abstract

In the Netherlands it seems likely that the large number of new policy measures in the past decade has influenced the response of households to changing prices. To investigate this issue the energy trends in the period 1990-2000 have been simulated with a bottom-up model, applied earlier for scenario studies, and extensive data from surveys. For a number of alternative price cases the elasticity values found are explained using the bottom-up changes in energy trends. One finding is that the specific set of saving options defines for a great part the price response. The price effect has been analysed too in combination with the policy measures standards, subsidies and energy taxes. The simulation results indicate that the elasticity value could be 30-40% higher without these measures.

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6.1 Introduction

For energy consumption both income and price elasticity, the ratio between the relative change in energy consumption and the relative change in income or price, have been studied by many researchers. Often, the income and price elasticity are used to describe future electricity and fuel consumption trends for households. This is especially convenient for a longer time frame when little is known about specific factors that may shape future energy consumption. However, it is difficult to justify transposing elasticity values observed in the past to the future. The elasticity is by nature a statistical entity at the level of aggregated energy use and it is hardly possible to relate elasticity values to real world causes for changes in energy consumption. These causes encompass, for instance, the chosen dwelling type with a certain energetic quality, the heating and hot water systems with more or less comfort and efficiency, the purchasing of all kind of electric appliances and finally the intensity of use of all these items. The choices made by households are not only affected by income and energy prices but also by many other factors, such as the composition of households, own versus rented dwellings and energy use standards for new dwellings or appliances.

As these underlying developments are ignored, it is difficult to judge the meaning and quality of ex-post elasticity values. This is especially true when new factors have affected energy consumption simultaneously. This has been the case in the Netherlands in the nineties, when a large number of policy measures were introduced to save energy in households (see Boonekamp (2002)). It seems likely that these measures have influenced the elasticity values in this period. For instance, in Jeeninga (2002) it is stated that the introduction of labels for energy efficient appliances increases the awareness of energy (cost) savings, and thereby makes decisions on appliances more sensitive to higher prices. From these observations one could argue that statistically identified elasticity values are of lesser use in future energy situations that differ from history.

Another policy issue is the fact that observed values of the price elasticity for household energy consumption are rather low in the Netherlands (a range of -0.1 to -0.6, see overviews in Linderhof (2001) and Groot (1998)), but also in other countries (see e.g. Branch (1993), Haas and Schipper (1998) and Filippini (1999)). Given the policy goal to offer society affordable energy prices, the future price induced reduction of demand will be relatively small. In that case a substantial set of policy measures to enhance energy efficiency will be needed to realise demand reduction in line with energy saving goals. In the light of the probable interaction between elasticity values and policy measures this raises again questions about the use of elasticities in scenario studies.

The issues at stake ask for investigating the mechanisms behind the price elasticity in general, and interactions between energy prices and policy measures in particular. To this end the energy developments for households in the period 1990-2000 have been simulated with a bottom-up model of household energy consumption. The detailed results provide a clear picture of actual changes in energy consumption that shape the value of the price elasticity. The model determines energy effects of various policy measures as well, e.g. standards for insulation in new dwellings, subsidies for more energy efficient appliances and energy taxes. The calculations for combinations of price changes and policy measures allow the price elasticity effect to be disentangled from the effect of policy measures. Knowledge of the possible range for the price elasticity is important when elasticity values for scenarios with more or less policies have to be chosen.

In Section 6.2 the key features of the model and the simulation of historic energy trends are described. Section 6.3 shows ex-post price elasticity values found for a number of price cases. In Section 6.4 these elasticity values are explained with the help of the underlying bottom-up changes in energy trends. The interaction between the saving effects of prices and the effects of policy measures is described and explained in Section 6.5. After a discussion in Section 6.6 of some issues raised during the analysis, conclusions and observations are given in Section 6.7.

6.2 Outline of the model and simulation of past energy trends

The simulation model, which is applied in the analysis of historic prices, policy measures and household energy consumption, is an adapted version of the SAVE households model, described in Boonekamp (1997). It has been applied for various energy policy scenarios for the Netherlands, e.g. ECN (1998). First some key elements of the model are presented; then the adaptations and the historic simulation are described.

Main structure of the simulation model

In the model, household energy consumption is divided into seven so-called energy functions: space heating, supply of hot water, cleaning (washing/drying/dishwasher), cooling (food), cooking, lighting, and other appliances (television, audio and all other electric devices). For each function energy demand follows from a set of driving factors, e.g. the number and type of dwellings for space heating, or the type of households and life style trends for cooking (see specification in Appendix 1).

The demand for each energy function is met by one or more energy consuming systems or appliances, e.g. boilers or geysers for hot water, or refrigerators and freezers for cooling (see Appendix 1). Dwellings are considered as an energy consuming system too. Their energetic characteristics, together with the heaters or boilers, provide for a comfortable living space. The development of energy consumption for all these energy systems or appliances determines the trend in total household energy consumption.

In the model total energy consumption of every system or appliance is defined by three factors: the ownership rate, the intensity of use and the energy efficiency of the system or appliance (see Figure 6.1).

The **ownership rate,** the fraction of households that use a specific system or appliance, is most often coupled to socio-demographic developments, such as the increase in the number of households. Increasing income levels lead to higher ownership rates, especially for some non-basic appliances in the Netherlands, such as dishwashers and dryers (see Steg (1999)). According to Gerritsen and Lelieveld (2002), income trends have only a limited influence on the type of new dwellings, due to the regulated housing market. The existing stock of dwellings hardly changes because of low demolition rates (0.2% per year) and restrictions on dwelling extensions. The rate of gas heating systems is partly affected by obligatory connection to town heating systems. This increases the rate of electric cooking devices too. The possible influence of energy prices on ownership rates is discussed in Section 6.6.

The **intensity of use** is the yearly number of hours a system or appliance is used or runs; in the model the intensity is defined as a relative value with regard to the base year value. This index-factor is coupled to socio-demographic developments such as the aging of the population and less members per household. The increasing labour market participation affects energy use via lower occupancy rates according to Steg (1999). Sometimes life style factors play a role, such as the increased watching of television by young people, and the decrease in home cooking activity, mentioned in van Praag and Uitterhoeve (1998). The effect of income and prices on intensity of use is discussed in Section 6.6 as well. The same applies for the rebound effect, a more intense use due to the cheaper energy services of efficient systems.

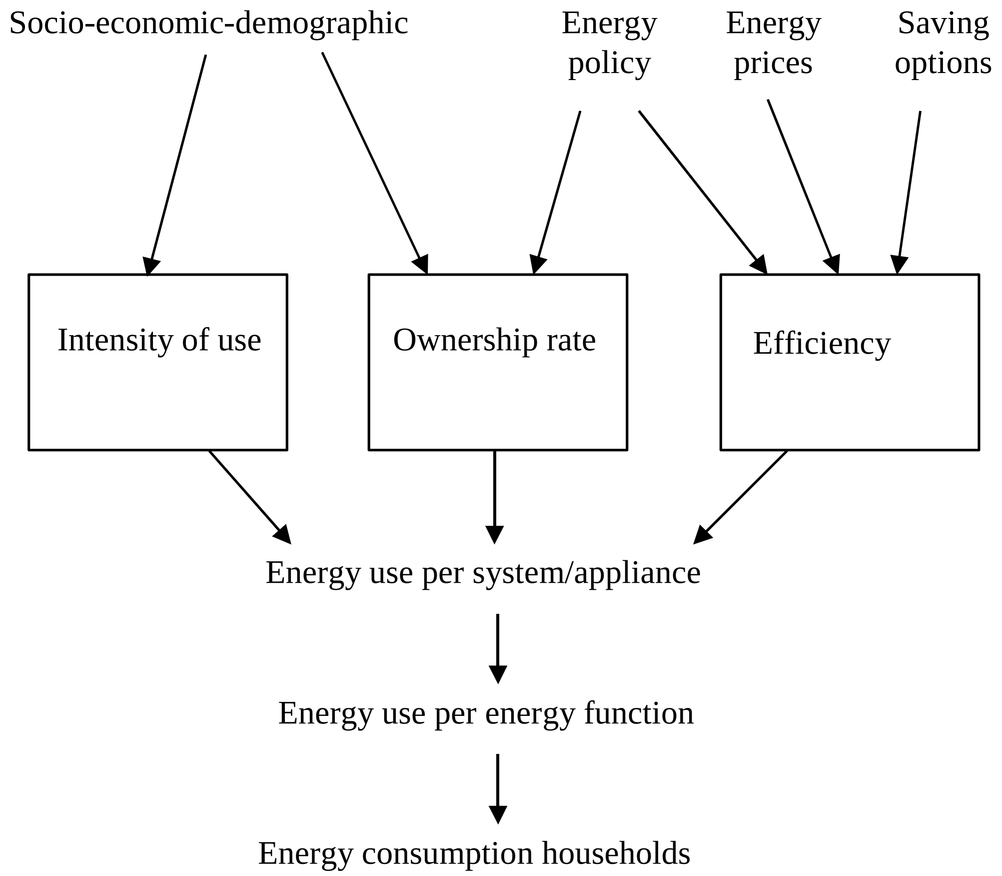

Figure 6.1   Key elements in the simulation model for Household energy consumption

The **energy efficiency** is defined as the reduction in energy use of a system or appliance compared to that of the reference system (producing the same output). For instance, the penetration of the high efficiency boiler, which uses 20% less gas than the conventional boiler, leads to an efficiency gain of 20%. Often, the reference system is already replaced partly by alternatives in the base year; in that case the model determines the extra efficiency gain with regard to the base year. The factor ‘efficiency’ depends on quite different developments than the factors mentioned earlier. The efficiency gains are realised by the purchase of more energy efficient systems and appliances, or by installing demand-reducing technologies, such as insulation of dwellings or water saving taps. The total amount of new systems/appliances in a year or period is determined by the change in total numbers deployed, and by gradual replacement of the existing stock. From this amount a greater or smaller part will be more energy efficient versions; this is dependent on available options, the (expected) level of the energy price, and policy measures to stimulate energy savings (see Figure 6.1). This process results in a gradual improvement of the mean energy efficiency of systems/appliances; for dwellings it results in a lower demand for heating.

Calculation of energy efficiency gains

This calculation forms an essential part of the simulation model; the description will be used later to explain the mechanism behind the elasticity and the interaction with policy measures.

For every conversion system or appliance a number of more energy efficient alternatives for the reference system are available. For the system ‘dwelling’ different insulation measures can lower the heat demand for space heating. Together these form the so-called saving options. When a system or appliance is replaced, the choice for a more energy efficient version is supposed to be taken on the basis of the cost/benefit ratio. Costs arise from additional investments in the more energy efficient option; the benefits are saved energy times mean price. A cost/benefit ratio CBR is calculated as follows:

$$\text{CBR} = [(\text{Inv} - \text{Subs}) \times \text{Ann}] / [\text{Saving} \times (\text{Price} + \text{Tax})] \qquad (1)$$

Inv = Extra investment in the saving option [€]
Subs = Subsidy on the saving option [€]
Ann = Fixed annuity factor to calculate yearly investment costs
Saving = Annual energy savings realised with the option [GJ]
Price = Price of energy excluding tax [€/GJ]
Tax = Tax on energy [€/GJ]

If costs are lower than benefits, thus a cost/benefit ratio <1, the option should always be chosen from an economic viewpoint. With a cost/benefit ratio >1 the penetration of saving options will be zero (see Figure 6.2, ‘All-or-nothing’). However, in practice this reasoning is too simple. Firstly, the situation differs per household because of greatly varying intensities of use, varying costs of saving options, (non) availability of investment money, etc. In case of a calculated CBR of 1 the real cost/benefit ratios for different households will vary around 1 and only a part of all households would choose the saving option. To account for this, the relation between cost/benefit ratio and penetration is modelled in the form of a S-shape curve (see Figure 6.2, ‘Dispersed’). A value of 1 for the cost/benefit ratio means that in 50% of the decision cases the more energy efficient option will be chosen.

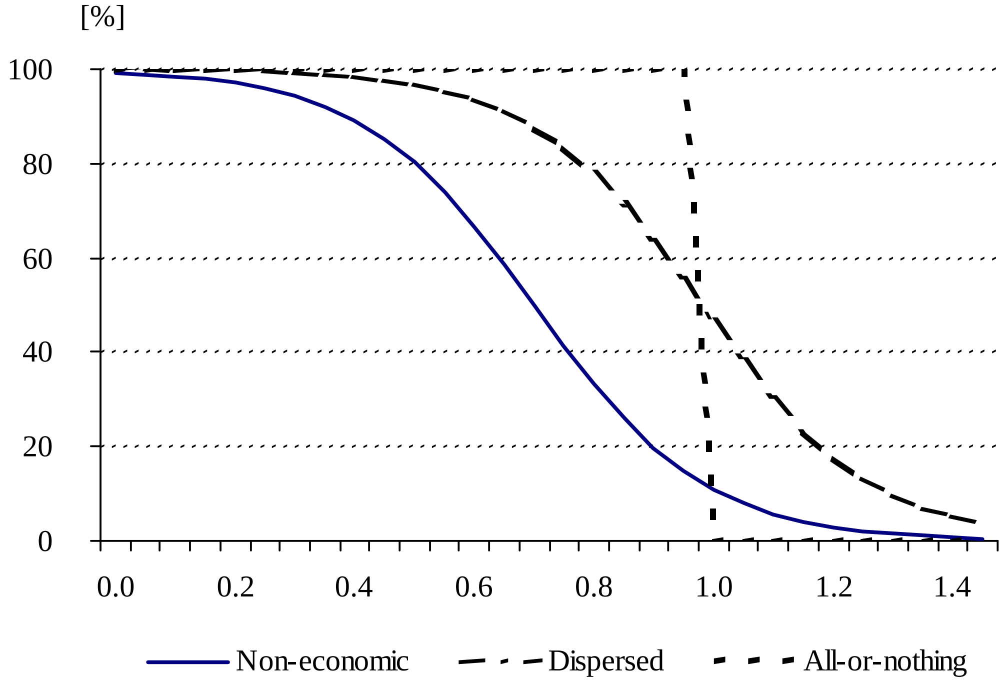

Figure 6.2 Relationship between cost/benefit ratio and penetration level for saving options (example)

A second, more fundamental objection to the 'all-or-nothing' approach is the focus on economy only. In reality some saving options offer non-economic benefits as well, for example extra living comfort owing to double-glazing. But other options lead to a non-economic burden, for instance the reduced amount of water with water saving showers. In practice high implicit discount rates are found, as highlighted in Hartman and Doane (1986) and the overview in Sansted (1995). Other barriers to a rational decision are lack of information with regard to the available options and costs and benefits (see Velthuijsen (1995)). According to Kooreman and Steerneman (1998) the expected (lower) lifetime of the more energy efficient option can lead to high implicit discount rates. Finally, apart from these peculiarities, households do not decide always on economic grounds alone (see Weber and Perrels (2000)). To take account of these additional factors the S-shaped curve is shifted along the horizontal axes in accordance with the specific situation for every saving option (see Figure 6.2, 'Non-economic'). Now the more energy efficient option will be chosen in 50% of the cases when the cost/benefit ratio is equal to the 'acceptable' ratio (see Equation 2).

$$\text{Penetration} = 1 - 1 / \{1 + \text{Exp}(-\text{Stp} \times (\text{CBR} - \text{CBR50}))\} \qquad (2)$$

Stp = Steepness of S-curve
CBR50 = Acceptable cost/benefit ratio

The acceptable ratio is estimated on the basis of data on costs, benefits and actual penetration rates in the past. For instance, very popular double-glazing for existing dwellings had a long pay-back time but nevertheless penetrated fast (yearly survey EnergieNed). To account for this non-economic behaviour the 50% penetration point had to be placed at a cost/benefit ratio above 1. The steepness of the curve can be varied too; it depends on the type of saving option. For proven options the S-curve will be rather steep because there are no real barriers, once the costs are lower than the benefits. For very new options, with functional differences in day-to-day use, a more stretched curve is used. The relatively low penetration rates at a CBR<CBR50 resemble the time consuming penetration process for these options (see Figure 6.2). The choice with respect to steepness is based on the characteristics of every option.

The market share of the options can be affected by policy measures, e.g. subsidies or energy taxes that influence the cost/benefit ratio (see Equation 1). In case of standards the choice on basis of cost/benefit ratios is overruled, and saving options are always chosen. The decisions to use more energy efficient systems or appliances can only be taken at the time of replacement of old ones. A vintage approach is applied to model the gradual replacement of the stock of systems and appliances due to aging.

The penetration of the saving options results in a decreasing value for energy consumption per system or appliance. After accounting for changes in intensity of use and ownership rate, the energy consumption per system/appliance is aggregated to the level of total energy consumption of households (see Figure 6.1). Via this bottom-up approach an indirect relationship is defined between total energy consumption of households and general socio-economic developments, price trends and energy policies.

Adaptations to simulate past energy consumption trends

The simulation model has been applied earlier to formulate energy scenarios for 1990-2015, e.g. ECN (1992). Because the same base year 1990 was used, the model is suited for the historic analysis too. However, because of the five-year interval applied in the model, it delivers results for 1995 and 2000 only. Therefore the yearly changes in variables are aggregated to five-year mean values. Costs and energy saving figures of most saving options, originally based on Worrell (1992) and de Beer (1994), were updated in accordance with newly published studies on costs and performance of energy systems in later years. A list of important saving options with their cost/benefit values is presented in Appendix 2. The model has been expanded to provide for inserting the realised value of every calculated variable. In this manner a comparison of model results and actual developments can be made at each level: penetration of saving options, number of systems or appliances, demand per energy function and total energy consumption. Furthermore the model was adapted to calculate energy consumption trends without policy measures (see Section 6.5). Apart from these rather simple model extensions most of work was devoted to an update of the model parameters. To this end the extended model was used to simulate, as good as possible, the known energy consumption trends in the period 1990-2000. This was achieved in two steps:

- Replacement of all scenario inputs by historical values for 1990-2000.
- Fitting of the outcomes to realised values by adjustment of model parameters.

The fitting process took place at different levels. Calculated penetration levels of saving options were fitted to known historical levels, as given by surveys of EnergieNed. This was accomplished by adjusting the parameters of penetration formulas (see Section 6.2 on S-curve).

Then the resulting energy consumption per energy function was fitted to historical values by adjusting activity levels (time devoted to cooking, number of showers per day, etc.), which define the intensity of use. Finally total household energy consumption was adjusted for some changes in general parameters like the average indoor temperature for space heating. The fitting has resulted in a base case simulation that differs less than 1% from historical values for fuel and electricity consumption.

Overall energy consumption developments

Table 6.1 summarizes household consumption trends for fuel and electricity in the period 1990-2000, based on the simulation of past trends. Fuel consisted for the most part (97%) of natural gas. The energy consumption excluding savings for 2000 was calculated by keeping all penetration rates of energy saving options at the 1990 level (see method described in Boonekamp (1997)). The difference with actual energy consumption in 1990 is due to growth effects: more households and dwellings, more appliances per household, higher thermostat setting, etc. As shown, fuel use without savings would increase by 20% and electricity consumption by 70%.

Table 6.1 Overview of household energy consumption developments in the Netherlands in the period 1990-2000[1]

	Fuel [PJ]	Electricity [PJ_e]
Actual energy consumption 1990	394	60.3
Growth effect 1990-2000	+78	+44.4
Consumption excluding savings 2000	472	104.7
Total energy saving effect	-79	-25.2
Actual energy consumption 2000	393	79.5

[1] Corrected for yearly variations in temperature during the heating season

The difference between energy consumption excluding savings and actual energy consumption in 2000 is equal to total energy savings. Total savings are the result of policy measures (taxes, subsidies, insulation standards, labels, etc.) or other developments, such as autonomous technical developments and price trends. Actual fuel use hardly changes during the nineties; the growth effect is neutralized by the saving effect. The electricity consumption increases with more than 30%, despite substantial savings at 24% of the consumption excluding savings.

6.3 Effect of energy price changes on historic energy consumption

Determination of price effects

The adapted model is capable of simulating energy trends, using inputs that depart from the (fitted) base case trend 1990-2000. In the following the effects of a number of price changes are analysed, keeping all other influencing factors unchanged. The development of fuel use proves to be quite different from that of electricity. Therefore both are analysed separately. Because gas accounts for 97% of all fuel use the analysis focuses on the relation between gas consumption and gas prices.

The gas and electricity prices for households, shown in Figure 6.3, include the normal VAT-rate of 19% but not the fixed grid connection costs; from 1996 on a special regulatory tax was introduced to stimulate energy efficiency further. The total gas price increased from 23 to 26 €ct-1990 per m^3; however without the regulatory tax the price in 2000 would have been substantially lower than in 1990. The electricity price first showed a minor decrease and than increased to almost 12 €ct-1990 per kWh in 2000. Without the tax the electricity price for 2000 would have been lower than in 1990.

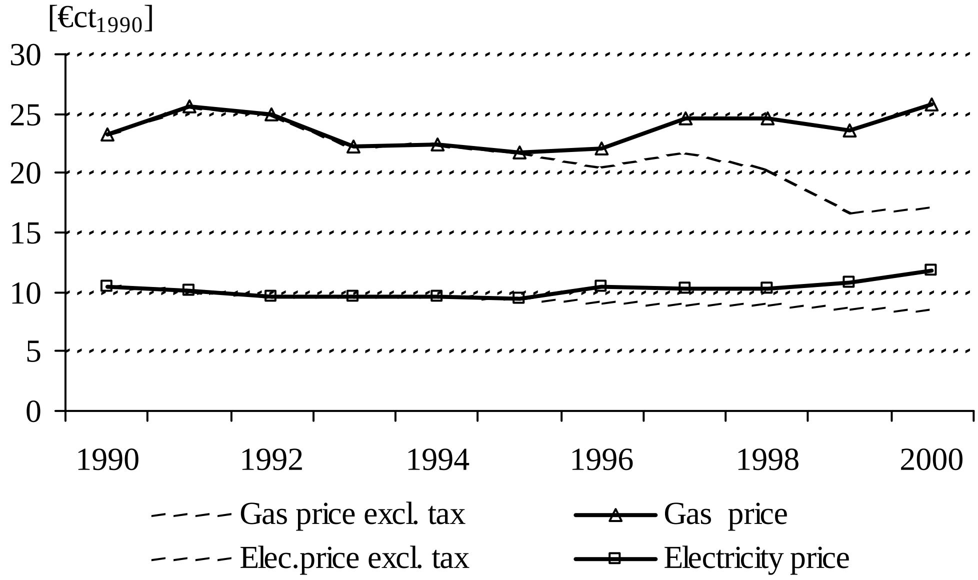

Figure 6.3 Gas and electricity price of households in the Netherlands, without and with regulatory tax in the period 1990-2000

In the model calculations for 1995 the average price level for the period 1991-1995 was used. The applied change in the gas and electricity price regards this average price. The changes are assumed to take place at once after 1990; thus all decisions taken up to 1995 are affected by the change in energy price. The same applies for the period 1996-2000 and the calculations for 2000. The price regime for electricity consists of flat rates for one-tariff or two-tariff systems at choice. The fraction of households with two meters increases from 40 to 53% in the period 1990-2000. The electricity price presented here regards the mean of both tariff categories. In the simulation model the second, off-peak, tariff is only specified for 'big' storage applications such as electric boilers and electric heat pumps. The discount for kWh used during night/weekend hours is the same in all price cases.

Price reactions for different price cases

Table 6.2 shows the results of five cases with prices that differ from the base case values. Results are given for 1995 and 2000, and for gas and electricity apart. For each case the price effect on total energy consumption was determined as the ratio between the relative change in energy **consumption** and the relative change in energy **price**. This ratio resembles the definition of elasticity and it will be referred to further as price elasticity. However, it should be remarked that the calculated ratio regards changes over five years (values 1995) or ten years (values 2000), thus lying between the periods relevant for short- term and long-term elasticities. Moreover, the scope of the price reaction is more limited, as will be elaborated on in the discussion section.

Table 6.2 Price elasticity for household gas and electricity consumption for different energy price cases

	1995		2000	
Total price changes	Gas	Electricity	Gas	Electricity
1. Minor increase (+20%)	-0.07	-0.07	-0.13	-0.11
2. Major increase (+100%)	-0.04	-0.05	-0.08	-0.07
3. Major decrease (-50%)	-0.05	-0.06	-0.10	-0.09
4. Gas only (+20%)	-0.08	(+0.02)	-0.15	(+0.03)
5. Electricity only (+20%)	(+0.01)	-0.09	(+0.02)	-0.13

In the **first case,** with 20% higher gas and electricity prices, gas use in 2000 decreases with 2.5% and electricity use with 2.1% in comparison to the base case. Thus the value of the elasticity is -0.13 for gas and -0.11 for electricity. The elasticity values found are lower than most long-term elasticity values from literature, e.g. Filippini (1999), Branch (1993), Booij (1992), Groot (1998) and Linderhof (2001). The values for 1995 are even lower, just 60-70% of that in 2000, as will be explained in Section 6.4. In the **second case** a five times higher price change is assumed; both gas and electricity become twice as expensive. Compared to the first case more energy savings are realised, but not with a factor of five; consequently the elasticity values are smaller. The **third case** is the inverse of the second; the price is halved instead of doubled. Lower prices lead to an increase in energy consumption; therefore the sign of the ratio is still negative. The elasticity values found are somewhat higher than in the second case, especially in 2000. In the **fourth case** the gas price increase is of the same magnitude as in the first case but the electricity price remains unaltered. The elasticity for gas in 2000 is slightly higher than in the first case. In the **fifth case** the electricity price increases but the gas price remains at the historic level. The elasticity for electricity is also slightly higher compared to the first case.

6.4 The mechanisms behind the price elasticity

For each case the mechanisms that define the value of the price elasticity are analysed using the detailed bottom-up results of the simulations. First some bottom-up results are presented; then they will be related to the elasticity values and the differences between the cases; finally deviations from other studies are explained.

Bottom-up results in the price-cases

The bottom-up results comprise the change in energy use owing to the penetration of each of the 64 saving options used in the model for the period 1990-2000. In Figure 6.4 the cumulative contribution of an aggregated set of 24 saving options in 2000 is shown for three price cases: +20%, +100% and -50%. Some saving options show a negative contribution; this is due to substitution between a less energy efficient option and a more efficient option. One example is the big increase in the energy savings owing to the HR-107 (maximum efficiency) boiler that goes at the expense of that of the HR (high efficiency) and the VR (improved efficiency) boiler.

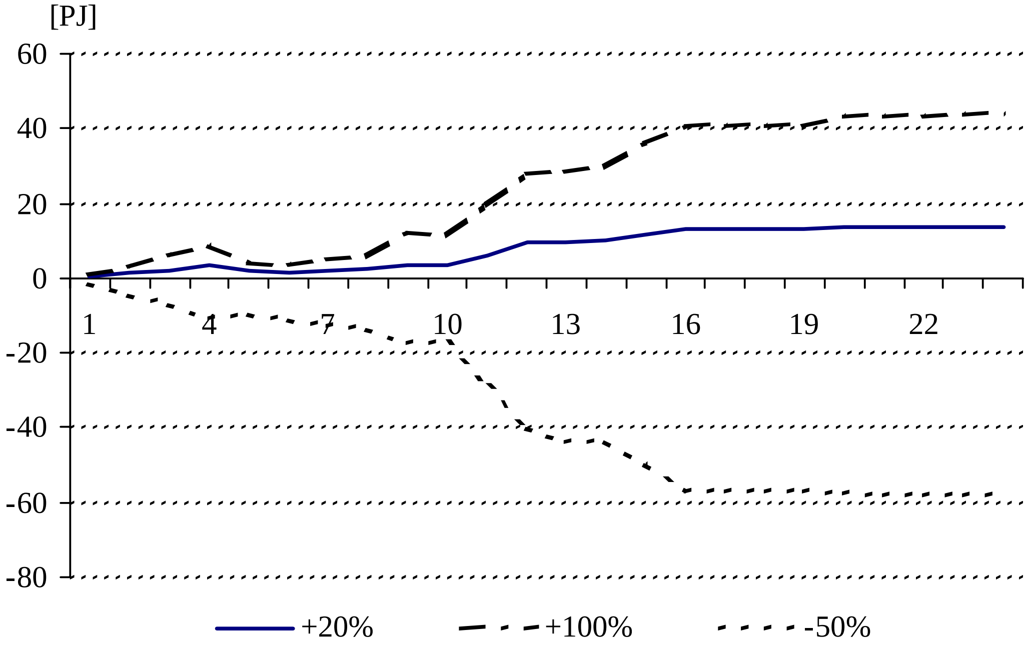

Figure 6.4 Cumulative contributions of 24 saving options to the change in total energy savings in 2000 for three price cases

In Table 6.3 the set of 24 saving options is split into three groups: state-of-the-art, break through and advanced options, based on their implementation status in the period 1990-2000. For three price cases the contribution per option is given; the total contribution of all options is given as a fraction of total energy consumption.

It proves that the **advanced** saving options do not provide a substantial contribution, even with major price increases. The reason is that they are too expensive, and presumably are not seen as market ready. For much lower prices the total contribution of advanced options does not fall substantially (see column -50%); the obvious reason is the minor contribution in the base case. For the **state-of-the-art** options the total contribution is relatively low in the price case +20%. Some of these options compete with break through options and show a negative contribution. The reaction to major price changes is asymmetric; the increase in the +100% case is much smaller than the decrease in the -50% case. One reason is that, high prices or not, there is little room left for further penetration of a number of ‘old’ saving options. For example, double-glazing for living rooms has almost reached its maximum penetration level in the base case. The **break through** options, introduced during the nineties, contribute by far the most to the observed changes in energy consumption (70% of the total changes). Their contribution is dependent on the price level because they are marginally attractive from an economic viewpoint. On the one side they are viable enough to gain market share in the base case, which represents actual developments. But on the other side they are not as attractive and proven as the state-of-the-art options. All in all it can be concluded that the break through options are of greatest importance for (extra) efficiency gains to be attained at medium term.

Table 6.3 Contribution of saving options to the savings on total primary energy consumption of households in 2000, for three price variants[1]

	Price +20% [PJ]	Price +100% [PJ]	Price -50% [PJ]
Type of saving option:			
STATE-OF-THE-ART	***+3.6***	***+11.7***	***-17.6***
Double-glazing	+0.4	+1.1	-1.8
Roof insulation	+0.8	+1.7	-2.9
Wall insulation	+0.9	+3.3	-2.3
Floor insulation	+1.3	+2.4	-3.7
VR-boiler (improved efficiency)	-1.5	-4.4	+0.9
HR-boiler (high efficiency)	-0.2	-0.7	-1.5
New gas stoves and geyser	+0.5	+1.7	-1.2
Gas-combi (replacing electric boiler)	+0.4	+1.0	-1.1
Hot water savings	+1,1	+6.0	-3.7
New (efficient) appliances	-0.1	-0.4	-0.3
BREAK THROUGH	***+9.6***	***+28.8***	***-39.4***
Low-E double-glazing	+2.6	+8.2	-11.8
HR-107 boiler	+3.1	+7.9	-11.1
Efficient combi-boiler	+0.4	+0.7	-3.3
Heat recovery (new dwellings)	+0.3	+1.4	-0.2
More energy efficient appliances	+1.8	+6.2	-6.1
Efficient lighting	+1.4	+4.4	-7.0
ADVANCED	***+0.7***	***+3.2***	***-1.1***
Extra insulation (new dwellings)	0	+0.1	0
Triple glazing	0	0	0
Heat recovery (existing dwellings)	0	+0.3	0
Very efficient combi-boiler	+0.5	+2.1	-0.8
Electric Heat pump (hot water)	+0.1	+0.3	-0.3
Gas Heat pump	0	+0.1	0
Gas heated clothes dryer	0	0	0
Hot-fill clothes/dish washer	+0.1	+0.3	-0.1
TOTAL			
All options (% of energy use 2000)	2.4%	7.5%	-9.9%

[1] Primary energy use calculated with a conversion efficiency of 40% for electricity.

Analysis of the first case (prices +20%)

The results in Figure 6.4 and Table 6.3 show that the majority of the saving options hardly have an effect on total efficiency gains. Options that are too expensive as well as options that are already on their maximum penetration level, do not respond much to a modest price change. The limited set of options that defines the price reaction will differ per country and in time. This can possibly explain why the elasticity values, found in literature vary so much between countries and time periods (see for instance overview in Linderhof (2001)).

Bottom-up results explain the dependence of elasticity values on length of analysis period as well. It usually takes 10-30 years to fully replace the existing stock of systems or appliances, and thus the same period to incorporate the effect of higher prices in the total stock. The elasticity value will increase with time, as the stock of systems and appliances is gradually replaced by more energy efficient versions owing to higher prices. This is shown in Table 6.2 as well, where the 2000 elasticity values prove to be higher than the 1995 values. This 'stock replacement' effect also explains part of the difference between the model results and the long-term elasticity values from literature. In the simulation the full effect of the higher prices is not yet attained because of the limited length of the analysis period (ten years). The results in Table 6.2 should be seen as mid-term elasticity values, which generally will be lower than the long-term elasticity values mentioned in literature.

Analysis of the second case (prices +100%)

In this case a greater part of the saving options contribute to total energy savings (see Figure 6.4 and Table 6.3, third column), and most options show a higher contribution. However the contributions do only increase threefold, against a five fold price increase, with respect to the first case. The more or less fixed pace of replacement limits the contribution of the attractive break-through options. The higher energy savings have to be provided for by more expensive, but also more energy efficient, options. In the model a number of more expensive saving options is present. However, these options hardly enter the simulation, resulting in a lower elasticity value. It can be concluded that the so-called law of diminishing returns is valid too for substantial energy price increases over periods of less than ten years. It should be remarked that the elasticity values, found in the second case, are not quite comparable with values from literature, as the use of the price elasticity concept is normally restricted to cases with modest price changes.

Analysis of the third case (prices -50%)

In the base case simulation (resembling the realised energy trend 1990-2000) the penetration rate of most saving options increased owing to the base line price trend, autonomous trends in the costs of saving options and policy measures. When prices are halved, this penetration rate increases less, or even decreases. From Figure 6.4 and Table 6.3 (see last column) it follows that both state-of-the-art options as well as break through options lose much ground. However, the price reaction is relatively less strong than in the first case, as the ongoing shift to ever more energy efficient systems and appliances prevents the use of old inefficient reference systems, which comply with the very low prices (see e.g. Haas and Schipper (1998)).

The elasticity values found here differ somewhat from the opposite +100% price case, especially in 2000 (see Table 6.2). According to Gately (1993) and Haas and Schipper (1998) the price reaction has, in general, an asymmetric nature; the reaction to rising prices is relatively more intense than the reaction when prices go down again. This can be explained from bottom-up analysis too. Once saving options have gained a reasonable penetration rate, further penetration becomes easier owing to decreasing investment costs, the proven character of the option and reduced information costs. In some cases the alternative is so successful that the reference system disappears altogether; there exists no possibility any more to save less with lower prices.

However, the asymmetric price reaction found here, contradicts with the preceding reasoning. The loss in energy savings in the -50% case is greater than the gain in the +100% case (see Table 6.3, Total). This result is caused by the formulation of the S-curve equation. Supposing a cost/benefit ratio (CBR) of 1 in the base case, the value will be 0.5 in the +100% case as the benefits double. In the -50% case the benefits are halved and the CBR increases to 2.0; the absolute distance to the base case CBR value of 1 is now twice as much. Given the S-curve relationship the penetration will change more in the -50% case than in the +100% case, leading to the seemingly contradicting price reactions found. To correct for this ‘distortion’ an extra price case, with 33% percent lower prices, was calculated. Here the CBR value will increase as much as it decreased in the +100% case (from 1.0 to 1.5 respectively 1.0 to 0.5). The price reaction is now less strong than in the +100% case: 0.06 against 0.08 for gas and 0.06 against 0.07 for electricity. This confirms that a decrease in economic incentive has relatively less influence than the same increase in incentive. It should be remarked that in the price cases described here the substantial increase or decrease in the prices is valid for the entire period 1990-2000. This departs from elasticity studies, which often look at rising and falling prices one after the other.

Analysis of the fourth case (+20% on gas price only)

The gas price increase is of the same magnitude as in the first case but the electricity price remains unaltered. The elasticity for the gas consumption is in 2000 marginally higher than in the first case (see Table 6.2). The elasticity for electricity must be seen as the ‘cross’ price elasticity between electricity consumption and the gas price increase. In accordance with most literature mentioned earlier the value has a positive sign. This result can be explained as follows. When the gas price rises and the electricity price is kept at the same level, some 'electrical' systems become more attractive and replace ‘gas’ systems. This substitution lowers the gas demand and results in a higher price elasticity value for gas consumption. Here, new electric options like electric heat pumps for space heating gain little market share; therefore the substitution effect is not profound.

Analysis of the fifth case (+20% on electricity price only)

The electricity price increases but the gas price remains at the historic level. Now the price elasticity for electricity consumption is somewhat higher than in the first case (see Table 6.2). Compared to the fourth case the substitution process runs the other way around. The baseline trend for replacing electric hot water boilers by gas fuelled combi-boilers is strengthened in this case, and electricity demand is decreasing faster than in the first case.

6.5 Price elasticity in conjunction with policy measures

In the preceding section the effect of changing prices on energy consumption was analysed, keeping all other influencing factors unaltered. In the following the effect of a price change is analysed with and without the presence of some policy measures. This enables the understanding of the influence of energy policy on the relation between energy prices and energy consumption.

Policy measures analysed

An overview of policy measures to decrease household energy consumption in the period 1990-2000 can be found in Oosterhuis and Nieuwlaar (1998). The most important measures were:

- standards for gas use in new dwellings,
- subsidies for more energy efficient systems and appliances,
- regulatory tax on energy carriers.

The standards for new dwellings at first focused on specific insulation measures (wall, roof, floor, windows) and energy efficient boilers. In 1996 a more stringent standard for total gas consumption of new dwellings was introduced; first 1200 m^3 for space heating in a normalized dwelling, later lowered to 1000 and 800 m^3. The total number of new dwellings build according to standards amounted to 13% of the total housing stock in 2000. Subsidies were provided for most of the period for the greater part of the saving options. The subsidy level amounted to 20-25% of the extra investments in energy saving options. The level of the regulatory tax on fuels and electricity was gradually increased from 1996 on. In 2000 the tax amounted to 36% of the total gas price and 32% of the total electricity price for households (see also the Figure 6.3).

Price elasticity values in relation to policy measures

First a no-policy base case, without the three measures mentioned, is analysed. Energy consumption has been calculated with and without a price increase of 20% for gas and electricity. Note that the price increase concerns the price without regulatory tax. Then a number of policy variants were simulated, again with and without a 20% price increase. In the first variant with standards, investment in saving options for new dwellings was obligatory instead of based on a cost/benefit approach, as was the case in the no-policy base case. In the second variant subsidies were subtracted from the investments in saving options; this resulted in lower cost/benefit ratios. In the third variant energy prices including the regulatory tax were applied; this increased the benefits, resulting in lower cost/benefit ratios of investments in saving options as well. Finally a case with all three measures was analysed. For each of the five cases the changes in consumption, due to 20% higher gas and electricity prices, were calculated. The resulting price elasticity values found are shown in Table 6.4 for the year 2000.

In the base case, with 20% higher prices and without the three policy measures, a price elasticity of -0.12 is found for electricity and -0.14 for gas. When one of the policy measures is present the price elasticity is generally lower, and the influence of the measures differs for gas and electricity. In the last case with the three policy measures present, the price elasticity for gas and electricity is 25-30% lower than in the situation without measures. The change in the price elasticity due to different policy measure can be explained as follows.

Table 6.4 Price elasticity for household gas and electricity consumption in the presence of policy measures[1]

Policy variants	Gas	Electricity
No policy case	-0.138	-0.124
Standards only	-0.113	-0.124
Subsidies only	-0.142	-0.119
Taxes only	-0.125	-0.100
Taxes/Subsidies/Standards	-0.103	-0.091

[1] For a change of +20% in the price without regulatory tax, results for 2000

Standards and price elasticity

In the presence of standards the price elasticity of gas is substantially lower in the period until 2000. Prices no longer affect the amount of gas saving options in new dwellings because there is an obligation to take these measures anyhow. For electricity the elasticity is practically equal to that in the base case, as standards are targeted at gas using saving options only.

Subsidies and price elasticity

Subsidies lead to a slightly higher elasticity for gas but a lower elasticity for electricity (see Table 6.4). To explain this phenomenon one should look at how changes in prices or subsidies ultimately lead to energy consumption changes. First the effect on the cost/benefit ratio is analysed. In Table 6.5 a saving option is presented with a cost/benefit ratio of 0.40 (see second column No Subsidy/Base price). With a 20% price increase this ratio decreases with 0.07. In case of a 25% subsidy the ratio is 0.30; with the same price increase this decreases with 0.05. It is obvious that subsidies cause a relatively smaller change in cost/benefit ratio; hence the change in penetration level of saving options should be lower, energy consumption should decrease less and finally the calculated elasticity should be smaller.

Table 6.5 Changes in cost/benefit ratio due to price increases and subsidies (example)

	No subsidy		25% subsidy	
	Base price	Price +20%	Base price	Price +20%
Investment costs (yearly)	20	20	15	15
Benefits from savings	50	60	50	60
Cost/benefit ratio	0.40	0.33	0.30	0.25
Change in ratio		-0.07		-0.05

However, to explain the **differences,** found for gas and electricity, two other factors have to be looked at: the relationship between cost/benefit ratio and penetration of saving options, and the composition of the set of saving options. Both subsidies and higher prices decrease the cost/benefit ratio and thereby increase efficiency. To analyse the interaction between subsidies and price changes the S-curve relationship (see Figure 6.2) is looked at into more detail. In Figure 6.5 three specific cases are shown with respect to the relation between penetration level and CBR. In case 1 the actual cost/benefit ratio is of the same order as the acceptable ratio; a change in the ratio leads to an almost proportional change in the penetration level. This applies for the change due to subsidies (arrow 1a), as well as for the following change due to a price increase (arrow 1b). When effects are modest it is clear that the effect of price on the penetration level is almost the same with or without subsidies. In case 2 the ratio is much higher than the acceptable ratio; because of the small angle with the horizontal axes the same price change results in a smaller change in the penetration. But if subsidies (arrow 2a) are introduced first, the effect of the price increase (arrow 2b) is much more profound. In the opposite case 3 the ratio is much lower than the acceptable ratio; a high penetration rate results that is difficult to increase further. But when subsidies change the ratio first (arrow 3a), the price effect (arrow 3b) is smaller even than without subsidies.

From the cases in Figure 6.5 it can be concluded that the effect of price increases on the penetration level of saving options can be influenced by subsidies in quite different ways. For options in the so-called take-off phase (2) subsidies enlarge the effect of price increases. For options in the so-called saturation phase (3) subsidies decrease the already small effect of price increases. In the grown-up phase (1) subsidies do not influence the effect of price increases on penetration levels. In conclusion, depending on the implementation phase of the saving options, subsidies can increase or decrease the value of the price elasticity of energy consumption, or they are indifferent.

In reality energy consumption of households is split into a number of energy functions and systems/appliances, each with one or more saving options in a different stage of development. In some cases subsidies increase the effectiveness of a price increase, in other cases the opposite is true or there is no effect. The composition of the 'stock' of saving options at a certain moment determines the overall influence of subsidies on the effect of price increases.

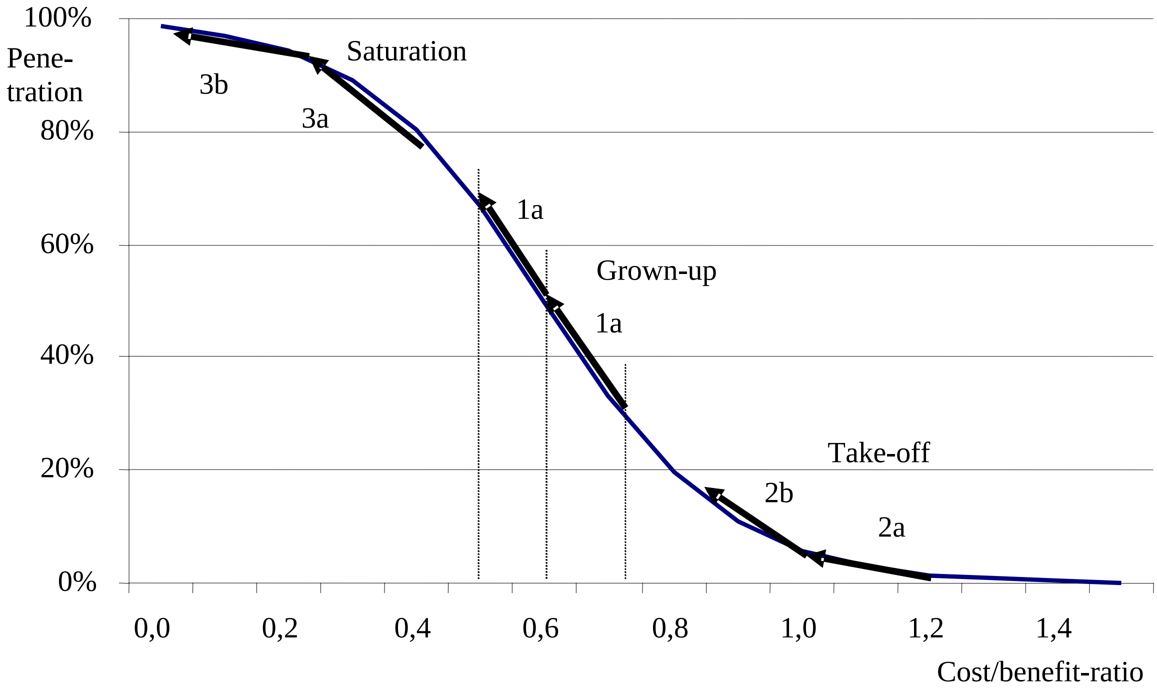

Figure 6.5 Effect of subsidies (a) and price changes (b) on the cost/benefit ratio and the penetration level of saving options

The preceding analysis can be used to explain the differences between gas and electricity elasticity values, with regard to the influence of policy measures (see Table 6.4). For gas the stock of saving options is composed of saving options in the ‘grown up’ or ‘take-off’ phase. Therefore subsidies increase, or at least do not influence, the price elasticity. This effect even offsets the general mitigating effect of subsidies on the elasticity value (see Table 6.5). An example of an important ‘take-off’ saving option is the HR (high efficiency) boiler for space heating. In the Netherlands the penetration of this option increased from 3% in 1990 to 30% in 2000, supported by subsidies, and creating a vast new saving potential. For electricity the observed decrease in the value of the elasticity can be ascribed to the general mitigating effect of subsidies. The apparent lack of influence of subsidies is due to the presence of mostly “grown up”-options. This is in line with the substantial efficiency improvements for washing machines, refrigerators and lighting that have been realised, even before 1990. Finally, it should be mentioned that the relative amount of subsidies differs somewhat per saving option; this probably contributes to the observed differences between the elasticity values for gas and electricity.

Taxes and price elasticity

The average level of the regulatory tax for 1995-2000, amounting to 17-20% of the total price, is comparable to that of the price increase used here. In the tax case, the price elasticity values for gas as well as for electricity are lower than without the tax (see Table 6.4). The cause is partly of an arithmetic nature; in the presence of a tax the 20% increase in the base price (without taxes) leads to less than 20% increase in the total price to be paid. The decrease in cost/benefit ratio is smaller now, and therefore the increase in penetration of saving options too. However, this does not explain that the difference between tax and no-tax case is smaller for gas than for electricity, despite a slightly higher tax on gas. The explanation follows the same reasoning as used earlier with subsidies. In Figure 6.5 the subsidy arrows can be thought of as tax arrows. From the figure it can be seen that for options in the 'take off' phase taxes will enhance the effect of higher prices; in the 'grown-up' situation taxes will not influence the effect of price increases. As indicated earlier this is the case for gas. Therefore taxes have a slight positive influence on the price elasticity for gas. For electricity the earlier found 'grown up' situation for most options means that taxes do not influence the elasticity value. The lower elasticity value in case of taxes (see Table 6.4) is due to the arithmetic effect described earlier.

Effects in the longer term

With all policy measures present the price elasticity for gas decreases from -0.14 to -0.10, and the elasticity for electricity from -0.12 to -0.09. The question is how these differences will develop in the longer term when the policy measures are prolonged. Standards were directed at a small part of total dwellings only; in the future more and more dwellings will have a design gas consumption that is independent of historic gas prices. The same applies for subsidies because, in the longer run, more and more saving options will be in place, not because of high prices but because of subsidies. The regulatory tax started in 1996 and will reach its maximum level after 2000. Again the historic energy price levels, without taxes, will explain less and less the energy consumption trends. The conclusion must be that in the longer term energy saving policy could drive the empirically determined price elasticity values for household energy consumption further down.

6.6 Discussion

In the simulation model there is no explicit relationship between energy and income. Moreover, the price elasticity is defined more narrowly than usually is the case in econometric analysis.

Implicit income elasticity

In energy demand modelling one can use a direct relationship between income and energy demand, for instance in the form of an income elasticity. However, the relationship between household income and energy consumption will materialize in the form of available energy using systems and appliances, and in a certain intensity of use (see Figure 6.1). In the bottom-up model used here the economic trend is translated into physical consequences, which can be coupled to energy consumption. The advantage is the clear definition of the relation between activities and energy applications, and the possibility to use all kind of non-economic information to determine energy trends. The importance of using these non-economic inputs is underlined by ex-post elasticity studies, which use a combination of economic and so-called structural variables (e.g. Haas (1997), Booij (1992), Linderhof (2001), Biermayr (1999) and Damsgaard (2003)). Structural variables are for instance the type of dwelling, the type of household and the ownership rate of appliances. The results of these studies show that the quality of the regression analysis improves considerable if, next to price and income variables, structural variables are included as well. The results also show that the importance of income as explaining variable is reduced to a great extent. Therefore, given a good prognosis of the non-economic, energy relevant variables, the role of income itself as explaining variable will be limited. Moreover, the model applied in this analysis, contains more structural variables than mentioned in the cited studies; therefore the role of income as explaining variable will be even less important.

The 'prognosis' of all the structural variables poses no problem in an ex-post analysis for the period 1990-2000. The trends for the structural variables are known from statistics and surveys. Therefore it can be concluded that the effect of increased income on energy consumption is sufficiently covered by the use of an extensive set of structural variables in the bottom-up model (see Table 6.6). One can say that an implicit income elasticity is used in the historic simulation.

Table 6.6 Included effects of income and price on the deciding factors for energy consumption

	Base case simulation		Price cases
	Income	Energy price	Energy price
Deciding factors			
Ownership rate	yes	yes	no
Intensity of use	yes	yes	no
Efficiency	×	yes	yes

Restricted definition of price elasticity

Prices have an effect on the choice for more energy efficient systems and appliances, but can affect ownership rate and the intensity of use as well. For the base case simulation the same reasoning as for income is valid: all ex-post price effects can be taken care of by applying a complete set of structural variables. Given the extensive set of inputs for the period 1990-2000 it can be stated that all price effects in the base case have been taken into account (see Table 6.6). For that matter, the same applies for the rebound effect, the increased energy use due to cheaper energy services from highly efficient systems. However, in the simulated price cases the price effect is based only on energy savings, originating from the penetration of saving options. As Table 6.6 shows, no effect was considered for purchasing behaviour/ownership rate. According to Dubin and McFadden (1984) this can lead to an underestimation of the true value of the elasticity in the simulated price cases. The same applies for not taking into account a price effect on energy saving behaviour/intensity of use in the price cases.

With respect to purchasing behaviour, higher energy prices can prevent households from purchasing new types of appliances, resulting in less energy consumption than without a price increase. However, ownership rates are often compulsory; households need a dwelling with a boiler, a hot water system and a number of basic 'heavy' appliances (washing machine, refrigerator, cooking stove, etc.). Central ventilation units are standard for new dwellings. From the EnergieNed surveys it follows that the ownership rates of non-basic ‘heavy’ appliances are determined mainly by the household composition, life style and having a job. On the other hand many ‘luxurious’ appliances are coupled to income but do not use much electricity (electric tooth brushes) or the intensity of use is very low (electric lawn mower). For these appliances the running costs of electricity are very low compared to the purchasing costs. Moreover, according to Swichem (2000) people have a good knowledge about the purchasing price but not about the running costs of appliances during their lifetime; therefore people will base their decision to buy hardly on actual prices. Booij (1992) finds no influence of energy prices on the ownership rate of basic appliances, such as washing machines. A price effect is found only for two non-basic appliances, the dishwasher and the clothes dryer. However, given the socio-demographic trends that define the ownership rate in the long run, these appliances will reach their saturation level anyhow. For heating equipment Dubin and McFadden (1984) state that the long run price sensitivity of electricity is underestimated when the choice of equipment is not part of the analysis. However, it must be remarked that in the Netherlands important substitution possibilities, where a rapid change in ownership rates for gas or electric systems can occur, do not exist. All in all it can be said that prices have a limited effect on the ownership rate in the period of analysis.

With respect to the effect of prices on saving behaviour it is of importance that households are able to influence major parts of electricity consumption. In reality the intensity of use can hardly be changed, for example in the case of a refrigerator or a central ventilation unit. For gas the most obvious possibilities are a lower thermostat setting and less use of hot water, decreasing the intensity of use of the boiler system. However, the more technical savings are realised, the less the effect of changes in behaviour will be. For electricity the changes in behaviour with respect to lighting, washing and drying are of importance; contrary to other countries electric heating is absent in the Netherlands. Given the fact that according to Steg (1999) and Swichem (2000) households do not know the energy consumption of appliances or actual energy prices (see Daamen and Bos (2000)), this suggests not much influence of prices on the intensity of use.

The changes in behaviour owing to higher prices represent the instantaneous reaction to higher prices, known as the short-term elasticity. A number of regression analysis studies support the view of limited influence of prices on behaviour. Biermayr (1998) finds short-term elasticities near zero for hot water use and electric appliances, and a medium value for space heating. Low short-term elasticity values of 0.1 for gas and 0.05 for electricity are found in Booij (1992). This study also reports higher values for a regression case with a one or two year delayed price reaction. The delay is due to receiving the final energy bill up to a year after the price increase. However, this delay increases the possibility that another price reaction, the purchasing of more energy efficient systems or appliances, becomes part of the short-term price elasticity. In the cited regression studies this effect could not be single out. Even without delay it is possible that the one-year short-term elasticity contains some contribution of new more energy efficient appliances. Therefore the short-term elasticity values from regression analysis must be seen as an upper bound for the contribution of changes in the intensity of use to the total price effect.

Overall it can be concluded that the most important way for prices to influence energy consumption is via the choice for more energy efficient new systems or appliances, at least in the

Netherlands and over a longer time frame. The possible price effect on intensity of use is not relevant because the analysis does not regard short-term price reactions. However, ignoring the effect of price changes on ownership rates could mean that the elasticity values found in the price cases are somewhat too low.

6.7 Conclusions and observations

Simulation of past energy trends

It has been possible to simulate historic trends in household energy consumption in detail with the help of micro data from surveys and an adapted forecast model, using a cost/benefit evaluation of saving options and a vintage approach for the stock of energy using systems and appliances. The successful simulation of past trends enabled to analyse the effect on energy consumption of price changes, policy measures and combinations. All analyses dealt with household energy consumption in the Netherlands in the period 1990-2000. The price reaction is not comparable with short-term elasticity because no energy using behaviour is accounted for. It is not a long-term elasticity either because the period of observation is five to ten years. It can be best described as a mid- to long-term elasticity.

Price elasticity values and bottom-up explanation

With a modest price increase (+20%) the simulation results show a price elasticity of -0.13 for gas and -0.11 for electricity. One reason for the relatively low values, compared to literature, is the limited period of observation (5 or 10 years). In this analysis the full response to a price increase will be found only after the complete turnover of energy systems (10-30 year). For the same reason the 1995-elasticity values found are lower than that for 2000. The detailed analysis also shows that a limited number of saving options contribute to the price induced total energy savings. Given country and time specific sets of saving options this can explain why elasticity values, presented in literature, vary so much.

A five times higher price increase (+100%) leads to more energy savings, but not in proportion; the elasticity value found is one-third lower than in the +20% case. Bottom-up information shows a lack of saving potential that fits to high prices. In the period observed there are not enough options available that are expensive as well as very energy efficient. It can be concluded that the so-called law of diminishing returns appears to be valid too for substantial energy price increases over periods of less than ten years. A major price decrease (-50%) leads to lower energy savings, but again not in proportion. The elasticity value found is smaller than in the +20% case. The reason is that the market, sometimes forced by minimum standards, does not supply any more the old less energy efficient reference systems that fit to the very low prices.

The two price cases, which lead to the same but opposite change in incentive to implement more energy efficient options, show an asymmetric price reaction. At high price levels (new) saving options penetrate more than they lose ground with low prices. This is in accordance with other analyses where a price increase leads to more energy savings than the amount of savings, lost when prices go down. Once saving options have gained a market share, they keep their position, even with low prices, thanks to lower investment costs and the proven character of the option.

If the price is raised separately for gas or electricity the (own) price elasticity value is 10-20% higher than in the case with both energy carriers being more expensive. The cross-elasticity values are rather low. Some substitution takes place between gas and electricity used for hot water supply. But it is absent in space heating due to the fact that direct electric heating and electric heat pumps are too expensive in the Netherlands. This indicates that cross-elasticity values are very dependent on actual possibilities to shift between gas and electric systems.

Price elasticity and policy measures

Simulation of past energy consumption was performed too for combinations of higher prices (+20%) and three important policy measures for the period 1990-2000:

- standards on gas use of new dwellings,
- subsidies on investment in most saving options,
- a regulatory tax on gas and electricity from 1996 on.

The simulation results indicate that the elasticity value in the case without policy measures can be 30-40% higher than in the case with all measures present. For gas the elasticity value increases most when standards are absent; for electricity subsidies and taxes are more important. Given an enduring application of present policies in the Netherlands the elasticity values, found in statistical analyses, will probably further decrease in the future.

The interaction between the effects of higher prices and subsidies, or higher prices and taxes, was analysed into more detail. In the model these combinations affect the cost/benefit ratio of saving options; the ratio in turn determines the penetration level of saving options in a non-linear manner. For saving options in the ‘take-off’ phase the presence of subsidies or taxes enhances the effect of higher prices; in case of an ‘saturation’ option the opposite is the case. In the grown-up case in between there is no interaction. Therefore the total influence of taxes or subsidies on the elasticity value depends on the ‘stock’ of saving options.

The meaning of the price elasticity

The range in observed values of the price elasticity can be attributed to:

- length of the period of observation,
- size of the price increases,
- presence of policy measures at the same time,
- composition of the stock of saving options,
- substitution between energy carriers,
- specific factors of the country observed.

The first factor is known very well from literature and confirmed by the analysis; for a longer period a higher elasticity value is found because of the lagging response to a price change. The simulations show that for a large price increase a saturation-effect occurs due to exhaustion of saving options (in a period up to ten years). The third factor has hardly been recognized in elasticity studies as an important issue. The simulation results indicate a substantial interaction between policy measures and elasticity values; that interaction probably will increase in time. The fourth factor is introduced here as a new explanation for the large variations in elasticity values found. The fifth factor is accounted for in literature by the cross price elasticity between energy carriers; it proves to be very dependent on actual substitution possibilities between gas and electricity. The last factor mentioned has not been looked after; this demands a comparable analysis for a number of different countries. Altogether elasticities should be seen as entities which are dependent on the specific circumstances. When historical elasticity values are used in forecasts one should take proper account of the influence of policy measures as well as the ‘supply side’, meaning the availability of saving options.

Observations for policy

From the low price elasticity values in economic literature one may conclude that higher prices will have only a minor effect on energy consumption in the future. Moreover increasing incomes will compensate these gains, especially for electricity. From an economic viewpoint limited possibilities seem to be available for a structural decrease in household energy consumption. However, it was concluded already that observed price elasticity values probably do not represent any more the real relationship between energy use and higher prices. Secondly, low price elasticity values should not be seen as an unchangeable property of the energy-economic system but as a signal that there is a lack of saving options that give households the opportunity to respond to higher prices. This problem can be overcome by a further intensification of R&D-policies to continuously create new saving options. Thirdly the effect of prices can be strengthened by policy measures that reinforce the price response. Energy labels for appliances are a good first step in providing cost information at the right time and place in the right form. Specific subsidies for saving options in the take-off phase can enhance the effect of (higher) prices. In case of temporarily low prices a tax can provide the minimum incentive to invest in proven saving options. Lastly, the successful household energy efficiency trend in the Netherlands shows that gas consumption can be stabilized and growth of electricity consumption restricted, even with rather low prices and low observed price elasticity values. Both from analysis and practice a more optimistic view on the possibilities for energy savings in households emerges than follows from the economic view given above.

Appendix 1

Energy functions, driving factors and energy systems

Energy functions and driving factors
The demand is divided into seven so-called energy functions (see Table A.1). The demand for space heating and hot water is expressed in the form of heat; for the other functions a demand for electricity is specified. The demand for every energy function is related to one or more driving factors (see second column). The demographic trends are the most important general driving factor; the number of households determines the total number of dwellings and, for all ‘basic’ appliances and energy systems, the total number deployed. For space heating the composition of the stock of dwellings is important; to describe developments, the stock is split into 14 types. Important social factors, with respect to energy consumption per household, are the decreasing number of persons per household, and the increasing fraction of older people. The first trend decreases energy consumption for most energy functions; the second factor increases energy use for heating. To describe trends, households are split into three or ten types, based on age and composition of the household. Examples of life style factors are the increased use of showers by younger people and the decrease in home cooking activity. The influence of economic factors is represented by (increasing) penetration rates for non-basic appliances (see discussion section).

Energy systems and appliances
The demand per energy function is met by deploying a number of energy using systems or appliances (see third column). For space heating, dwellings are defined as a system as well; the combination of a dwelling, with more or less insulation, and a, more or less efficient, heating system provides for the need for a comfortable living space. Hot water can be supplied by a combi-boiler, which delivers both space heat and hot water. For hot water and cooking a choice between gas and electricity can be made. In these cases substitution between gas and electricity is possible. The compact fluorescent lamp (CFL) is an alternative for the standard bulb. All devices that consume more than 1% of total electricity use are modelled separately. The very great number of appliances with a low utilization rate and/or ownership rate, for instance portable ICT, is taken together as ‘miscellaneous’. In 2000 these consume 5% of all electricity for households.

Table A.1 Energy functions, demand driving factors and systems/appliances

Energy function	Demand driving factors	System/Appliance
General	Number of households/dwellings	
Space heating	Type of dwelling and central of local heating (14 types), occupation rate, etc.	Dwelling Boilers or heaters Central ventilation units
Hot water	Household size and age (10 types) and life style	Geysers Combi-boilers
Cleaning	Household size (3 types)	Washing machines Clothes dryers
Cooling (food)	Household size (3 types) and life style trends	Refrigerators Freezers
Cooking	Household size (3 types), life style trends and gas connection	Stoves and ovens Kitchen appliances
Lighting	Household size (3 types) and life style trends	Conventional light bulbs Compact Fluorescent Lamp
Other appliances	Household size or composition	Audio/video/computer Waterbed/electric blanket

Appendix 2

Saving options period 1990-2000

From the 90 saving options in the original model only 64 are of interest for the period 1990-2000. A number is left out because of a very low contribution; others, like double glass for the living room and double glass for the sleeping room, are combined. This results in 24 saving options presented in the Table A.2. The cost/benefit ratio is valid for the actual situation in the period 1990-2000. The costs are equal to the extra investment with regard to the reference system, times an annuity factor; this factor is calculated on the basis of the lifetime of the system and an interest rate of 8%. The benefits are equal to energy savings times energy price. For 1995 the price is the average value in the years 1990-1995, and for 2000 that of the years 1995-2000. The range in the CBR originates from different applications of saving options, for instance a low or a high heat demand for energy efficient boilers, and from changing energy prices and increase in efficiency parameters as well.

Table A.2 Cost/benefit ratios of selected saving options for 1990-2000

	Saving options	CBR-range	Remarks on range
	STATE-OF-THE-ART		
1	Double-glazing (existing dwellings)	0.5-2	Living/sleeping room, combined with renovation
2	Roof insulation (existing)	0.7-0.9	Existing dwelling
3	Wall insulation (existing)	0.2-1.4	Cavity/outside
4	Floor insulation (existing)	1.0-1.2	Existing dwelling
5	VR-boiler (improved efficiency)	0.3-1.6	Low/high heat demand
6	HR-boiler (high efficiency)	0.4-2.2	Low/high heat demand
7	Gas stoves/geyser	0.4-0.8	
8	Electric boiler to gas-combi	1.0-1.6	Low/high hot water use
9	Hot water savings	0.3-0.4	Excluding savings on cost of water use
10	New energy efficient appliances	0.0-0.2	
	BREAK-THROUGH		
11	Low-E glass (existing dwellings)	0.3-0.5	Living/sleeping room
12	HR-107 boiler (max. efficiency)	0.5-2.3	Low/high heat demand
13	Efficient combi-boiler	0.3-0.8	Low/high heat demand
14	Heat recovery (new dwellings)	2-3	Year of installation
15	Efficient appliances	0.1-0.6	
16	Efficient lighting	0.3-1.4	Intensity of use of lamp
	ADVANCED		
17	Extra insulation (new dwellings)	1.2	
18	Triple glazing, new dwellings	5-9	Living/sleeping room
19	Heat recovery (old dwellings)	5	
20	Max. energy efficient gas-combi	0.7-1.3	Low/high heat demand
21	Electric heat pump	2-5	Normal/special tariffs
22	Gas-heat pump	3-6	Low/high heat demand
23	Gas-clothes dryer	0.4	Gas supply close at hand
24	Hot-fill options	0.8-1.0	Cloth/dish-washer

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Chapter 7 SYNTHESIS OF IMPROVEMENTS

7.1 Approach taken

In the introductory chapter, the goal of this thesis has been formulated as: *“to provide improved methods to analyse and explain energy trends and energy savings achieved at national and sectoral level, taking into account specific needs of policy makers*. In the problem formulation a number of research questions, relating to problems and issues in the evaluation of energy savings, was formulated (see Section 1.5). Addressing these questions should contribute to improved evaluation practices. The research questions were grouped according to four themes:
A. Improved methods for monitoring and evaluating energy savings achieved.
B. Interaction in calculated energy savings effects and contributions of policy measures.
C. Presentation of evaluation results in a form that meets information needs of policy makers.
D. Explanation of the causes of observed total and policy-induced energy saving trends.

In following Sections 7.2 trough 7.5, for each theme the research questions are addressed. The resulting improvements of evaluation methods are highlighted too, referring to the preceding Chapters 2 to 6 of this thesis. However, the improvements are described in such a way that the synthesis presented here is comprehensible on its own. A few research questions not covered in the preceding Chapters 2 to 6 are addressed in Section 7.6.

The preceding chapters contain descriptions of four newly developed evaluation methods:

- the PME-method (Protocol Monitoring Energy savings, Chapter 2),
- reconstructing energy balances method (MONIT, Chapter 3),
- simulation of historic household energy use (Chapters 4, 5 and 6),
- a matrix-method to investigate interaction between policy measures (Chapter 5).

The contributions of these methods to improvements are summarized in the final Section 7.7.

7.2 Improved methods for monitoring and evaluating energy savings achieved

In the problem formulation the overall problem for this theme was formulated as: “*How can existing calculation methods on energy savings at national and sectoral level be improved as to provide meaningful results, calculated in a consistent and transparent manner?”* A number of improvements will be presented and elucidated following the research questions formulated for this theme.

A.1 What aggregation level and which reference variables must be chosen as to construct reference energy consumption?

This research question regards methods to analyse national and sectoral energy trends and savings, among which decomposition methods (see Chapter 2 of this thesis). Energy savings have been defined as the difference between calculated reference energy consumption and actual energy consumption. Thus, to calculate savings, the trend for reference energy consumption must be determined. This trend depends on growth in socio-economic activities and structural changes, i.e. shifts between energy-intensive and energy extensive activities. Without structural changes the trend for reference energy consumption is in conformity with that for an aggregated growth variable. At national level GDP often is used as the growth variable; leading to national reference energy consumption (see Figure 7.1). To take account of structural changes, total energy consumption is split into five components related to the sectors industry, agriculture, services, transportation and households. For each sector the development of reference energy consumption is determined using a relevant growth variable (for instance: value added in industry). The sum of sectoral reference energy consumptions will differ from that according to GDP growth; this difference represents the sectoral structure effect (see Figure 7.1). It is also possible, and often necessary, to disaggregate energy consumption and sector activities further. Examples are the subsectors in industry, or transportation of persons versus transportation of freight in the transport sector. Further disaggregation can lead to a total reference energy consumption that differs from that found for the higher aggregation level, thus indicating additional structure effects. The emergence of additional structure effects means that the total structure effect found will be dependent on the level of disaggregation applied. The reference energy consumption, found at the lowest aggregation level applied, defines the energy savings (see Figure 7.1). Therefore one should be aware that the calculated energy saving effect also depends on the aggregation level applied in the analysis.

In Chapter 2 this aggregation dependency of calculated energy savings was illustrated for an industry case. Total industrial energy consumption was disaggregated to four different levels. At each level the structure effect and energy savings were calculated, using value added as indicator of growth in activities. It appeared that calculated energy savings first increased with lowering the aggregation level. However, at the lowest level calculated energy savings were almost equal to that at the next higher aggregation level. This example shows that shifts in total industrial value added that occur between parts of industry must be dealt with into sufficient detail.

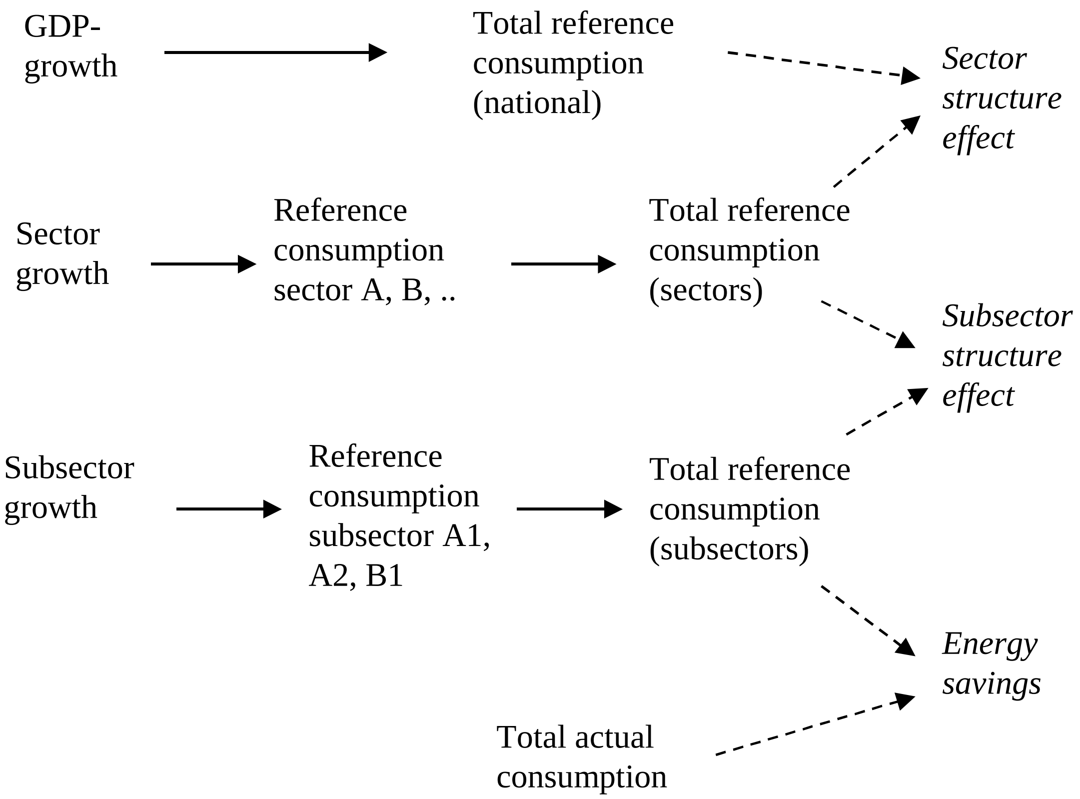

Figure 7.1 Structure effects and energy savings derived from reference (energy) consumption at various aggregation levels and actual (energy) consumption

For an industrial sub-sector the energy intensity, defined as the ratio between energy use and value added, can be interpreted as the product of the ratio ‘energy use per unit of physical production’ (known as Specific Energy Consumption or SEC) and the ratio ‘physical production per unit of value added’. It shows that a change in the ratio between physical production and value added (called dematerialization) affects the energy intensity. To take account of dematerialization when calculating energy savings, trends in physical production instead of value added should be used in determining reference energy consumption (see Figure 7.2). The reference consumption based on physical production differs from actual energy consumption, providing energy savings. The difference with reference consumption based on value added trends shows the dematerialization effect. In this way calculated energy savings are not influenced by dematerialization effects. This approach demands an aggregation level that must be at least such low that a suitable physical variable is available to construct reference energy consumption in a reliable way.

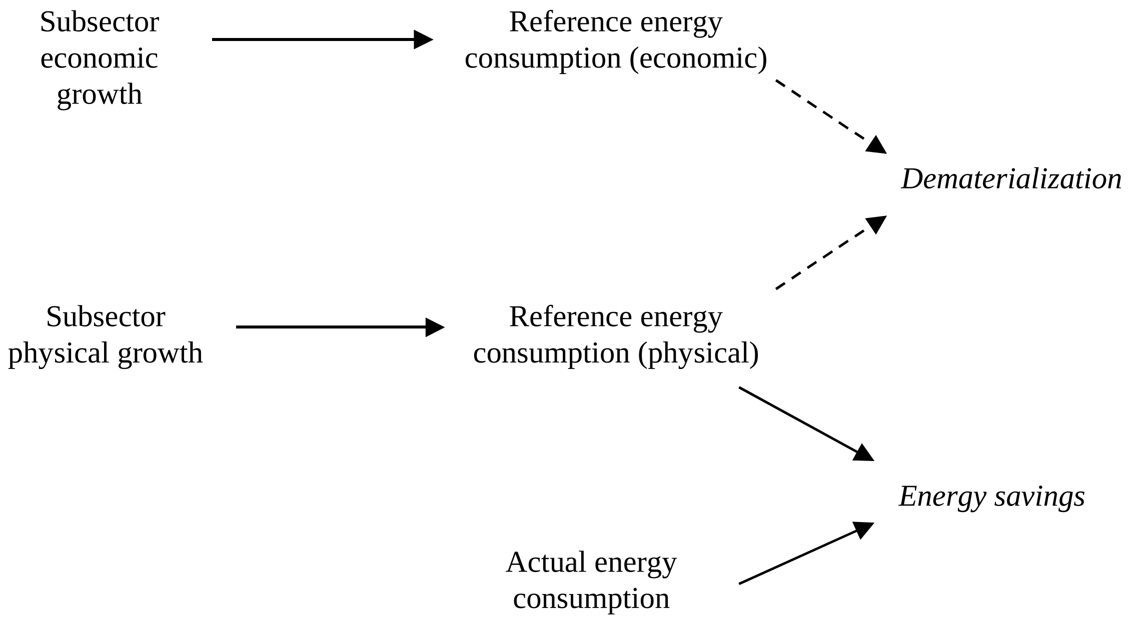

Figure 7.2 Determination of dematerialization and energy saving effects in industrial subsectors, applying economic and physical production variables to construct reference energy consumption trends

In Chapter 4 it is shown for Dutch households that the change in reference energy consumption (excluding energy savings) from 1990 to 1995 is the result of a great number of structural changes. Examples are increased gas use due to a shift from local to central heating, less gas use owing to a lower occupation rate of dwelling (because of increased labour market participation of women) or increased electric cooking in dwellings with grid supplied heat. Almost all structural changes stimulate energy consumption; therefore a more detailed analysis, taking into account extra structural changes, leads to higher calculated reference energy consumption. As the difference with actual energy consumption defines energy savings, in this case higher calculated savings result from more detailed analysis. In Chapter 2 it is shown that these savings prove to be substantially higher than in the case where only the increase in number of households is used to determine reference energy consumption. Thus, at high aggregation levels the calculated saving effect is mixed up with many structure effects.

The experiences described show that a lower aggregation level often will provide more reliable saving results. From the household example it must be concluded that sometimes very low aggregation level are needed, up to the level where specific energy systems and saving options can be discerned. In production sectors the chosen aggregation level should enable the use of physical production quantities, as to capture dematerialization effects. In other cases the minimum disaggregation level will depend on the diversity in energy intensity of activities or important changes in energy applications. For instance in the service sector a distinction can be made between offices with or without air conditioning to capture the structural effect of this application on energy consumption. The use of appropriate driving variables to calculate reference energy consumption can define the disaggregation level too. For instance, for offices a distinction between appliances and heating should be made, as the energy trend for the first can be coupled to number of employees, and that for the second to amount of floor space. Generally speaking the choice of aggregation level and the choice of quantities to construct reference energy consumption coincide.

A.2 Which energy quantity should be used, that both meet demands of sound calculation and presentation of meaningful results?

In Chapter 2 three choices are given for energy quantity to be used in evaluations for end-use sectors:

- Energy consumption, the total energy content of all delivered energy carriers.
- Primary energy consumption, taking into account the losses in conversion and distribution for each energy carrier delivered.
- Final energy demand, in end-use forms, such as heat, electricity and feedstocks.

In Figure 2.3 the relationship between these quantities is illustrated.

On the one hand it can be argued that primary energy consumption should be used because it presents a more realistic view of the burden on the energy supply system for energy carriers such as electricity. Another, more practical, reason is that realised energy savings from cogeneration at end-users site do not show up in plain energy consumption figures. Actually, energy consumption of end-users will increase in case of own electricity production with cogeneration. However, when primary energy consumption is analysed, it proves that the avoided fuel use in central power production owing to cogeneration exceeds the extra fuel consumption for end-users.

On the other hand it can be argued that final energy demand should be used, because it is a more appropriate quantity when defining a relationship between energy use and socio-economic needs. Households do not need delivered gas but the heat it provides for space heating. In industry part of fuel consumption is not needed in processes, but used in own cogeneration units to cover the need for electricity. Therefore, final demand for energy instead of energy consumption should be used in the analysis. Moreover, demand for heat and demand for electricity are based on quite different socio-economic factors. Thus final demand must be split into the end-use forms heat and electricity, each coupled separately to socio-economic trends. In some energy-intensive industry sectors ‘feedstocks’ constitute a third type of final demand. In Chapter 2 of this thesis it was illustrated that constructing reference trends, using final energy demand, leads to savings that differ from the results obtained when using delivered energy carriers (energy consumption).

The two preferences with regard to energy quantity seem to conflict. However, the proposed energy quantities can be combined into ‘final demand for heat and electricity, both expressed in primary units[14]. In Boonekamp (2004) it is described how this approach is applied throughout the analysis of realised energy savings in the Netherlands.

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[14] It is common practice to transfer energy consumption of end use sectors to primary energy consumption. However, here all energy quantities for end users are transferred to primary equivalents, including final demand. To avoid terms such as ‘primary final demand for electricity’ the phrase ‘expressed in primary units’ is used here.

A.3 In case of primary energy consumption, which calculation approach must be chosen (static or dynamic) and which factor to convert electricity use (average or marginal)?

To obtain energy consumption figures expressed in primary units, the consumption per energy carrier is multiplied by a so-called primary multiplication factor representing conversion losses in the energy supply sector. E.g. electricity consumption of end-users is multiplied by a primary multiplication factor of 2.5, in case electricity is produced with 40% conversion efficiency. A choice must be made between 'static' or 'dynamic' primary multiplication factors. In the latter case primary energy consumption is calculated, using the conversion efficiencies of energy supply for the actual year. In the former case the conversion efficiencies of the base year are applied (see Chapter 2 of this thesis). The static approach has the advantage that observed trends only show developments for end-users. The results are not mixed up with the effect of changing conversion efficiencies at the supply side. However, the dynamic approach provides the ultimate energetic effect of end-use savings, including the effect of changes in supply efficiencies.

In Chapter 3 of this thesis it is described how the MONIT evaluation system combines the two methods. In MONIT the energy balance for a chosen year is reconstructed in a number of steps, starting from the energy balance of the base year. In each step changes owing to different factors (GDP growth, structural changes, efficiency improvements and substitution between energy carriers) are calculated. In this way the total change in energy consumption over a period is decomposed into a number of contributions, among which various energy saving effects. Figure 7.3 shows the mutations in total primary energy consumption for services in the Netherlands from 1996 to 1997. In the first seven steps developments for end-users have been processed. All resulting changes at end-users are transferred to changes in extraction or import, using the base year supply system properties. Therefore changes in use of energy carriers lead to proportional changes in primary energy consumption. For the eight contributions (including energy savings) this means that a 'static primary energy' approach has been applied. The contributions are not mixed up with energetic effects of changes in energy supply. In the last six steps developments in energy supply are processed (keeping the figures for end-users unaltered). The changes in supply lead to new values for the primary multiplication factors, and thus to mutations in primary energy consumption figures for end-users. The combination of static results and additional mutations provides the dynamic results. The figure shows that for services the mitigating effect of final energy savings ('savings end-use') is enhanced by the efficiency gains in energy supply ('CHP E-sector' and 'Efficiency E-sector'). With respect to the research question it can be concluded that both the static and dynamic calculation approach should be applied to meet the evaluation needs. The MONIT evaluation system shows that it is possible to combine the two approaches.

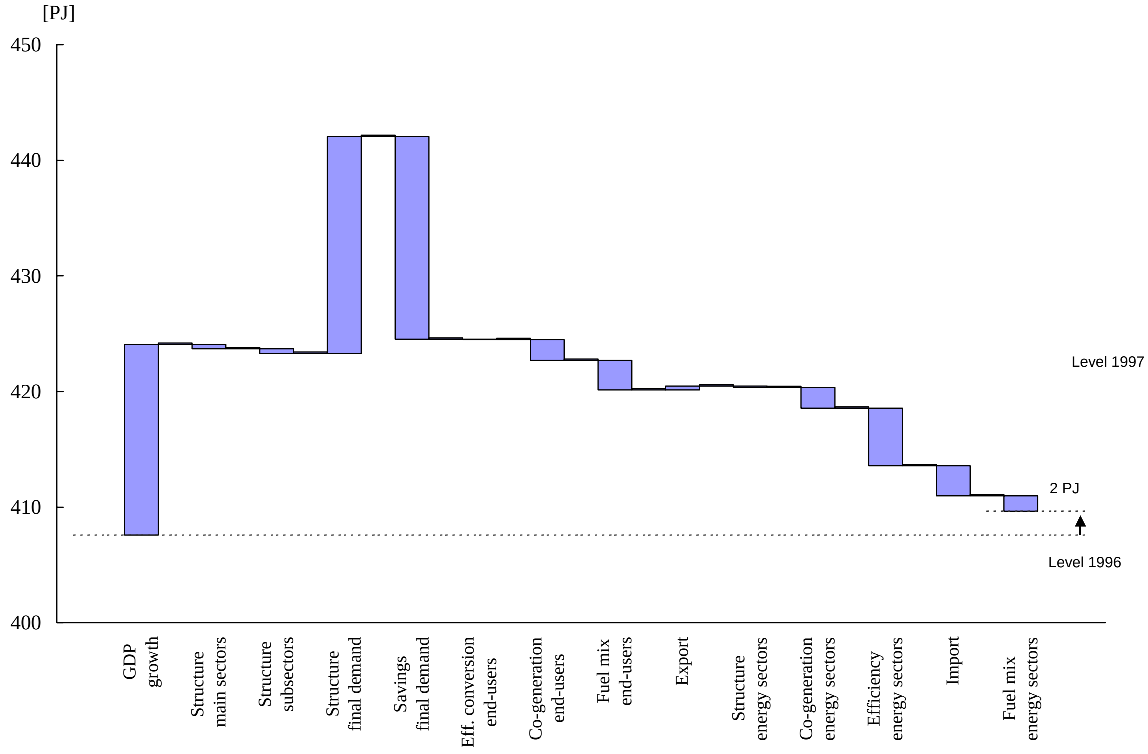

Figure 7.3 Decomposition of the observed change in primary energy consumption of the service sector in the Netherlands, from 1996 to 1997

The MONIT evaluation system uses average values for primary multiplication factors which are based on the composition of the overall supply system. Implicitly this assumes that changes in energy consumption of end-users would result in up- or downscaling of energy supply in line with the existing properties of the system (either in the base year or the current year, depending on a static or dynamic approach). For savings on electricity, expressed in primary units, this supposes that without savings all plant types would have produced extra electricity with unaltered conversion efficiency. However, this assumption is not always realistic as, for instance, some plant types are restricted in capacity or operating hours. It is also possible to suppose a specific alternative for electricity savings, for instance a combined steam and gas turbine with a higher than average conversion efficiency. In this 'marginal efficiency' approach the electricity savings expressed in primary units should be rated lower than for the 'average efficiency' approach. However, the marginal efficiency approach introduces uncertainty in the saving results, as in most cases it cannot be proven that the chosen alternative for electricity savings would (not) have been build. Moreover, consistency is lost between calculated end-use savings, using marginal electricity production efficiency, and calculated savings in electricity production, using average efficiencies per type of power plant. The marginal efficiency approach can be used quite well in scenario studies where the choice of new power station is part of the scenario building. It is concluded that, in case of evaluation of trends in the past, the use of average conversion efficiency values for energy supply provides in general more consistent and less arbitrary results.

A.4 How can indirect CO_2 emissions from electricity use be determined in a consistent manner as to the primary energy consumption approach?

In Chapter 3 it is described how the MONIT system calculates CO_2 emissions from energy consumption data, using a fixed emission factor per energy carrier. The emission reduction owing to energy savings can be calculated right away too. However, non-fossil fuel energy carriers, such as electricity, do not emit CO_2 at the place of utilization. Therefore, calculated emissions for end-users only regard so-called direct emissions from fuel use, and not the indirect emissions from electricity use. As a consequence emission reductions obtained by savings on electricity are not counted. These savings do cause indirect emission reduction because less fuel is used in power stations though.

The detailed energy balance approach in MONIT enables the calculation of indirect emissions that result from the use of electricity by end-users. To this end the calculated total emission of power stations is attributed to total delivered electricity. The resulting emission factor per unit of delivered electricity is used to calculate the indirect emissions for end-users. Emission reductions owing to electricity savings now show up as lower indirect emissions. The calculation of indirect emissions resembles the way in which conversion losses in energy supply are incorporated in primary energy consumption of end-users (see question A.3). The resemblance is maintained for the static and dynamic calculation approaches described earlier. In MONIT the observed changes in total emissions for end-use sectors are decomposed into the same contributions as valid for energy consumption. The first half of contributions represent the static approach, where only developments for end-users matter. Here, the indirect emissions due to electricity use are calculated with an emission factor that is valid for base year electricity supply. The last part of the set of contributions regards additional emission effects related to developments in energy supply. Here, increases in conversion efficiency and changes in fuel mix are of importance for the dynamically calculated emissions of end-users.

With respect to indirect emissions of electricity another choice should be made, namely how to treat emissions related to imported electricity. In MONIT emission factors for electricity are calculated in two ways. One calculation method assumes that imported electricity is CO_2 free, in conformity with international accounting rules of IPCC. According to this method the emission factor for electricity has decreased in recent years owing to substantial extra electricity imports. As a consequence electricity savings contribute relatively less to reduction of CO_2 emission. This method resembles the way how primary energy consumption for end-users is calculated, as in MONIT no conversion losses are attached to imports of secondary energy carriers. The other calculation method supposes that imported electricity has the same emission factor as inland production. Now electricity savings contribute fully to emission reduction, as it is assumed that these savings decrease inland electricity production. This calculation method for emissions resembles the way in which electricity savings are taken into account in the Netherlands. According to the Protocol on Monitoring Energy savings (PME, see Chapter 2) electricity savings are rated as if they decrease inland electricity production only.

It can be concluded that it is possible to calculate indirect CO_2 emissions of electricity use and primary electricity consumption in a consistent manner. However, it must be concluded too that the IPCC approach for dealing with CO_2 emissions of imported electricity is not consistent with the present national approach for determining energy savings achieved.

A.5 How to assure an integrated and consistent calculation of sectoral results?

Evaluations of energy trends and energy savings focus on the national level and/or the sectoral level. When evaluating changes in energy consumption or CO_2 emissions for a specific end-use sector only, consistency with other sectors and with the national level must be maintained. This can be attained by using a common set of results from a national calculation scheme. For instance, evaluations of industrial energy consumption trends regard savings on electricity consumption and savings achieved by cogeneration. In both cases information on trends in conversion efficiency of central power production is needed, as to calculate the saving effect in primary energy units. Actually, as the results in Figure 7.3 show, changes in the fuel mix of power plants and changes in electricity imports should be account for as well in sectoral evaluations. The same reasoning applies for evaluations of CO_2 emission trends per sector.

Another way to deal with the consistency issue is the integration of sector results in a national calculation structure, like MONIT. However, this means that the format of sectoral results must meet that of MONIT. In Chapter 4 it is shown that total household energy savings can be calculated into great detail using a simulation model with a vintage approach for energy consuming systems and incorporation of all actual saving options. Separate energy saving figures are available for final demand for electricity or heat, and for more efficient conversion of various energy carriers. Moreover, information on energetic effects of substitution between energy carriers and various structural changes is available. Generally speaking, in case of sectoral evaluations with sufficient detail, supplying results in the appropriate national format does not pose a problem. However, in some sectoral evaluations in literature only total energy consumption is regarded, e.g. Doblin (1988), or separate figures on final energy savings are not presented, e.g. Schipper (2001), preventing a sound transfer of results to the national level.

As to integrate sectoral results into the national level, sector studies on realised energy savings should at least make a distinction between savings on final demand for heat and final demand for electricity. Saving a unit of electricity has quite different energetic effects at national level than saving a unit of heat (using fuels). Without this distinction it is not possible to calculate the energy savings in primary units or the total effect on CO_2 emissions. Preferably the saving effect of more efficient conversion per fuel type should be provided separately. This prevents the mixing of energetic effects of fuel substitution and more efficient fuel conversion. It is not always necessary that sector evaluations provide energy saving figures obtained by cogeneration. For consistency reasons it is even preferable to do this at national level, as savings of cogeneration are strongly dependent on the characteristics of the electricity production system, applied in the calculation (see description of choices to be made for research questions A.3 and A.4).

A.6 How to increase transparency between energy statistics used and results presented?

Evaluation studies often use processed statistical data on energy use. One reason for processing data is that so-called climate-corrections are needed because of yearly variations in outdoor temperature during the heating season. Another reason can be that formats of evaluation study and statistics do not fit. However, in many publications it is not clear whether the data sources applied are based on higher or lower heating values for the energy content of fuels used, or which part of energy use is climate-corrected. Moreover, historical data are often updated, especially the preliminary figures for most recent years that determine the calculated results for a great part, when studies focus on changes over a period of time. As a consequence, often it happens that results of an evaluation study cannot be traced back to the original data used. For every data update a new study is needed to show the influence of data updates on evaluation results presented earlier.

Another issue regards data outside the direct scope of the study, having an impact on the results. In case of evaluation of energy savings for end-users, data on energy supply are needed to calculate primary energy consumption. In case national emissions are evaluated, data on energy imports are needed (see question A.4). These supplementary data often are available only as processed data, for instance average conversion efficiency for electricity production.

The description of the MONIT evaluation system (see Chapter 3) shows how the decomposition approach is applied to energy balances in standard format. The processing of the original statistical data and the decomposition analysis are integrated in one system, based on a set of actual and constructed energy balances. The processed data, e.g. temperature corrections, become available for general use in the standard energy balance format. The step by step reconstruction of actual energy balances, starting from the base year balance, provides for intermediate balances from which changes in energy consumption can be decomposed, showing the impact of the various contributions. The decomposition regards all recognized and well-defined (combinations of) economic sectors and energy carriers.

A way to reach maximum transparency with regard to the connection between statistics and evaluation results is to integrate the original energy balances into the evaluation system. It can be concluded that in such a system the effect of updated statistics on the results can be determined rather easily. Moreover, because complete energy balances are available, it is always possible to trace back how additional inputs, such as average conversion efficiency of electricity production, have been determined. If only part of energy balance statistics is used, it is still worthwhile to lay down how the data have been extracted from the original and complete energy balances.

A.7 How to correct energy statistics for yearly variations in outdoor temperature?

Figures on energy consumption, as reported in energy statistics, are influenced by stochastic yearly variations in climate, for instance relatively warm winters that decrease energy consumption for space heating. Evaluations of energy trends and savings focus on man-made changes in energy use and energy savings. Therefore, statistical data on energy consumption must be corrected for these yearly variations. The climate-correction involves three issues:

- Which type of energy use is dependent on temperature variations?
- How is the temperature variation defined?
- Which fraction of energy use must be corrected?

In the Netherlands only natural gas use was corrected for temperature variations in the past in conformity with Wieleman (1994). Although natural gas is by far the most important fuel for space heating, this approach omits corrections for grid delivered heat. In MONIT (see Chapter 3) temperature corrections regard all energy carriers used for space heating in end-use sectors. This approach compares with international evaluation studies, such as IEA (2004).

The corrected MONIT-figures are also applied in the calculations of realised energy savings in the Netherlands, using the PME-method (see Chapter 2).

Another type of temperature dependent energy consumption is electricity use for air-conditioning. In countries with moderate summer temperatures, like the Netherlands, this type of energy consumption is still limited (in offices) or nearly non-existent (in dwellings). In IEA (2004) no climate correction is applied for space cooling, although it is recognized as a major growth factor for electricity consumption internationally. Therefore, this type of energy use can de disregarded for the moment in evaluation studies but this may change in the future.

Generally, the temperature variation regards the yearly variations in outdoor temperature during the heating season, expressed in so-called degree-days. Each day with an average temperature below 18°C contributes to the number of degree-days. In most studies the variation is defined as the ratio between actual degree-days and the fixed 30-year mean value for 1960-1990. This is true as well for the evaluation methods presented in this thesis.

Other definitions of temperature variations are applied too. Up to 2004 in MB-RIVM a yearly shifting 30-year average was used as the reference to rate the actual degree-days. Due to many ‘too warm’ years since 1990 the reference number of degree days decreased in the Netherlands. Therefore, the figures for historic energy consumption and related CO_2 emissions were corrected to a lesser extent than done in this thesis. Recently, a long-term decreasing trend for degree-days due to climate change has been assumed, both for past and future years (see National Reference Outlook for the Netherlands in Dril (2005)). Yearly variations are defined as the ratio between actual and climate trend degree-days. The resulting temperature corrections for past years are much lower than according to the method used in this thesis. For instance, the correction for 2000 almost disappears, as this ‘too warm’ year fits to the structural trend assumed. However, both the incorporation of recent ‘too warm’ years and the climate trend fall outside the scope of evaluation of man-made changes in energy consumption.

The fraction of energy consumption that is used for space heating differs strongly between end-use sectors, as Wieleman (1994) shows for the Netherlands. Contrary to this source, these fractions can change from year to year in the MONIT approach (see Chapter 3). For the industry, energy use for space heating is coupled to the number of employees that need a heated working space. For households the fraction of fuel use devoted to space heating is taken from a detailed simulation over the period 1990-2000 (see Chapter 4). These results show that the fraction of gas used for space heating decreases continuously, partly owing to relatively large energy savings for this application. Climate-corrections for end-users may affect energy consumption of energy supply sectors. In MONIT the corrections on energy consumption of end-use, in PJ’s, are transferred into changes in the energy supply sector, and ultimately result in changes in import or extraction. In Wieleman (1994) fixed fractions were applied to correct gas use of energy supply sectors, irrespective of the amount of correction for end-users.

It is concluded that in evaluations on energy trends and savings the climate corrections should regard energy use for space heating. In the near future also corrections to energy use for space cooling are needed. Corrections should be made to all relevant energy carriers, and the fractions of energy consumption to be corrected should be year and sector dependent. When calculating the correction, the actual degree-days must be related to a fixed 30-year historic average, as to eliminate all climate influences on energy consumption.

7.3 Interaction in calculated (policy-induced) energy saving effects

With respect to the second theme in this thesis the problem was formulated as:
How to deal with various interaction effects in the calculation of total energy savings and policy-induced energy savings? This will be elaborated on by addressing the research questions formulated for this theme.

B.1 How can interaction between various energy saving effects be dealt with?

In Chapter 2 three types of interaction are described for respectively:

- combinations of two end-use saving options,
- savings on electricity use and efficiency improvements in electricity production,
- savings achieved by cogeneration and efficiency improvements for conventional electricity and heat production.

An example of the first type, is the interaction between the saving effects of better insulation and that of more efficient boilers for dwellings. After insulation of the dwellings heat demand will be lower. Therefore, the energy savings owing to the higher conversion efficiency will be lower than without insulation. Thus the separately calculated savings of both options will not sum up to the combined savings. The need for taking into account this kind of interactions depends on the level of analysis. In the detailed simulation of households energy use, presented in Chapter 4, the interaction is dealt with by first calculating realised savings owing to better insulation, and than calculating the saving effect of high-efficiency boilers (starting from the heat demand after insulation). However, the evaluation method also permits calculation with the opposite sequence, resulting in a different split of the realised savings. In most decomposition analyses a higher aggregation level is applied, for instance gas use for space heating per dwelling. In this case calculated gas savings regard by definition the combined effect of various saving options. Thus, in decomposition analysis with a sufficiently high aggregation level, interaction between two end-use saving options will be accounted for automatically.

In the second case, the energy saving effect of electricity savings is calculated using a given conversion efficiency for electricity production. The energy saving effect of more efficient power plants is calculated for a given electricity consumption (and total production). Both saving effects do not add up to the combined result (see Table 2.8). Decomposition methods correct the two separate effects in such a way that they fit the combined saving effect (see overview in Ang (1995)). Although arithmetically handsome, most developers of various algorithms do not take a formal view on the right calculation of both saving effects. Again, an approach can be to use a calculation sequence. For instance, one first calculates the effect of electricity savings on primary energy consumption, using the base year power station efficiency. Then one calculates the effect of increased conversion efficiency of power station, on primary energy use, based on actual electricity production (including realised savings for end-users). This approach is applied in Boonekamp (2001), the Protocol on Monitoring Energy savings, in conformity with policy evaluation practices. In the MONIT evaluation system this method is applied too (see Chapter 3).

The calculation of energy savings achieved by cogeneration are complicated by the fact that both the reference systems for electricity (conventional electricity production) and for heat (conventional boiler) can change as to their conversion efficiency. In MONIT the analysis of changes in cogeneration production is one step in the process of decomposing the observed change in energy consumption (see Figure 7.3). The calculated cogeneration savings depend on the current values for the two reference systems at this step. In the standard sequence of steps the calculation uses actual boiler efficiency and base year central electricity production efficiency (see Chapter 3). However, this sequence can be changed according to the needs of the user of the results. According to the Protocol on Monitoring Energy savings for the Netherlands, cogeneration savings are determined with the base year characteristics of the two reference systems (see Boonekamp (2004)). In scientific literature no other decomposition studies have been found that make a distinction between cogeneration and end-use, when analysing total energy consumption of end-users. In that case the savings obtained by cogeneration cannot be presented separately. Other studies only regard final energy consumption, without cogeneration at the site of end-users, e.g. Odyssee (2003). In that case cogeneration savings are part of total efficiency gains in energy supply. In both cases the aggregation level used in the analysis does not permit an investigation into interaction effects.

To summarise, interaction between the saving effects of various saving options can be dealt with by applying either standard attribution rules (decomposition algorithms) or a calculation sequence. Actually, both methods are more or less arbitrarily, and will therefore raise continued discussions. In case the aggregation level in the analysis is higher than that for the interacting saving options the issue cannot be dealt.

B.2 How to deal with interaction between energy savings and other (growth) effects?

Volume effects, such as GDP growth, generally increase energy consumption. Structure effects, such as shifts in the contributions of sectors to GDP, either increase or decrease energy consumption. The saving effects by definition decrease energy consumption. If these effects are calculated separately over a number of years, they do not add up to the observed change in energy consumption. This is true at national level as well as lower aggregation levels. For instance, in Chapter 4 it is shown that calculated savings owing to high-efficiency boilers vary considerably, as these savings depend on volume and structure effects that define the number of dwellings with a central heating system using natural gas.

Special decomposition methods have been developed to deal with the overlap in an arithmetically efficient way (see Chapter 2). In so-called ‘complete’ decomposition methods, presented in Ang (1995), the residual term, representing the overlap is attributed to the various effects. However, these methods do not take a stand on the way the combined effect should be split. Another approach, as already described for interactions between saving effects, is the use of a calculation sequence. For instance, in MONIT the volume effect is calculated first, than the structure effect and lastly the saving effect for end-use energy demand. However, especially in case of longer periods and/or substantial yearly effects, results will be dependent on the sequence chosen. Therefore it is concluded in Chapter 2 that, generally speaking, ‘complete’ decomposition methods are the preferred way to deal with this kind of interaction.

B.3 How can interaction effectively be investigated in sets of policy measures to stimulate energy savings?

The previously described interaction regarded total energy savings. With regard to policy-induced energy savings, the issue is interaction between the saving effects of various policy measures. In the last few decades a great number of policy measures have been introduced in the Netherlands and other developed countries, as presented in MURE (2005). It is plausible that the saving effects of these measures overlap each other, at the detriment of total policy effectiveness. For instance, if stringent standards for energy use in new buildings are in place, these will overrule any stimulating effect of an energy tax to reduce energy consumption in new buildings. However, it is also possible that two measures reinforce each other's effect, as observed in the Netherlands a few years ago for the combination of labels and subsidies for new appliances (see Chapter 5). Given the large set of policy measures present, a great number of interactions between these measures can exist. Therefore it is necessary to efficiently select the relevant combinations of policy measures, which can be analysed further with quantitative methods.

In Chapter 5 a qualitative method is presented that enables a quick selection of combinations of measures that interact. The method is based on the four conditions that define the successful introduction of saving measures: availability, known to appliers, no restriction on application and sufficient motivation (to choose the saving options). Depending on the way two policy measures influence these conditions, the combination of measures is rated as overlapping or reinforcing. The method delivers a matrix, in which each cell contains information on the type and strength of interaction between two policy measures.

In this thesis an investigation is presented, executed for a set of 15 policy measures to stimulate energy savings in households in the Netherlands for the period 1990-2003 (see Chapter 5). From the resulting matrix it is clear that only a limited fraction of all possible combinations is either of a strong overlapping or a strong reinforcing nature. It is shown that only six combinations of policy measures have a substantial saving effect, and should be analysed further.

The method was also applied to the household sector in all EU-15 countries. This application, described in Boonekamp (2005), shows that it is possible to make a quick first selection of policy measure combinations that probably show substantial interaction effects. The result shows that a larger set of policy measures often leads to a more unfavourable ratio between the numbers of reinforcing and overlapping combinations of policy measures. This indicates that ever increasing sets of policy measures can become less effective in realising energy savings.

B.4 How to quantify interaction between specific policy measures that stimulate energy savings?

In scenario studies on energy trends it is common practice to analyse the energetic effect of policy measures on future energy consumption. Energy models are used to quantify the influence of policy measures on investment decisions for saving options and on energy use itself (good housekeeping). For instance, in the Netherlands simulation models are extensively used in energy scenario studies, e.g. in Dril (2005). These models are validated using observed trends for deciding factors, energy consumption and savings in the past.

In Chapter 5 it is described how the energy model for households was adapted to simulate historic energy consumption for 1990-2000. With this simulation model, interaction between policy measures to stimulate energy savings has been analysed in a quantitative way. The analysis concentrates on three important types of measures for households: a regulatory energy tax, investment subsidies and standards in the field of space heating. Energy consumption has been simulated for all cases with and without these measures. The results indicate, for households in the Netherlands, that combinations of policy measures yield 13% less savings in 2000 than the sum of savings of the separate measures. It is estimated that the overlap can further increase to 30% after the year 2000.

It can be concluded that simulation of historic energy trends with bottom-up models, used for scenario studies, offer good opportunities to analyse interaction between the saving effects of various policy measures to stimulate energy savings.

B.5 How do policy measures and energy prices interact, as to stimulate energy savings?

According to IEA (2004) energy efficiency has improved considerably in OECD countries due to the high energy prices of the eighties. On the other hand low price elasticity values are found for households in the Netherlands (see Chapter 6) and much of realised energy savings is attributed to policy measures. This raises questions on how the saving effect of prices and that of policy measures interact. For instance, do subsidies to stimulate investments in energy saving systems provide extra energy savings in case energy prices are already high? Are higher prices ineffective because efficient energy use is already heavily regulated?

Some actual interactions have been analysed with help of the same simulation model that was used to analyse interaction between various policy measures (see B.4). For Dutch households in the period 1990-2000 the effect of prices on energy consumption has been analysed in conjunction with three policy measures: a regulatory tax (up to about 30% of total energy price), subsidies for various saving options (20-25% of investments) and regulation of space heating demand (13% of all dwellings in 2000). According to the results, presented in Chapter 6, the combination of policy measures lowers the effect of higher energy prices with 25-30%. A main cause is the stringent energy performance standard for new dwellings, which overrides the influence of higher prices almost completely. To a lesser extent this is also true for subsidized saving measures applied in existing dwellings, and for subsidized more efficient electric appliances. Another finding is that price reactions are dependent on a limited set of saving options only. The finding of low elasticity values can be interpreted as a lack of market ready saving options. Along this line of thinking, stimulating the introduction of new saving options into the market should increase price elasticity, i.e. strengthen the effect of higher prices.

From the results presented in Chapter 6 it can be concluded that the analysis of saving effects of policy measures should not be done without regarding energy price effects at the same time, and vice versa. The same simulation models, used to analyse interactions between policy measures on energy savings, can be used to analyse the interaction between energy prices and policy measures.

7.4 Presentation of evaluation results focusing on policy needs

With respect to a policy oriented focus of evaluations, the problem was formulated in the introduction as: *How to define the analysis structure and presentation format, as to provide more useful information to policy makers on energy savings achieved and on the policy contributions to these savings?* This problem is tackled by addressing a number of research questions for this theme. It must be remarked that research questions C.7 and C.8 are addressed separately in Section 7.6 because it is not based on information in preceding chapters.

C.1 How to supply policy relevant results for cogeneration, import/export and substitution between energy carriers?

Next to total and policy-induced energy savings, policy makers sometimes need other information on specific topics. Both the EU and various member states have introduced specific policy to stimulate cogeneration of electricity and heat. Therefore policy makers need separate information on total savings achieved with cogeneration. Liberalization of energy markets has led to increasing imports and exports of secondary energy carriers, especially electricity. For small open economies like the Netherlands these imports and exports can have considerable influence on national energy consumption and CO_2 emissions (see Chapter 3). Therefore, this influence will be of interest to policy makers. Also, fuels or fuel/electricity substitution can be of importance to policy makers because of reliability of energy supply, but also because of the mitigating effect on total energy consumption.

With regard to cogeneration it is shown in Chapter 2 that methodological choices made in evaluation studies may prevent the presentation of saving figures on cogeneration. In Odyssee (2003) energy consumption data have been corrected for cogeneration at end-users site, thus ruling out cogeneration in analyses of end-use sectors. In other cases, such as Schipper (2001), Howarth (1991) and Fischer (2002), plain energy consumption figures are used in the analysis instead of primary energy consumption. As highlighted under A.2, using this energy quantity makes it impossible to present savings by cogeneration. Even if the analysis uses primary energy figures, separate figures on cogeneration savings will not become available unless a distinction is made between final energy demand and conversion (including cogeneration) in end-use sectors. In Chapter 3 it is shown that the MONIT evaluation system can present separate saving effects for cogeneration in end-use sectors and electricity supply. The same applies to the PME method described in Chapter 2.

According to MURE (2005) cogeneration is stimulated by various policy measures. The calculation of total policy contribution to cogeneration savings must take into account relevant interaction between these measures. In Chapter 5 it is described how possible interaction is investigated for policy measures aimed at household energy consumption. The method, using an interaction matrix, can also be applied for evaluating policy measures to stimulate cogeneration.

National decomposition studies known from literature use figures on total energy consumption (and parts of it), being the aggregate of import, export and extraction. Values for energy import and export are not observed separately. Moreover, decomposition studies regard volume, structure and saving effects without defining an energetic effect of changes in imported or exported energy on total energy consumption. However, changes in export of secondary energy carriers do lead to more or less conversion losses in the energy supply system. Changes in import of secondary energy carriers, such as electricity, lead also to more or less conversion losses in energy supply. Both trends change total energy consumption but can neither be ascribed to the volume (GDP) effect, nor to the saving effect. They should be regarded as structural changes in the total economy and their energetic effects should be part of the overall structure effect calculated. In order to present separate effects, export should be treated in the analysis as an extra end-use sector, to be supplied by inland production. Import should be treated as a direct substitute for inland production when meeting the demand from all end-use sectors. In the decomposition analysis the changes in export and import should be taken into account explicitly. This approach is realised in the MONIT evaluation system that works with standard energy balances, including import, export and extraction (see Chapter 3). It provides a separate contribution (to observed energy consumption changes) for energy export changes and one for energy import changes.

Substitution in end-use sectors regards various fuels, grid supplied heat versus fuels or electricity versus fuel. In energy supply substitution mainly regards fuel mix shifts in electricity production. Substitution at end-users sometimes is made part of energy savings, for instance in case of electric heat pumps, being a more energy-efficient alternative for gas boilers. However, generally it is not the result of dedicated saving actions. Moreover, in energy supply substitution can also increase energy consumption (in case of nuclear or coal power instead of gas use). Therefore substitution and energy savings should be treated separately. In the analysis this asks for a distinction between savings on final energy demand, more efficient conversion per fuel type and shift between fuels. Electricity production must be split according to fuel type. In MONIT this approach enables to present separate contributions to observed energy consumption changes for both substitution at end-users and substitution in energy supply.

Other evaluation methods can also provide the information supplied by MONIT. For instance, some decomposition studies take account of substitution between energy carriers (e.g. Schipper (2001)) or import/export (e.g. Hoen (2004)). The frozen technology method described in Chapter 2 is capable of calculating savings achieved with cogeneration. Generally speaking, methods that apply sufficiently low aggregation levels, use primary energy consumption figures and work with complete energy balances, should be able to provide this policy relevant information.

C.2 How can policy-induced, autonomous and total energy savings be calculated consistently?

In the introduction a distinction was made between calculations for total energy savings or policy-induced savings. These activities are often performed separately, and generally different methods are applied. For policy makers it is important to know which part of total energy savings is the result of autonomous developments (such as improvement of technologies without government support and higher prices in energy markets), and which part is owed to policy measures on energy savings. Therefore the results for total energy savings, autonomous savings and policy-induced savings should be calculated in a consistent way.

The first prerequisite for consistency is a **common format** for the analysis, i.e. the same level of disaggregation, the same definition of sectors and energy applications and the same energy quantities. Then, in principle, it should be possible to combine the results of decomposition methods for total energy savings with that of bottom-up investigations of policy-induced energy savings.

The second prerequisite is a consistent choice of the **reference system** and the way **interaction** is taken care of. In practice this often is not the case. For instance, policy-induced energy savings are often calculated, using the reference system that is valid for the starting year of the policy measure, e.g. in the cogeneration evaluation in Rijkers (2003). Total energy savings are calculated, using one single base year. Interaction is also treated differently in evaluations of total or policy-induced savings. Interaction between energy savings due to policy measures and volume or structure effects (e.g. more savings because of an increased potential for efficient systems) is hardly quantified. On the other hand, decomposition methods do try to calculate total energy savings, taking into account the overlap with volume and structure effect.

The third prerequisite is a consistent calculation of the energetic effect of **driving factors** for each type of energy savings (autonomous, policy-induced and total). Autonomous savings are dependent on energy prices and economic growth (that affect the speed of replacing old energy equipment by new probably more efficient, energy systems). Policy savings are dependent on the level of energy taxes, subsidies, regulation, voluntary agreements and information. Total savings are the result of the combination of all driving factors. Consistency requires that calculations of policy-induced savings take into account already realised autonomous savings.

The simulation of historic household energy consumption, as described in Chapters 4, 5 and 6, provided consistent results on total energy savings and policy-induced savings. Format and reference systems were by definition the same in both calculations; the same applied to dealing with interaction between saving effects. With respect to the driving factors the simulation did regard energy prices and the policy measures energy tax, investment subsidies and regulation of gas use for space heating. Both separate effects and combined effects were calculated using the same simulation model. This assured a consistent calculation of autonomous savings (related to prices) and policy-induced savings (related to policy measures).

C.3 How to determine uncertainty margins for calculated energy savings?

In Chapter 2 various methods used to calculate energy savings at national and sectoral level were evaluated. It was concluded that these methods only estimate total energy savings achieved. Part of the problem is due to energy savings being a (small) difference between two (much bigger) values for reference energy consumption and actual energy consumption. Therefore, relatively limited uncertainty margins in the values of both quantities can lead to substantial margins in the calculated figures on energy savings. In the Netherlands margins for energy consumption data (see Appendix 3 in Boonekamp (2001)) often are greater than calculated yearly energy savings. Still, the main problem is finding appropriate quantities at a low enough aggregation level that permit to construct the ‘real’ reference energy consumption trend. For an industrial case it was illustrated that calculated energy savings depended on the chosen level of aggregation. For households in the Netherlands it was shown that energy savings depended strongly on the factors that were taken into account when constructing reference energy consumption (see Chapter 2).

In order to find the ‘real’ reference energy consumption, the observed change in the applied quantity should cover all factors that affect energy consumption in absence of saving activities. For instance, more floor space in offices is not the only deciding factor influencing electricity use for lighting. Changing occupation rates, tighter lighting standards, etc. play a role too. In practice not all influencing factors are known, and for many known factors no statistical data are available. Therefore evaluation studies are forced to apply less optimal aggregation levels and quantities in the calculation of energy savings.

Given this persistent problem it is of utmost importance that policy makers are informed as to the uncertainty margin in saving figures provided by evaluations. However, in literature no evaluation study for national or sectoral energy savings has been found that meets this demand. Two methods, presented in this thesis, show that it is possible to provide information on uncertainty margins for the calculate energy savings and other effects.

In the MONIT evaluation system, the observed changes in energy consumption are decomposed into contributions for several factors, e.g. GDP growth, savings on end-use, fuel substitution or energy import/export (see Chapter 3). A qualitative analysis of uncertainty in the contributions shows, for the majority, that the margin is dependent on the quality of available statistical data only. However, the uncertainty margin in the calculated saving and structure effect for final energy demand mainly depends on the quality of the construction of the reference energy consumption. The limitations mentioned earlier lead to substantial uncertainty in the figure on end-use savings. Because end-use savings define total energy savings to a large extent, the total saving figure will be uncertain too.

In Chapter 2 a description is given of the PME method (Protocol Monitoring Energy savings) that explicitly accounts for uncertainty margins in energy data, and for uncertainty in results due to (lack of) quality in the construction of reference energy consumption. This quality of construction is rated according to the difference between the known set of deciding quantities and the available quantities in the calculation. In Gijsen (2004) it is shown that a monte-carlo algorithm can be used to calculate margins for saving results, using the inserted uncertainty of all inputs. These margins prove to be quite large for the Netherlands; for the period 1995-2002 total energy savings of 1.0% per year are found, with a margin of 0.3%. Margins are dependent on the length of the analysis period owing to the fact that the cumulative saving effect increases every year while the uncertainties of the input data remain at about the same level (see Gijsen (2004)).

C.4: How can the quality of calculated figures about energy savings be improved?

In the preceding paragraph the level of uncertainty in calculated saving figures has been discussed. Uncertainty margins in the input data and the quality of constructed reference energy consumption are mentioned as deciding factors as to the margin in saving results.

In paragraph A.1 the choice of aggregation level and driving factors in constructing reference energy consumption was discussed. It was concluded that an analysis at a lower aggregation level is preferable, as calculated saving figures are less ‘diluted’ by structural effects. At a lower aggregation level it is possible to make distinctions between various energy applications, and to find suitable variables to construct reference energy consumption. Thus, the quality of the reference energy trends, and that of calculated energy savings, increase. In the uncertainty analysis, described in paragraph C.3, this favourable effect is dealt with by applying a lower uncertainty margin to the reference consumption values, narrowing the margin in calculated total saving figures.

A lower aggregation level also contributes in another way to more accurate saving results, as total energy consumption is split into more segments. This does not lead to smaller margins for the calculated saving figures per segment. However, owing to the ‘law of great numbers’, the margin in total savings will decrease because positive and negative deviations will partly compensate each other’s effect on total savings. Therefore more detail in energy consumption improves the reliability of saving figures, apart from quality issues mentioned earlier.

A third way of improving the reliability of saving figures is of course improving the accuracy of input data. However, it is often difficult to raise efforts for data gathering in general. To restrict costs of data gathering it should be made clear which efforts will contribute most to better figures and thus must be given higher priority. The method used in PME decomposition to calculate uncertainty margins (see Chapter 2) can also supply this information. From additional analysis in Gijsen (2004) it appears that in the Netherlands unreliable energy data for the sector services contribute most to the margin for total calculated energy savings.

It is concluded that applying a lower aggregation level in the analysis, as well as using more accurate data, will improve the accurateness of saving results. The contribution of better data is not the same for all data; the uncertainty analysis as part of the PME-method can help to direct the efforts at data that offer much improvement.

C.5 What possibilities exist for changing the base year in presentation of results?

Evaluation studies are executed for a period between a chosen base year and a more recent year for which data are available. The base year is chosen for practical reasons, e.g. availability of data, or for policy reasons, e.g. the base year used in the formulation of energy policy targets. Another reason regards acceptable uncertainty margins, as has been touched upon in the preceding paragraph C.3. For instance, the base year should be 1995 or earlier if realised energy savings until 2003 are evaluated (according to the PME-method for the Netherlands). With this minimal length of the evaluation period, the margin in total calculated energy savings will not exceed 30%, which is thought acceptable yet.

Differences in the base year for various evaluation studies prevent a sound comparison of results. Therefore it would be an advantage if calculation methods are set up such that they enable the choice of a different base year. In standard decomposition methods, the change in energy consumption from one year to the next one is decomposed into volume, structure and saving effects, taking the preceding year as ‘base year’ (see Ang (1995)). The yearly results can be aggregated over a variable period; a change to a different base year does not pose fundamental problems for calculation. However, in practice this demands a recalculation. In the MONIT system (see Chapter 3) the base year can be chosen at one’s discretion, once the calculation for the total period is completed. On the other hand it must be remarked that MONIT uses a simple decomposition method, whereby the values of volume, structure and saving effect are dependent on their sequence in the calculation.

C.6 How can ‘top-down’ and ‘bottom-up’ evaluation demands of the EU-directive on energy savings be met?

At the end of Chapter 2 the monitoring and evaluation of the new Energy Service Directive (ESD) of the European Union was discussed. For each country the attainment of the target for energy savings to be realised will be checked in two ways. Total energy savings achieved are calculated using a top-down method, i.e. an aggregated indicator, called ODEX. Part of energy savings (probably 50% of the target value) must be ‘proved’, using bottom-up evaluations of specific policy measures and programmes.

According to Figure 2.4 neither the top-down method, nor the proposed bottom-up method meets ESD evaluation needs. Both methods do not focus on energy savings that are the result of general policy measures (such as energy taxes). Moreover, no account is taken of interaction between the specific and general policy measures, and between the policy measures and exogenous factors, i.e. energy prices.

In this thesis methods are presented that can meet the demands of the ESD. In Chapter 2 it is highlighted that two methods, frozen technology and simulation of energy trends, can provide a detailed picture of energy savings achieved. In Chapter 4 detailed saving results are presented for households in the Netherlands, using the simulation approach. The (very) low aggregation level, applied in this method, allows to incorporate the results from the bottom-up evaluations of various policy measures and programs. Moreover, the simulation method can take account of interaction between various saving effects. In Chapter 5 it is shown that the simulation model can deal with interaction between various policy measures, e.g. the specific policy measure ‘investment subsidies’ and the general policy measures ‘regulatory tax’. Finally in Chapter 6 simulation results are presented that show how autonomous energy savings depend on energy price developments, and how this interacts with policy measures. Given these results, it is expected that the simulation approach can meet the evaluation needs of the ESD, although this has not been tested yet.

7.5 Explanation of causes of energy saving trends

For the theme ‘explanation of causes for saving effects found’ the problem was formulated in the introduction as: *How can calculation of energy saving effects be extended to explanation of the saving effects found?*

Evaluations of energy developments can range from a simple presentation of energy consumption trends to a detailed analysis taking into account all relevant factors, relationships and effects. The calculation methods presented in Chapter 2 give insight into quantitative contributions of factors to observed energy consumption changes, for instance volume, structure and saving effects. However, these methods do not explain the causes of the energy savings found. Explaining the trends for total energy savings, and especially policy-induced savings, demands an analysing structure that incorporates relationships between energy use and deciding factors, such as energy price and policy measures, on savings. The simulation model, presented and applied in Chapter 4, 5 and 6, is meant to provide this structure (focused on energy developments in households). In the following, several applications of the simulation model are described. The results correspond to research questions mentioned in Section 1.5.

D.1 How do factors with system wide effects influence energy consumption and energy savings?

Answering this question will be limited to household energy consumption. Total realised energy savings were analysed in Chapter 4, using a simulation model. Part of the analysis constituted the calculation of the overall effect on energy use of a lower number of persons per household. Fewer persons per household led to an increased need for new dwellings. These dwellings all had central heating, as opposed to existing dwellings that partly had local heating. However, the newly build dwellings were generally (much) better insulated, and had more efficient boilers, than the average dwelling. Less hot water was used per (smaller) average household but average hot water demand per person increased (due to economies of scale). The same developments were valid for electricity use (for e.g. clothes washing and lighting). The changes in energy demand per household sometimes influenced the profitability of investments in energy saving options. These second order effects also influenced total energy consumption. Given the many and interacting energetic effects of smaller household size it was virtually impossible to calculate the overall effect by hand. The analysis, by means of simulation, showed that total energy consumption of all households increased by 2.5%, for a 3.7% decrease in average household size.

Another case presented in Chapter 4 regarded the system wide effects of an increased number of dwellings using distributed town heat. The case showed that more of these dwellings led to a number of secondary effects that changed the possibilities for other saving options. For instance, it decreased the number of boilers installed and thus limited the saving effect of applying high-efficiency boilers. Because town-heating systems in the Netherlands were generally not combined with gas supply to dwellings, electric cooking was stimulated offering possibilities for more efficient electric appliances. Calculating the overall effect on primary energy consumption was further complicated because of the substitution between gas and electricity. However, simulations with extra dwellings supplied with town heat showed that this led to lower primary energy consumption, but less than calculations by hand would show.

These examples show that deciding factors, such as autonomous decrease in household size and policy-driven introduction of town heating, can lead to many interwoven changes in the households energy system that in turn affect overall energy consumption in various ways. Application of a simulation model of household energy use was needed to present a coherent picture of developments that contributes to a better understanding of energy developments.

D.2 How do energy prices affect energy savings?

Simulations of household energy consumption in the Netherlands have been performed, for the period 1990-2000, with a bottom-up energy model, both for the actual energy price trend and for several assumed price trends (see Chapter 6). From the results it follows that the level and development of gas and electricity prices had a rather small effect on energy consumption. The calculated price-elasticity amounts to 0.13 for gas and 0.11 for electricity, which is in line with other studies on households in the Netherlands (see Linderhof (2001)). Detailed analysis shows that the price response is dependent on a limited set of saving options. Advanced saving options are generally too expensive to be applied, even in cases with high prices, whereas common saving options are attractive, even for low price levels. Therefore (modestly) higher or lower prices do not influence the majority of saving options.

If one supposes a lasting price increase from 1990 on, the results show that the price-elasticity increases from 1995 to 2000. Because of the gradual replacement of energy systems it takes time for households to adapt to the higher prices. The simulations also show that five times higher energy prices only result in three times higher energy savings. The lower impact is due to lack of market ready saving options that are profitable at very high price levels. Again it takes time before the market will supply saving options that fit to the new price level.

Price elasticity values are dependent on the presence of policy measures, as has already been described in paragraph B.5 on interaction between energy prices and policy measures. In Chapter 6 it is concluded that energy developments in household in the Netherlands are more and more independent from price trends.

D.3 How much do energy taxes, subsidies and regulation contribute to energy savings achieved?

The household energy model was also used to study explicitly the saving effects of the three policy measures: regulatory tax, investment subsidies and regulation of gas use for space heating (see Chapter 5). The regulatory tax started in 1996 and increased to more than 30% of the total gas price or electricity price in 2000. Calculated energy savings amounted to about 2% of total gas as well as total electricity use in 2000. The subsidies, regarding a great deal of the saving options for most of the years, amounted to 20-25% of the extra investment compared to the reference system. The saving effect of subsidies was equal to about 3% for electricity and 4% for gas in 2000. Regulation encompassed agreed saving measures for renovated dwellings and standards for new dwellings. Until 1995 standards regarded insulation and boiler efficiency, followed by an energy performance standard, which was sharpened regularly. This led to 4-5% savings on total gas use, predominantly owing to new dwellings.

The combined saving effect of these policy measures amounted to 50% of total gas savings achieved, and 15% of total electricity savings. It must be remarked that also other policy measures influence energy use, although extra savings owing to these measures are estimated as minor. The interaction between the three policy measures mentioned was already described in paragraph B.3 and B.4.

7.6 Other topics in the problem formulation

In the introduction a few evaluation issues and problems were presented that have not been dealt with in the analysis described in Chapters 2 to 6 (see overview in Table 1.5). These items, belonging to theme C on policy-oriented results, are:

- comparing energy savings achieved with saving targets,
- the saving effect of earlier policy measures.

In the following the possibilities to deal with these issues and problems will be described, based on experience obtained with operating the simulation model, described in this thesis, and knowledge of capabilities of other methods to analyse energy savings.

C.7 How can realised saving figures be compared with targets for energy savings?

The process of policy formulation, implementation and evaluation often starts with the formulation of targets for energy savings, for instance x % savings per year over the next y years. Often, these targets are based on scenario studies where energy models are used to calculate expected savings, given assumptions about economic growth, energy price trends, saving options, technological developments and policy measures deployed. This exercise, in advance of the implementation of policy, is called the ex-ante evaluation (see ex-ante savings in Figure 7.4).

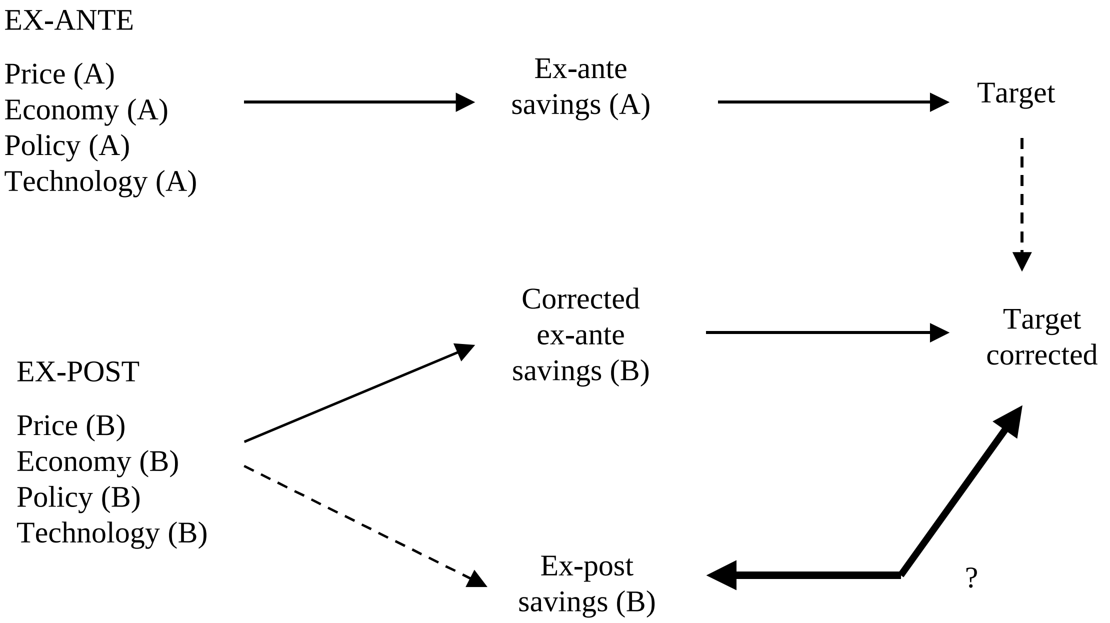

Figure 7.4 Comparison of energy saving target and realised energy savings

Some time after implementation of energy saving policy, realised energy savings are calculated as part of the so-called ex-post evaluation (see ex-post savings in figure 7.4). A comparison of target value and ex-post saving figures should show success or failure of energy saving policy. However, a number of factors complicate this simple comparison. Often the assumptions (A) about exogenous developments, such as economic growth and energy prices, diverge from reality (B). Also the set of policy measures applied could have changed. Therefore a direct comparison of saving target and realised savings can be regarded as not ‘fair’. What is needed is a revised target based on realised trends (B) for economy, prices, technology and policy measures (see corrected ex-ante savings in Figure 7.4). If a revision of the target is not possible, another approach is correcting realised savings for the divergence of driving factors. This method has been deployed in CPB (2000).

The simulation model described in this thesis is an adapted version of a household energy model, used in scenario studies (see Chapters 4, 5 and 6). The adaptations regard the facility to compare model outcomes with realised results, and to correct model parameters in such a way that the simulation results match actual trends at all aggregation levels. Actually, this adjustment of model parameters for historic years is part of regular validation of models used in scenario studies. Using such a validated simulation model means that model structure, definition of model variables and relationships will be the same for the evaluation version and the scenario version of the simulation model. Therefore it should be possible to calculate corrected ex-ante savings based on actual input values. The corrected target can be compared with calculated ex-post savings. Thus the simulation method can solve the problem associated with comparing saving targets and realised energy savings in a changing world. However, it must be remarked that up till now this has only been done for one end-use sector, namely households.

For savings obtained by policy measures, the same applies as for total energy savings. A sound comparison demands a correction of the policy target for deviations from earlier made assumptions. If the policy target has been based on model calculations, the same model can be used to recalculate the target value for policy-induced savings. An alternative solution is correcting the realised policy savings for changes in saving policies and exogenous trends since the formulation of targets. This demands an evaluation method that enables the simulation of realised policy savings for diverging (theoretical) circumstances. The simulation model for households presented in this thesis should be able to make this kind of corrections (see Chapter 5 and 6).

In the Netherlands the ex-ante (scenario) and ex-post (realised) evaluations have been done in such a way that results are more or less comparable. At national and sectoral level the changes in future energy consumption are decomposed in conformity with the PME approach, used to evaluate realised energy savings. Therefore, the figures on future energy savings, and related targets, should be comparable with historical energy saving figures. However, the PME decomposition for years in the past is less detailed than the decomposition for future years. The historic results are based on an analysis at a relatively high aggregation level and with a limited set of data (see also Chapter 2). Results for a future period are based on output of bottom-up simulation models that cover all saving options. Therefore, targets for savings based on scenario results are not wholly comparable with realised energy savings from historic evaluations. As mentioned earlier, complete comparability can be realised by using the same (bottom-up simulation) model for historic and future analysis.

C.8: How to deal with energy saving effects of former policy measures?

Policy evaluations often are restricted to policy measures that are active in the period of evaluation. However, as there has been energy saving policy in many countries for more than two decades, realised energy savings in the evaluation period can be partly the result of earlier policy measures. So, there is a need to discern between the saving effects of actual policy measures, earlier policy measures and autonomous developments (see Figure 1.6).

Actual policy measures are generally known, but earlier policy measures must be traced, taking into account the possible length of their ongoing effects. In this respect the interaction-matrix method, to investigate possible interaction between policy measures, as described in

Chapter 5, can be of help. It uses the data in MURE (2005) to specify actual and earlier policy measures. Moreover, it can indicate whether interaction exists between actual and earlier policy measures.

In Chapters 5 and 6 it has been shown that a bottom-up simulation model can show the saving effect of separate policy measures. When it is possible to make a distinction between “earlier” and ‘actual’ policy measures, it should also be possible to calculate separately the saving effect of actual and earlier policy measures. This has not been demonstrated in thesis though. However, bottom-up simulation models, with their vintage approach, seem a promising tool to solve the problem of discerning delayed and present policy-induced saving effects.

7.7 Contributions of new methods to improvements

In this thesis a number of new evaluation methods have been presented that help to take hold of evaluation problems and issues mentioned earlier. These new methods constitute:
- PME-method (Protocol Monitoring Energy savings, Chapter 2),
- MONIT evaluation system (reconstructing energy balances, Chapter 3),
- simulation model (historic household energy use, Chapters 4, 5 and 6),
- interaction matrix (investigation of interaction between policy measures, Chapter 5).

Protocol Monitoring Energy savings (PME)

The PME-method forms an extension to regular decomposition methods that split the observed change in total energy consumption into various effects, such as a volume effect (GDP growth), a structure effect (related to socio-economic changes) and a saving effect. However, its policy-oriented focus has lead to the following special features:
- In end-use analysis extensive use is made of physical (instead of economic) quantities because they are more appropriate to construct reference energy consumption trends.
- Cogeneration savings are separately calculated, next to savings in end-use or in energy supply.
- All energy consumption quantities are expressed in static primary energy units (taking account of conversion losses in base year energy supply), facilitating the calculation of cogeneration savings and the aggregation of savings on fuel and electricity.
- Interaction between the saving effects mentioned is dealt with by applying a calculation sequence in conformity with policy evaluation rules.
- Uncertainty margins in national and sectoral saving figures are calculated, based on margins in input data and the quality of the construction of reference energy consumption trends.
- The PME-method has been fitted to the way energy savings are calculated in scenario studies that underscore policy targets on savings.

In Table 7.1 the contribution of the PME-method to addressing problems and issues mentioned earlier are shown. Especially with respect to uncertainty margins this method provides an essential contribution.

Table 7.1 Contribution of new methods as to addressing problems and issues in evaluation

		PME method	Reconstructed balances	Simulation households	Interaction matrix
	(improved methods)				
A1	Aggregation/reference variable	×		×	
A2	Energy quantities used	×	×		
A3	Value of primary factors		×		
A4	Indirect CO_2 emissions		×		
A5	Integrated sectoral results		×	×	
A6	Transparency statistics/results		×		
A7	Temperature correction		×	×	
	(interaction effects)				
B1	Interaction for saving effects	×	×	×	
B2	Interaction saving/other effects	×	×		
B3	Possible interaction P&M				×
B4	Quantifying interaction P&M			×	
B5	Interaction policy/other factors			×	
	(policy focused results)				
C1	CHP, im-/export, substitution	×	×		×
C2	Policy/autonomous savings			×	
C3	Uncertainty in saving results	×	×		
C4	Data quality/margin in result	×			
C5	Change of base year		×		
C6	Top-down and bottom-up			×	
C7	Realised savings versus targets	×		×	
C8	Effects of earlier policy			×	×
	(explanation of changes)				
D1	System wide effects			×	
D2	Explanation price effects			×	
D3	Explanation policy effects			×	×

Reconstructed energy balances (MONIT)

The MONIT approach constitutes a mix of decomposition analysis for end-use and ‘book-keeping’ simulation of supply, based on a set of energy balances. It offers the following features:

- Analysis of energy trends using both static and dynamic primary energy consumption.
- Calculated CO_2 reduction effects are consistent with calculated energy savings.
- Consistent saving results over all aggregation levels (national, sectoral, end-use and supply and all energy carriers).
- Direct coupling of analysis results to statistical data in energy balances.
- Interaction between savings in end-use and energy supply are dealt with.
- Important other effects (import/export, substitution) are calculated too.
- Flexible base year choice in presentation.
- Information presented at various information levels (time series, indicators, 14 contributions to the observed change in energy consumption).

MONIT thus contributes to taking hold of a number of problems shown in Table 7.1 (third column). Unique contributions regard the opportunity to use static as well as dynamic primary energy quantities in the analysis, emission calculations consistent with energy calculations, transparency as to the data used and the free choice of the base year.

Historic simulation approach

The simulation of household energy consumption is executed with an adapted bottom-up model used for scenario studies. The important features with respect to evaluation of past trends are:

- Lowest aggregation level (saving options) enabling the use of most appropriate variables to construct reference energy consumption.
- Bottom-up results on savings and structural changes enable analysis of interaction between saving effects and between savings and structure effects.
- Insight in the (changing) fraction of climate dependent energy use.
- Analysis of integrated energetic effects of developments with system wide consequences (such as smaller families).
- Contribution of policy measures to realised savings, interaction between policy measures and interaction with energy price changes.
- Joint calculation of autonomous and policy-induced energy savings.
- Separate evaluation of earlier policy measurers possible.
- Comparison between realisation and saving target is possible (total/policy).

The simulation approach contributes the most with respect to the problems and issues under theme C (policy-oriented presentation) and D (explanation of developments). Owing to its detailed analysis it can provide the best approximation of ‘true’ energy savings achieved.

Interaction matrix for sets of policy measures

Contrary to the preceding quantitative methods the interaction matrix regards a qualitative investigation that is meant to get a quick overview of policy measures where substantial interaction can be expected. For the selected combinations, interaction should be analysed in a quantitative way with methods such as simulation. Special features of the interaction matrix method are:

- Both the strength and the type of interaction (overlap or reinforcing) are mapped.
- The rating of the interaction is based on how policy measures help meet four requirements for successful implementation of saving options.
- Policy measures are grouped according to energy application, therefore the analysis can be restricted to combinations of measures that aim at the same application.

The selection of interacting policy measures, using the matrix method, contributes to addressing some problems shown in the Table 7.1. From Table 7.1 it can be concluded that the new methods cover almost all issues and problems in evaluation as highlighted in the introduction of this thesis. In Section 8.2 it is discussed what should be done further, as to apply these new approaches in future evaluation of energy trends and savings.

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Chapter 8 SUMMARY, OBSERVATIONS AND CONCLUSIONS

8.1 Summary

Developments in evaluating energy trends and energy savings

Energy savings are defined as the difference between reference energy consumption, i.e. energy use in absence of energy saving activities, and observed (actual) energy consumption (see Figure 1.1). Reference energy consumption is determined using observed trends for the variables, such as growth of population or economy, defining energy consumption.

Evaluation of realised total energy savings requires registration (monitoring) of actual developments in energy consumption, calculation of reference energy consumption, and calculation as well as interpretation of energy savings. In this thesis, evaluation also regards analyses of the effects of policy measures to stimulate energy savings. For the calculation of total energy savings at national or sectoral level a number of methods are described in the literature, such as decomposition analysis, the use of energy efficiency indices or energy efficiency indicators and a method called ‘frozen technology’. For the analysis of policy-induced energy savings other methods are applied, such as engineering calculations based on total implemented saving options, field surveys of investments in saving options, and regression analysis of energy trends.

In the last few decades the need for energy savings evaluation has grown together with upcoming importance of energy savings and increased government involvement. This is true for the Netherlands and, more recently, also for the EU (see recent directive on energy savings) and OECD (see e.g. recent IEA analysis of energy efficiency trends). The demand for evaluation has expanded for the following reasons: the host of new policy measures launched after recognition of the problem of climate change due to greenhouse gas emissions, mainly coupled to energy use (see Brundtland report of 1987), the explicit formulation of sectoral and national targets on energy savings, increasing amounts of government money spend on supporting saving measures, a political trend to question the effectiveness of policy in general and finally international reporting obligations, coupled to the Kyoto-agreement on reduction of greenhouse gas emissions. The new directive on energy efficiency of the EU will probably further increase demands for monitoring and evaluation of energy savings.

Evaluation has become an indispensable part of energy saving policy. In the Netherlands, the Platform Monitoring Energy savings (PME) provides since 2001 yearly evaluations of realised total energy savings, national and for the sectors households, industry, agriculture, services, transport, refineries and electricity production. Another example is the Odyssee-project of the EU, which provides indicators on energy efficiency in European countries, which are comparable. However, execution of evaluations and actual use of results are seriously hampered by various problems (see Table 8.1). Problems with availability and reliability of input data lead to a 30% uncertainty margin in the yearly calculated figure for total energy savings of the Netherlands. With regard to policy-induced energy savings the problem of interaction between (increasing) numbers of policy measures should be mentioned. This interaction may influence the saving effect of specific measures and reduce the effectiveness of energy saving policy.

Table 8.1 Issues and problems in evaluating energy trends, dealt with in this thesis

	Improved methods:
A1	Aggregation level / variable in calculating reference energy consumption
A2	Energy quantities to be used in the analysis
A3	Static or dynamic, average or marginal conversion efficiencies
A4	Indirect CO_2 emissions that are consistent with primary energy use
A5	Integrated calculation of sectoral saving effects
A6	Transparency in the relation between energy statistics and analysis results
A7	Temperature correction for climate dependent energy use
	Interaction effects:
B1	Interaction between saving effects
B2	Interaction between energy savings and other factors affecting energy use
B3	Investigation into possible interaction in set of policies and measures
B4	Quantifying interaction effects for specific policies and measures
B5	Interaction between policy measures and other factors
	Policy focused results:
C1	Effects of cogeneration, import/export, fuel substitution
C2	Consistent policy dependent-, autonomous- and total energy savings
C3	Uncertainty margins in calculated energy savings
C4	Relationship between data quality and margin in result
C5	Change of base year in the presentation of results
C6	Top-down and bottom-up evaluation combined
C7	Comparability of realised savings and targets for energy savings
C8	Effects of earlier policy measures on current energy savings
	Explanation/ causes for changes:
D1	Effect of system wide factors as to energy consumption and savings
D2	Explanation/causes of price effects
D3	Explanation/causes of policy effects

Goal, scope and problem formulation in this thesis

The goal of this thesis is *"to provide improved methods to analyse and explain energy trends and energy savings achieved at national and sectoral level, taking into account specific needs of policy makers"*.

This goal implies a number of choices with regard to the scope of analysis. This thesis looks at total realised energy savings and additional factors that define energy consumption trends, i.e. volume and structure effects, related to economic and socio-demographic developments, fuel substitution and energy import/export. Energy related CO_2 emissions are also part of the analysis. The analysis regards effects at national and sectoral level, with a focus on households as to some issues. Special emphasis is given to the policy contribution to total realised energy savings. The issue of effectiveness, i.e. comparison of targets and realisations, and the role of driving factors is dealt with too. Another major subject is the interaction between various policy measures as to their saving effects. Finally the analysis does not restrict itself to bringing about results (calculation) but also pays attention to meeting the demands of the users of the results (presentation).

The general problem formulation of this thesis has been transferred into a number of research questions (see Section 1.5 and Table 8.1). In addressing these questions, necessary and realised improvements to evaluation methods are shown. The research questions are clustered in four themes:
A. Improved methods for monitoring and evaluating energy savings achieved.
B. Interaction in calculated energy saving effects and the contributions of policy measures.
C. Presentation of evaluation results in a form that meets information needs of policy makers.
D. Explanation of the causes of observed total and policy-induced energy saving trends.

The research questions are addressed using the results of five case studies, presented in Chapter 2 to 6 of this thesis.

Design and results of study cases

Chapter 2 presents an evaluation of methods used to determine realised energy savings. Six methods, focusing on national or sectoral level, are analysed. Special attention is given to choices made and neglected problems that hamper the calculation of sound and useful energy saving figures. Issues investigated are the choice of the right aggregation level, the appropriate variables to determine reference energy consumption, the energy quantities to be used and the interaction between various effects. Also the (generally lacking) uncertainty margins for the results presented are looked at. An optimal treatment is defined that addresses the calculation problems and choices in such a way that detrimental effects on saving results are minimized. The methods are scored in fulfilling the demands of such treatment. A number of improvements are proposed, among which the use of final demand for heat and electricity and energy use figures in primary energy units, and executing bottom-up analyses at the level of real energy saving options. The last one is especially important, as it provides both the top-down monitoring results (how much has been saved in total?) and bottom-up monitoring results (what have specific policy measures contributed to realised savings?), both being crucial to the recently implemented European energy saving policy.

Chapter 3 regards a new approach to energy and emission monitoring for policy use, applying reconstructed energy balances. A tool, called MONIT, has been developed for the presentation and analysis of energy and emission developments in the past. The evaluation system covers national and sectoral energy use and the accompanying CO_2 emissions, from 1982 onwards. Next to all energy variables and sectors, MONIT provides information about final demand for electricity and heat, cogeneration, primary energy use and indirect CO_2 emissions of electricity use. To allow a proper evaluation, the energy balance with statistical figures is corrected for disruptions in statistics and yearly climate variations. In the analysis part of MONIT the developments in energy use are mapped with a step-by-step constructed set of energy balances, starting from the balance for the base year. In this way the observed changes in energy use are unravelled into 14 explanatory factors, including four energy-related structural changes, five saving factors, fuel mix changes and changes in export and import of energy. Most of the 14 contributions can be calculated with a small uncertainty only. The MONIT evaluation system offers policy makers an integrated set of monitoring results at various levels: (corrected) statistical data, time series, final and primary energy use, direct and indirect CO_2 emissions, energy intensity values per sector, and policy relevant contributions to the observed changes in energy and emission variables.

In **Chapter 4** the monitoring of energy use of households, using a simulation model, has been dealt with. A bottom-up model for simulation of future energy use of households was adapted to simulate energy trends and savings in the past. Trends for a great number of saving options are analysed in conjunction with growth factors and structural changes that affect energy use. The calculated change in energy use is presented in the form of so-called volume, structure and saving effects, focused on energy use in the period 1990-1995. The method offers a very detailed analysis of realised energy savings, up to the level of individual saving options. It also shows the contributions of 30 structural changes that almost all lead to an increase in energy consumption. The adapted model is capable of handling the interdependency between structural changes and saving options, interaction between various saving options and between savings and energetic effects of fuel substitution. It is also shown that complex changes in energy use due to system-wide factors, such as smaller household sizes or a larger fraction of dwellings connected to district heating, can be easily analysed.

Chapter 5 addresses the question of interaction between policy measures to improve energy efficiency. The chapter starts with the presentation of a qualitative matrix method to investigate possible interactions in sets of actual policy measures. Interaction regards the influence of one measure on the saving effect of another measure. Starting from the conditions for a successful implementation of saving options, a general framework is developed to investigate possible interaction in sets of energy policy measures. The method delivers a matrix for all combinations of measures, with each cell containing qualitative information on the strength and type of interaction: ‘overlapping’, ‘reinforcing’, or ‘independent of each other’. Results are presented for the set of measures, implemented in the period 1990-2003 to improve energy efficiency in households in the Netherlands.

Then, for the most important interacting combinations found, a quantitative analysis has been executed, using a simulation model, applied earlier in scenario studies (see also Chapter 4). This model makes use of extensive data from surveys. The quantitative analysis has been made for combinations of three important measures: a regulatory energy tax, investment subsidies and regulation of space heating, including standards. Using a detailed bottom-up model, household energy use in the period 1990-2000 is simulated with and without these measures. The results indicate that combinations of three policy measures yield 13-30% less savings than the sum of the savings of the separate measures.

In **Chapter 6** it is analysed how energy prices and policy measures influence household energy consumption for the Netherlands. Energy developments in the period 1990-2000 are simulated using the earlier described bottom-up simulation model. Simulations are performed for a number of alternative energy price developments. From the changes in energy consumption price elasticity values follow. The price reactions are explained using the bottom-up changes in energy use and saving options. One finding is that a limited set of saving options defines for a great part the price response. Another result, in conformity with literature, is that elasticity values increase in time, owing to the gradual replacement of energy using systems. The price effect is also analysed in combination with the policy measures (performance) standards, investment subsidies and energy taxes. The simulation results indicate that the price elasticity could be 30-40% higher without these measures. E.g., because of strict standards on gas use in new dwellings, energy prices hardly define their actual level of gas consumption any more.

Synthesis of findings and improvements

Chapter 7 presents a synthesis of the findings in the case studies of this thesis, including the improvements in evaluating energy trends and savings. In Chapter 2 to 6 four new methods were presented that contributed to the improvements, namely:

- simulation model (for household energy use),
- PME-method (Protocol Monitoring Energy savings),
- MONIT evaluation system (reconstructed energy balances),
- interaction matrix (investigation of possible interaction in sets of policy measures).

The following findings, grouped to the four themes used in the problem formulation, emerged from addressing the research questions.

A. Improved methods for monitoring and evaluating energy savings achieved:

- Reliable saving results demand an aggregation level where suitable physical variables are available to calculate the reference energy consumption (energy use in absence of energy saving activities). For industry, the PME-method offers such an approach (for the Netherlands). For households, the simulation model applies a disaggregation of energy use up to the level of saving options, thus enabling to calculate reference consumption.
- As to the energy quantity to be used in the analysis, there are reasons for either using final demand for electricity and heat, or using primary energy consumption. The combined solution: final demand for electricity and fuel/heat, expressed in primary energy units is applied in the PME-method and the MONIT evaluation system.
- Use of static primary energy units, based on supply system characteristics in the base year, shows developments at end-users that are not ‘disturbed’ by energetic effects of simultaneous changes in supply. The use of dynamic primary energy units, based on actual supply characteristics, provides the ultimate effects of end-use developments on primary energy consumption. Both results can be provided in a stepwise decomposition of the changes in energy use as performed with the MONIT evaluation system presented in this thesis.
- Methods to analyse energy trends and savings can be applied to analyse related emission (reduction) developments as well, provided that indirect emissions of electricity use in end-use sectors can be calculated. This demands an integrated analysis of both end-use and supply sectors which the MONIT evaluation system supplies.
- The emission effect of electricity savings depends on the definition of electricity supply: inland production of total delivery including import. In the second case, savings on electricity will result in less reduction of CO_2 emissions, as no emissions are attributed to the

imported electricity, thus lowering average emission per kWh. In MONIT, emission effects can be calculated for both definitions of electricity supply.

- To assure consistency at national level, decomposition analysis at sectoral level must meet certain requirements, such as discerning between savings on final demand and savings from cogeneration. Both the PME-method and MONIT use this level of detail.
- The transparency in calculations can be enhanced by integrating the statistical database and the calculation scheme. In MONIT it is possible to trace differences in results due to updates of statistics or changes in the processing of data.
- Analysis of man-made changes in energy consumption requires consumption of all relevant energy-carriers be corrected for variations in outdoor temperature. The variation should be defined as yearly diversions from the average number of degree-days, as determined for a fixed period in the past. The corrections for end-users should be transposed to changes in energy supply too.

B. Interaction in calculated energy saving effects and contributions of policy measures:

- Interaction between various saving effects, e.g. savings on electricity use and a higher conversion efficiency of power plants, is arithmetically dealt with in decomposition analysis. MONIT and PME-method use a stepwise introduction of saving options in the analysis. The sequence used in analysing these options defines how combined saving effects are attributed to the interacting saving options.
- The interaction between a saving effect and other effects, e.g. larger energy savings for efficient processes when production in industry grows faster, is best dealt with using standard decomposition methods.
- In a sizable set of policy measures there are many potential interactions between saving effects of combinations of policy measures. The qualitative matrix method presented in this thesis provides for a quick selection of (often few) combinations with substantial interaction.
- For policy measures aimed at household energy use, the interaction was quantified using a bottom-up simulation model that simulates historic developments. Calculated energy savings for the combination of taxes, subsidies and regulation of space heating proves to be lower than the sum of separately calculated saving effects. As this overlap is expected to increase futher, energy saving policy for households becomes less effective.
- With the same simulation model it is possible to analyse interaction between the effects on energy savings of policy measures and energy prices. It shows that policy measures, present in the period 1990-2000, decrease the price-sensitivity of energy consumption of households, especially gas use.

C. Presentation of evaluation results in a form that meets information needs of policy makers:

- The MONIT evaluation system can provide specific policy relevant energy effects, such as the contribution of import/export and substitution between fuels to the observed change in total energy consumption. This demands well-chosen energy quantities, energy data based on energy balances (including extraction, import and export), sufficient disaggregation of energy consumption and an integrated approach for end-use and energy supply developments.

- Realised total energy savings and policy-induced savings are often calculated separately, using different methods. The simulation method offers an integrated calculation of policy-induced, autonomous and total energy savings, because a common format (definitions of energy use and driving factors) is used and the effects of all influencing factors are analysed simultaneously.
- Calculated saving figures have an uncertainty margin that is partly due to margins in the data used, but mainly originates from errors in the determination of reference energy consumption. Only the PME-method calculates the uncertainty margins, which is about 30% for yearly total energy savings in the Netherlands.
- The analysis of uncertainty margins as part of the PME-method also shows that the quality of evaluation results can be improved by choosing a lower aggregation level. Both the greater number of segments in total energy use, and a ‘better’ reference energy consumption reduce the uncertainty margin in calculated saving results.
- A first prerequisite for comparing the results from various studies is the use of the same base year. Most methods are not prepared to recalculate at one’s discretion results for a different base year. In MONIT it is possible to recalculate results for any base year after 1990.

D. Explanation of the causes of observed total and policy-induced energy saving trends:

- The explanation of mutations in total energy consumption, owing to complex changes in energy use due to system-wide factors such as decreasing number of persons per household, asks for a method that takes hold of all secondary effects and interdependencies between various developments (e.g. lower cost/benefit ratios for efficient boilers for space heating due to a lower heat demand). The bottom-up simulation model for household energy consumption enables such an analysis.
- Simulations of historic energy use, using models with behavioural relationships between energy use and the driving factors, can explain actual energy consumption and savings. For instance, simulations for households in the Netherlands show a low price elasticity (value 0.12-0.13) that increases with time. The small impact of price is due to the fact that only a limited fraction of all saving options is sensitive to price changes. Also it takes some time to react to price changes, due to the gradual replacement of energy systems.
- Calculations with simulation models can provide figures on the energy savings of separate policy measures, without the interference with other policy measures. In this thesis it has been done for households in the Netherlands. Realised energy savings were calculated for regulatory energy taxes, investment subsidies for saving options, and regulation of energy use for space heating in new and existing dwellings.
- Calculation methods for realised (ex-post) energy savings often differ strongly from the methods used to determine expected (ex-ante) savings, which serve as basis for saving targets. The simulation method presented in this thesis can close this methodological gap because the ex-post evaluations are based on calculations with an (adapted) bottom-up model that can also be used for ex-ante scenario calculations.
- In general, realised energy savings cannot be compared with the targets set for savings because actual developments diverge from earlier made assumptions in formulating the targets. The simulation approach enables a correction, either by correcting the target (recalculation to bring the target in line with actual trends) or by correcting realised savings

(recalculation of realised savings, using original assumptions about driving factors), thus enabling a ‘fair’ comparison.

- Next to energy savings owing to actual policy measures or autonomous trends, savings can be the result of earlier policy, before the start of the analysis period. For households these ‘earlier policy’ savings can be investigated using the simulation model. However, this has not been demonstrated yet.

8.2 Observations

Restricted use of results of monitoring and evaluation

For the calculation of total energy savings achieved at national and sectoral level various methods, including the ones in this thesis, have been developed. A substantial number of applications can be found in literature. For the calculation of policy-induced energy savings other methods are available, with even greater numbers of applications available in literature.

However, the use of results of monitoring and evaluation studies is still disappointing. Until a few years ago quantitative results of ex-post analyses did not play a deciding role in the formulation of energy policy. In the Netherlands, energy saving policy, formulated in various white papers, was based on the results of ex-ante scenario studies. Only since 2000 the evaluation of realised energy savings led to changes in formulated saving targets and policy.

At EU-level, energy saving targets were formulated only recently. In the new directive on energy services, reference is made to the Odyssee indicators on energy savings. However, this regards evaluating energy savings to be achieved in coming years. The available figures on already realised savings have not been used to support the choice of target value.

For developed countries energy (efficiency) trends were investigated recently by IEA. Although the results could have influenced present energy saving policy in OECD-countries, they were not explicitly mentioned when (re) formulating policy targets on energy savings. The same observation can be made for the UN-level, where worldwide trends in energy supply and demand were investigated in the 2000 World Energy Assessment study.

The reasons for the weak position of ex-post monitoring and evaluation have already been highlighted in the problem formulation in the introductory chapter of this thesis. The improvement of existing methods, and the development of new methods, may change this situation.

Ways to improve evaluations

The improvements presented in this thesis can overcome, to a large extent, the present shortcomings in evaluations. However, to take hold of all issues and problems (see Table 8.1) at the same time, the new methods should be applied in combination. In this thesis it has already been realised for the combination of interaction matrix and simulation of energy developments in the past (see Chapter 5). Further opportunities regard the combination of the two decomposition approaches, applied in the PME-method and in the MONIT evaluation system.

Finally, combining these methods with the simulation approach asks for a fitting of formats, definitions and calculation rules for the various methods.

A second condition for improved evaluations at national and sectoral level is complete coverage of end-use sectors. The interaction matrix and simulation model are now available for one sector only (households) and should be made available too for the end-use sectors industry, agriculture, transportation and services. With regard to the interaction matrix this should not pose a problem as the international MURE database supplies information on policy measures in all end-use sectors. With regard to simulation for other sectors, bottom-up simulation models are already available in the Netherlands for industry, agriculture and services. Here some extra effort is needed to adapt the models and to fit the simulation to observed trends. The bottom-up simulation method demands detailed information about penetration of saving options and about structural changes. It is believed that demands on data are not the limiting factor, provided that enough time and effort is spent on data gathering. The experience with the household model shows that a rather small but focused yearly survey can deliver this information. These efforts will be useful too in evaluating the new policy instrument White Certificates to stimulate energy savings. The work on simulating past energy developments will also contribute to validation of the simulation models used in ex-ante evaluations, as the fitting of simulation outcomes to reality provides information about model parameters.

A third condition for improved evaluations concerns reliable statistics on actual energy consumption and the variables, used to determine reference energy consumption. Presently, uncertainty margins in calculated energy savings (30% for total yearly savings in the Netherlands) restrict their usefulness in policy making. As was shown in the uncertainty analysis of the PME-method, the margin in statistical data often is of the same order as (relative) year-to-year energy savings. Therefore, saving figures with an acceptable uncertainty margin can only be provided as average values over a period of at least seven years (see Section 7.4). Smaller margins in input data enable both more reliable results and quicker reporting to policy makers of changes in the saving trends.

A further problem to be solved is comparability of results, firstly for various evaluation studies on the same subject, secondly for ex-post and ex-ante analysis, and thirdly between various countries. The first problem has been dealt with, at least in the Netherlands, by developing a general framework for calculating realised energy savings, the so-called PME-method. Comparison of ex-post evaluation results with targets based on ex-ante scenario results, asks for tuning formats of results, definitions and calculating rules. In this thesis it is described how application of the same simulation model in the analysis for the future and for the past can greatly enhance comparability. International comparability regards predominantly the EU-level, where the Kyoto agreement, CO_2 emisiontrading and especially the new directive on energy saving targets ask for comparable figures on realised energy savings per country. Presently common European indicators on energy efficiency are already provided for by the Odyssee-project. This information can be used to implement a method like the PME-method or MONIT in every country. However, due to lack of bottom-up simulation models in many countries, comparability of policy-induced energy savings remains a problem to be solved.

Quantitative results on energy savings and driving factors

The main subject of this thesis was about methodological improvements in evaluation methods. The importance of these improvements was highlighted with quantitative results. However, the obtained quantitative results are important for policy making in their own right. Here a number of obtained results will be summarized for each new method mentioned earlier.

All results obtained with the **simulation model** regard *household* energy consumption in the Netherlands for the period *1990-2000*. These results are:

- Total energy savings, converting electricity to primary energy supposing 40% conversion efficiency, amounts to 2.2% per year.
- A regulatory energy tax started in 1996 and increased to more than 30% of the total gas or electricity price in 2000. Calculated savings amount to about 2% of total gas use as well as electricity use in 2000.
- Subsidies, regarding a great deal of the saving options for most of the years, amounted to 20-25% of the extra investment compared to the reference system. The calculated saving effect of subsidies in 2000 is equal to about 3% of electricity use and 4% of gas use.
- Regulation of gas use for space heating led to 4-5% lower total gas consumption in 2000, predominantly owing to new dwellings. Regulation encompassed saving measures in renovated dwellings, agreed upon with housing corporations, and standards for newly built dwellings (until 1995 standards for insulation and boiler efficiency, followed by an energy performance standard which was sharpened regularly).
- As of 2000 the combined saving effect of these policy measures amounts to 50% of the total gas savings achieved, and 15% of the total electricity savings. The extra savings owing to other policy measures are estimated to be small.
- For the policy measures regulatory energy tax, investment subsidies and regulation of space heating, the combination of measures yields 13-30% less savings (for gas use) than the sum of the savings of separate measures.
- Price elasticity values of 0.13 for gas use and 0.11 for electricity use are found, based on the calculated reduction of energy use in 2000 after a fixed relative price change of 20% from 1990 on.
- The presence of the policy measures energy taxes, investment subsidies and regulation of energy use for space heating decreases price elasticity values by 25-30% (period 1995-2000).
- Structural changes lead to a 3-4 times greater increase of electricity consumption than valid for gas. This is partly due to substitution of electricity for gas in hot water production and cooking.
- Calculated fuel savings (in PJ) of more efficient boilers differ by a factor of 1.5 or more, depending on the sequence in which structure effects (e.g. higher thermostat setting) and other saving options (e.g. water saving shower heads) are calculated.

Results obtained with the **PME method** for realised energy savings in the Netherlands:

- Average national energy savings are 1.2% per year for the period 1990-2000 and 1.0% per year for the period 1995-2002 of (with a margin of +/- 0.3%).
- Average yearly energy savings per sector amount to 1.5% in households, 1.3% in industry, 0.4% in transportation and 1.8% in agriculture/horticulture for 1990-2000.

- Total national savings of 1.2% for the period 1990-2000 were the result of final savings (0.9%), cogeneration (0.2%) and more energy efficient energy supply (0.1%).

Some striking results from calculations with the **MONIT evaluation system** are:

- The change in total annual CO_2 emissions between 1998 and 1999 of 3 Mton was heavily influenced by changes in energy (electricity mainly) imports that saved 6 Mton of emissions at power plants (see Figure 3.13).
- In the period 1990-1998 the initial increase in energy savings related to extra industrial cogeneration, was almost halved by the increased conversion efficiency of central power production and electricity imports (which lowered the amount of saved energy due to electricity from cogeneration, see Figure 3.14).

An analysis of 15 policy measures, aimed at reducing energy consumption of households in the Netherlands, using the **interaction matrix method**, shows:

- Only 9% of all 136 possible combinations of two measures show a strong interaction, of which the greater part is of a overlapping nature.
- Only 6 combinations deserved further quantitative analysis as to the effects of interaction, implying standards for new dwellings, the regulatory energy tax, investment subsidies, the energy saving advice and appliance labels.

8.3 Conclusions and recommendations

The evaluation of energy savings achieved at national or sectoral level has become a regular activity, both for total savings and savings owing to policy measures. However, the actual use of the results to (re)formulate energy (saving) policy is hampered by various shortcomings of existing evaluation methods.

Many shortcomings are due to evaluations not paying enough attention to the needs of the users of the results, especially policy makers. For instance, results do not fit to the subjects in formulated policy, e.g. no separate saving figures for cogeneration. Also there is a lack of tuning between the calculation of total savings and the calculation of policy savings. Figures on realised energy savings (ex-post evaluations) are not comparable with the saving targets, based on scenarios (ex-ante evaluations). The lack of generally accepted methods prevents a sound comparison of results between countries as well, especially the savings due to policy measures. Further on, the methods do not take account of interaction between policy measures. The calculated effects are presented without explaining them with help of known trends in driving factors. Finally policy makers are not informed about the (substantial) uncertainty margins in the saving results.

Other shortcomings are due to methodological choices made, e.g. the use of energy quantities that restrict the analysis of energy savings from cogeneration. Another issue is the (too) high aggregation level in the analysis, leading to calculated energy savings being mixed up with structure or substitution effects. In addition, problems arise from a too narrow scope of analysis, e.g. end-use analysis without incorporating supply trends, or national analysis without taking into account import/export developments.

As shown in this thesis, most shortcomings can be resolved, some by improvements to existing methods, and others by applying newly developed methods. The new methods, presented in this thesis, are:

- bottom-up simulation of historic energy trends in end-use sectors,
- a policy-focused variant of decomposition (the PME-method),
- decomposition analysis with reconstructed energy balances (MONIT evaluation system),
- interaction matrix, to investigate possible interaction in sets of policy measures.

Especially the use of bottom-up simulation models, also used in energy scenario studies, can play an important role in improving evaluations of energy developments in the past. The use of a common model for ex-post and ex-ante evaluations overcomes many shortcomings as to diverging formats or definitions. It facilitates the comparison of targets for energy savings and figures on realised energy savings. More important, it stimulates an exchange of information on how driving factors influence energy consumption, which will be profitable for both historic evaluation and scenario studies. A general objection to the use of bottom-up models, lack of knowledge about detailed future trends, is not valid for analyses for the past, as detailed data are, in principle, available.

The new EU-directive on national energy saving targets demands an evaluation of total realised savings owing to policy, and a bottom-up evaluation of the effects of focused policy measures. The improved methods presented in this thesis can correct and supplement currently used methods as to meet the evaluation needs of the EU.

As to redeem the promise of improved evaluations some more work should be done. Firstly, simulation models have to be developed for other end-use sectors than households, or existing models have to be adapted for this application. Further, the PME-method and MONIT-evaluation system should be integrated in one system, as to get an overall evaluation scheme incorporating sector models. In the field of energy data there is a need for better statistical information for some sectors, such as services and agriculture. There is also a need for statistical data about specific variables, used to calculate reference energy consumption. However, the most important activity is the gathering of ‘micro data’ about penetration of saving options and structural changes at a low aggregation level. This can be accomplished by regular surveys in various sectors. Possibly, informatie will be available as part of the monitoring due to the EU-directive on energy savings, or monitoring of the effects of the new policy measure White Certificates in the Netherlands. Finally, more research is needed as to better calculate the uncertainty margins in the results, especially on transferring the ‘quality’ of constructed reference energy consumption to an uncertainty margin for this quantity.

Even applying all improvements, or improved methods, presented in this thesis does not guarantee that calculated energy savings represent the ‘true’ savings achieved. Energy savings cannot be directly observed; they are calculated as the difference between calculated reference energy consumption and observed energy consumption. Margins in input data and remaining limitations in the determination of reference energy consumption keep leading to uncertainty margins in calculation results that should always be provided.

At a lower aggregation level in the analysis of energy developments other values for energy savings will be found than at the higher level, because the figure is less mixed up with structure effects. For households in the Netherlands this thesis shows that a more detailed analysis provides higher energy saving figures. However, this cannot be generalized for other sectors.

The quantitative results, obtained using the improved methods, enable the following conclusions for energy (saving) policy in the Netherlands:

- Policy measures on energy savings in households have contributed significantly to realized total savings in the period 1990-2000.
- The effect of energy prices on energy consumption is limited for households; moreover its influence is decreasing owing to policy measures deployed.
- Interaction between various policy measures for households sometimes regards measures that reinforce each other’s effect. However, it mainly regards measures that overlap in their saving effects, thus decreasing the effectiveness of the set of policy measures.
- The development of the average national energy saving figure shows a decreasing trend in the period from 2000 to 2002. However, given the 30% uncertainty margins, conclusions should be drawn cautiously, especially for savings on final demand.
- Next to commonly calculated volume, structure and saving effects, changes in import and export of energy can affect energy trends. Especially for small internationally oriented countries, like the Netherlands, import or export can affect national energy developments substantially, and should therefore be taken into account when evaluating national energy trends and savings.

SAMENVATTING, OBSERVATIES EN CONCLUSIES

Samenvatting

Ontwikkelingen in de evaluatie van energietrends en energiebesparing

Energiebesparing is in dit proefschrift gedefinieerd als het verschil tussen het referentie energieverbruik,[15] d.w.z. het verbruik in afwezigheid van besparingsactiviteiten, en het waargenomen energieverbruik (zie Figuur 1.1). Het referentie energieverbruik wordt bepaald met behulp van waargenomen ontwikkelingen voor de variabelen die het energieverbruik bepalen, zoals groei van de bevolking en economie.

Evaluatie van gerealiseerde energiebesparing vereist het registreren (monitoren) van de werkelijke ontwikkelingen in het energieverbruik, het bepalen van het referentie energieverbruik, en het bepalen alsook interpreteren van de bereikte energiebesparing. In dit proefschrift omvat de evaluatie ook een analyse van de beleidsmatige besparing, ofwel de effecten van beleidsmaatregelen ter stimulering van energiebesparing.

Voor de berekening van de totale energiebesparing op nationaal of sectoraal niveau worden in de literatuur een aantal methoden beschreven, zoals decompositie analyse, het gebruik van energie efficiency indices of energie efficiency indicatoren, en een methode die ‘frozen technology’ wordt genoemd. Voor de analyse van beleidsmatige energiebesparing worden andere methoden toegepast, zoals technische berekeningen gebaseerd op de geimplementeerde besparingsopties, veldonderzoek naar investeringen in besparingsopties, en regressie analyse van energie ontwikkelingen.

In de laatste paar decennia is de behoefte aan energiebesparingsevaluaties gegroeid in lijn met het toegenomen belang van energiebesparing en de sterker wordende betrokkenheid van de overheid bij besparing. Dit geldt voor Nederland maar, meer recent, ook voor de EU (zie b.v. het recente *directive* over energiebesparing) en de OECD (zie b.v. de recente IEA-analyse van energie efficiency trends). De behoefte aan evaluaties is toegenomen om de volgende redenen. Allereerst is er de golf van nieuwe beleidsmaatregelen die gelanceerd zijn nadat het probleem van klimaatverandering, als gevolg van broeikasgassen in met name de energiesector, politiek erkenning kreeg (sinds het Brundtland rapport van 1987) Verder speelden een rol de expliciet geformuleerde sectorale en nationale doelstellingen over energiebesparing, de toegenomen financiele overheidssteun voor besparingsmaatregelen, een algemene politieke trend om de effectiviteit van beleid te toetsen, en tenslotte internationale verplichtingen tot het maken van rapportages, zoals in het kader van de Kyoto-overeenkomst over beperking van broeikasgas-emissies. Het nieuwe *directive* over energie-efficiency van de EU zal waarschijnlijk de vraag naar monitoring en evaluatie verder doen toenemen.

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[15] Formeel moet hier energiegebruik worden gehanteerd omdat, volgens de eerste hoofdwet van de thermo-dynamica, energie niet verloren gaat. Hier wordt echter aangesloten bij het normale spraakgebruik.

Evaluatie is dus een onlosmakelijk deel van het energiebesparingsbeleid geworden. Zo voert het Platform Monitoring Energiebesparing (PME) sinds 2000 jaarlijks een evaluatie uit van de gerealiseerde energiebesparing in Nederland, zowel op nationaal niveau als voor de sectoren huishoudens, industrie, landbouw, diensten, transport, raffinage en elektriciteitsproductie. Een ander voorbeeld is het Odyssee-project van de EU, waaruit indicatoren voor de energie efficiency in Europese landen beschikbaar komen die onderling vergelijkbaar zijn. Echter, de uitvoering van evaluaties en het gebruik van de resultaten wordt sterk gehinderd door verschillende problemen (zie tabel 8.2). Problemen met beschikbaarheid en betrouwbaarheid van inputdata leiden tot een onzekerheidsmarge van 30% in het jaarlijks berekende cijfer voor de totale energiebesparing in Nederland. Wat betreft beleidsmatige energiebesparing moet het probleem van de interactie tussen (steeds meer) beleidsmaatregelen genoemd worden. Deze interactie kan ten koste gaan van het besparingseffect van specifieke maatregelen en ook de effectiviteit van het energiebesparingsbeleid verminderen.

Tabel 8.2 Onderwerpen t.a.v. het beter evalueren van energietrends en besparing, behandeld in dit proefschrift

	Verbeterde methoden:
A1	Aggregatie niveau/keuze grootheden bij bepalen referentie energieverbruik
A2	Toe te passen energiegrootheden in de analyse
A3	Statische of dynamisch en gemiddelde of marginale conversierendementen
A4	Indirecte CO_2-emissies die consistent zijn met primaire energieverbruik
A5	Integrale berekening van sectorale besparingseffecten
A6	Transparantie in de relatie tussen energiestatistieken en analyseresultaten
A7	Temperatuurcorrectie van klimaatafhankelijk energieverbruik
	Interactie effecten:
B1	Interactie tussen besparingseffecten
B2	Interactie tussen energiebesparing and andere factoren die het verbruik bepalen
B3	Onderzoek van mogelijke interactie in sets van beleidsmaatregelen
B4	Kwantificering van interactie-effecten voor specifieke beleidsmaatregelen
B5	Interactie tussen beleidsmaatregelen en andere factoren
	Beleidsgerichte resultaten:
C1	Effecten van warmte/kracht, import/export, brandstofsubstitutie
C2	Consistente bepaling beleidsmatige-, autonome- en totale energiebesparing
C3	Onzekerheidsmarges in de berekende energiebesparingscijfers
C4	Relaties tussen datakwaliteit en de marges in resultaten
C5	Gebruik van ander basisjaar bij de presentatie van resultaten
C6	Top-down en bottom-up evaluaties gecombineerd
C7	Vergelijkbaarheid van gerealiseerde besparing en doelstelling voor besparing
C8	Effecten van eerdere beleidsmaatregelen op de lopende energiebesparing
	Verklaring/oorzaken van ontwikkelingen:
D1	Effect van systeembrede invloedsfactoren op energieverbruik en besparing
D2	Verklaring/oorzaken van prijseffecten
D3	Verklaring/oorzaken van beleidseffecten

Doel, onderwerp en vraagstelling van dit proefschrift

Het doel van dit proefschrift is *"voorzien in verbeterde methoden voor het analyseren en verklaren van energietrends en de bereikte energiebesparing op nationaal en sectoraal niveau, rekening houdend met de specifieke behoeften van beleidsmakers."*

Dit doel houdt een aantal keuzes in met betrekking tot de onderwerpen in de analyse. Dit proefschrift beschouwt de gerealiseerde energiebesparing en andere factoren die energieverbruikstrends bepalen, zoals volume- en structuur-effecten die zijn gerelateerd aan economische en sociaal-demografische ontwikkelingen, brandstofsubstitutie en import en export van energiedragers. Energiegerelateerde CO_2-emissies zijn ook onderdeel van de analyse. De analyse is gericht op nationaal en sectoraal niveau, met op onderdelen een focus op de sector huishoudens. Speciale nadruk ligt op de beleidsmatige bijdrage aan de gerealiseerde energiebesparing. De beleidseffectiviteit, dat wil zeggen de vergelijking van doelstellingen en realisaties, en de rol van bepalende factoren hierbij, komt ook aan de orde. Een ander belangrijk onderwerp is de interactie tussen diverse beleidsmaatregelen ten aanzien van hun besparingseffecten. Tenslotte beperkt de analyse zich niet tot berekening en evaluatie van resultaten, maar wordt er ook veel aandacht gegeven aan de presentatie van de resultaten, teneinde te voldoen aan de behoeften van de gebruikers van het onderzoek.

De algemene vraagstelling van dit proefschrift is vertaald in een aantal onderzoeksvragen (zie Paragraaf 1.5 en Tabel 8.2). Bij het ingaan op deze vragen komen ook de noodzakelijke en gerealiseerde verbeteringen van evaluatiemethoden naar voren. De onderzoekvragen zijn gegroepeerd naar vier thema's:

A. Verbeterde methoden voor monitoring en evaluatie van bereikte energiebesparing.
B. Interactie bij berekende energiebesparingeffecten en de bijdrage van beleidsmaatregelen.
C. Presentatie van resultaten in een vorm die voldoet aan behoeften van beleidsmakers.
D. Verklaring van de oorzaken van waargenomen totale en beleidsmatige besparing.

De onderzoekvragen worden beantwoord met gebruikmaking van de resultaten van vijf case studies die beschreven zijn in Hoofdstukken 2 tot en met 6 van dit proefschrift.

Aanpak en resultaten van case studies

Hoofdstuk 2 betreft een evaluatie van methoden die gebruikt worden om de gerealiseerde energiebesparing te bepalen. Zes methoden, gericht op nationaal of sectoraal niveau, worden beschouwd. Speciale aandacht wordt gegeven aan gemaakte keuzes en de genegeerde problemen die de berekening van juiste en bruikbare energiebesparingscijfers schaden. Onderzochte onderwerpen betreffen de keuze van het juiste aggregatieniveau, de geschikte variabelen om het referentie energieverbruik te bepalen, de toe te passen energiegrootheden en de interactie tussen diverse effecten. Ook de (veelal ontbrekende) onzekerheidsmarges bij de gepresenteerde resultaten komen aan de orde. Er wordt een optimale aanpak gedefinieerd, welke de negatieve effecten van problemen en keuzes op besparingsresultaten minimaliseert. De methoden worden beoordeeld op de mate waarin ze voldoen aan de eisen van deze aanpak. Verder wordt een aantal verbeteringen voorgesteld, waaronder het werken met finaal verbruik van warmte en elektriciteit en met energieverbruik in primaire termen, en het uitvoeren van bottom-up analyses op het niveau van concrete besparingsopties. Het laatste is van speciaal belang omdat het zowel top-down monitoring resultaten levert (hoeveel is in totaal bespaard?)

als bottom-up resultaten (wat hebben diverse beleidsmaatregelen bijgedragen aan de gerealiseerde besparing?). Beide typen resultaten zijn cruciaal in de evaluatie van het komende Europese energiebesparingsbeleid.

Hoofdstuk 3 presenteert een nieuwe benadering van energie- en emissie-monitoring voor beleidsdoeleinden, waarbij geconstrueerde energiebalansen worden toegepast. Met het onwikkelde rekensysteem, MONIT genaamd, kunnen historische energie- en emissie-ontwikkelingen gepresenteerd en geanalyseerd worden. Het evaluatiesysteem dekt het nationaal en sectoraal energieverbruik, en de bijbehorende CO_2-emissies, vanaf 1982. Naast alle gebruikelijke energiedragers en sectoren, geeft MONIT ook informatie over finaal verbruik van elektriciteit en warmte, warmte/kracht productie, primair energieverbruik en de indirecte CO_2-emissies van elektriciteitsverbruik. Om een goede evaluatie mogelijk te maken worden de energiebalansen met statistische verbruikcijfers eerst gecorrigeerd voor trendbreuken in statistieken en jaarlijkse variaties in klimaat. In het analysedeel van MONIT worden de ontwikkelingen in het energieverbruik weergegeven met een stap-voor-stap geconstrueerde set van energiebalansen, beginnend met de balans voor het basisjaar. Op deze manier wordt de waargenomen verandering in het energieverbruik ontrafeld in 14 factoren, inclusief vier energiegerelateerde structurele veranderingen, vijf besparingsfactoren, brandstofmix verschuivingen en veranderingen bij export en import van energie. De meeste van de 14 bijdragen kunnen berekend worden met slechts een kleine onzekerheid. Het MONIT-evaluatiesysteem biedt beleidsmakers een geïntegreerde set van monitoring resultaten op verschillende niveaus: (gecorrigeerde) statistische data, tijdreeksen, finaal en primair energieverbruik, directe en indirecte CO_2-emissies, energie-intensiteiten per sector, en beleidsrelevante bijdragen aan de waargenomen veranderingen in energie en emissie variabelen.

In **Hoofdstuk 4** wordt de monitoring van het energieverbruik van huishoudens met een simulatiemodel behandeld. Een bottom-up model voor simulatie van het toekomstige energieverbruik van huishoudens is aangepast om energietrends en gerealiseerde energiebesparing in het verleden te simuleren. Voor een groot aantal besparingsopties worden de ontwikkelingen geanalyseerd in samenhang met de groeifactoren en structurele veranderingen die het energieverbruik beïnvloeden. De verandering in het energieverbruik wordt gepresenteerd in de vorm van volume-, structuur- en besparingseffecten, waarbij de focus ligt op het energieverbruik in de periode 1990-1995. De methode biedt een zeer gedetailleerde analyse van de gerealiseerde energiebesparing, tot op het niveau van individuele besparingsopties. Er worden ook bijdragen van 30 structurele veranderingen gevonden die bijna allemaal leiden tot een toename in het energieverbruik. Met het aangepaste model is het mogelijk om analyses te maken van de onderlinge afhankelijkheid van structurele veranderingen en besparingsopties, van interactie tussen diverse besparingsopties, en van interactie tussen besparing en energetische effecten van brandstofsubstitutie. Ook wordt aangetoond dat complexe veranderingen in het energieverbruik ten gevolge van systeembrede factoren, zoals kleinere huishoudens of een grotere fractie woningen op stadsverwarming, gemakkelijk geanalyseerd kunnen worden.

Hoofdstuk 5 gaat in op het vraagstuk van interactie tussen beleidsmaatregelen voor energiebesparing. Het hoofdstuk begint met de presentatie van een kwalitatieve matrix-methode om de mogelijke interacties in een set van beleidsmaatregelen in kaart te brengen. Interactie betreft de invloed van de ene maatregel op het besparingseffect van de andere maatregel. Uitgaande van de voorwaarden voor een succesvolle implementatie van besparingsopties, wordt een algemene aanpak ontwikkeld om mogelijke interactie bij alle combinaties van twee beleidsmaatregelen in kaart te brengen. De methode levert een matrix op voor alle combinaties van maatregelen, met in iedere cel kwalitatieve informatie over de sterkte en het type interactie: ‘overlappend’, ‘elkaar versterkend’, of ‘onafhankelijk van elkaar’. Resultaten worden gepresenteerd voor de set van maatregelen ter verbetering van de energie-efficiency bij Nederlandse huishoudens in de periode 1990-2003. Vervolgens is voor een aantal belangrijke interacties een kwantitatieve analyse uitgevoerd met een simulatiemodel dat eerder is gebruikt voor scenarioberekeningen (zie ook Hoofdstuk 4). Dit model maakt gebruik van gedetailleerde data over huishoudelijk energieverbruik, verkregen uit enquetes. De kwantitatieve analyse is gemaakt voor combinaties van drie beleidsmaatregelen: een regulerende energieheffing, investeringssubsidies voor besparingsopties en regulering van het gasverbruik voor ruimteverwarming, waaronder normgeving. Het huishoudelijk energieverbruik in de periode 1990-2000 is gesimuleerd met en zonder deze drie beleidsmaatregelen. De resultaten wijzen uit dat de combinatie van beleidsmaatregelen 13-30% minder besparing oplevert dan de som van de besparingen van iedere beleidsmaatregel apart.

In **Hoofdstuk 6** wordt geanalyseerd hoe energieprijzen en beleidsmaatregelen het energieverbruik van huishoudens in Nederland beïnvloeden. De ontwikkeling van het energieverbruik in de periode 1990-2000 wordt gesimuleerd met het eerder beschreven bottom-up simulatiemodel. Eerst worden simulaties uitgevoerd voor een aantal alternatieve energieprijsontwikkelingen. Uit de verandering in het energieverbruik volgt een waarde voor de prijselasticiteit. Vervolgens wordt de prijsreactie verklaard aan de hand van de bottom-up veranderingen bij energieverbruik en besparingsopties. Een belangrijk resultaat is dat een beperkte set van besparingsopties voor een groot deel de prijsreactie bepaalt. Verder blijkt dat de grootte van de elasticiteit toeneemt in de tijd (overeenkomstig de literatuur op dit punt) ten gevolge van de geleidelijke vervanging van energieverbruikende systemen. Het prijseffect is ook geanalyseerd in combinatie met de beleidsmaatregelen (prestatie) normen, investerings-subsidies en energieheffingen. De simulatieresultaten wijzen uit dat bij afwezigheid van deze beleidsmaatregelen de prijselasticiteit 30-40% hoger zou kunnen zijn. Bijvoorbeeld omdat, door de strenge normen voor gasverbruik in nieuwe woningen, hogere of lagere energieprijzen daar nauwelijks nog van invloed zijn op het niveau van gasverbruik.

Synthese van bevindingen en verbeteringen

In Hoofdstuk 7 is een synthese gemaakt van de bevindingen in de case studies van dit proefschrift, inclusief de gevonden verbeteringen voor de evaluatie van energietrends en energiebesparing. In Hoofdstukken 2 t/m 6 zijn vier nieuwe methoden gepresenteerd die bijdragen aan de verbeteringen, namelijk:

- een simulatiemodel (voor huishoudelijk energieverbruik)
- de PME-methode (Protocol Monitoring Energiebesparing)
- het MONIT-evaluatiesysteem (geconstrueerde energiebalansen)
- de interactie matrix (onderzoek van mogelijke interactie in sets van beleidsmaatregelen).

De volgende bevindingen, gegroepeerd naar de vier in de vraagstelling gebruikte thema’s, zijn naar voren gekomen bij het beantwoorden van de onderzoekvragen.

A. Verbeterde methoden voor monitoring en evaluatie van bereikte energiebesparing:

- Het verkrijgen van betrouwbare besparingsresultaten vereist een aggregatieniveau waarop geschikte fysieke grootheden beschikbaar zijn om het referentie energieverbruik (energieverbruik in afwezigheid van besparingsactiviteiten) te bepalen. Voor de industrie biedt de PME-methode zo’n benadering (voor Nederland). Voor huishoudens biedt het simulatiemodel een dis-aggregatie van het energieverbruik tot op het niveau van besparingsopties, welke het mogelijk maakt het referentie energieverbruik nauwkeurig te bepalen.
- Wat betreft de in de analyse te gebruiken energie-grootheid zijn er enerzijds redenen om te werken met finaal verbruik van elektriciteit en warmte. Anderzijds zijn er redenen om te werken met primair energieverbruik. De gecombineerde oplossing is “finaal verbruik van elektriciteit en warmte, uitgedrukt in primaire energie-eenheden”. Deze aanpak wordt toegepast in de PME-methode en in het MONIT-evaluatiesysteem.
- Gebruik van statische primaire energie-eenheden, gebaseerd op eigenschappen van het aanbodsysteem in het basisjaar, laat de ontwikkelingen bij eindverbruikers zien zonder verstoring door effecten van gelijktijdige veranderingen bij het aanbod. Het gebruik van dynamische primaire energie-eenheden, gebaseerd op werkelijke ontwikkelingen in het aanbod van energie, laat de uiteindelijke effecten zien van eindverbruikmutaties op het primair energieverbruik. Beide resultaten kunnen getoond worden in de stapsgewijze decompositie, zoals uitgevoerd met het MONIT-evaluatiesysteem.
- De methoden voor analyse van energietrends en energiebesparing kunnen ook de toegepast worden op de bijbehorende ontwikkeling in CO_2-emissies, mits de indirecte emissies van elektriciteitsverbruik in eindverbruiksectoren bepaald kunnen worden. Dit vraagt om een geïntegreerde analyse van eindverbruik- en aanbodsectoren, welke bijvoorbeeld het MONIT-evaluatiesysteem verzorgt.
- Het emissie-effect van elektriciteitsbesparing hangt af van de definitie van de elektriciteitsvoorziening: binnenlandse produktie of totale levering inclusief import van elektriciteit. In het tweede geval levert elektriciteitsbesparing minder reductie van CO_2-emissies op, omdat aan import geen emissies worden verbonden en import dus de gemiddelde emissie per kWh verlaagt. In MONIT kunnen de emissie-effecten berekend worden voor beide definities van de elektriciteitsvoorziening.
- Om consistentie te verzekeren op nationaal niveau moeten decompositie analyses op sectoraal niveau voldoen aan zekere eisen, zoals onderscheid maken tussen besparing op finaal verbruik en besparing met gekoppelde warmte/kracht produktie. Zowel de PME-methode als het MONIT-evaluatiesysteem passen dit niveau van detail toe.
- Transparantie in de berekeningen kan bevorderd worden door integratie van de statistische data en het rekenschema, zoals in MONIT is toegepast. Hier is het mogelijk om verschillen in resultaten, ten gevolge van updates van statistieken of veranderingen in de bewerking van data, te traceren.
- Analyse van door de mens veroorzaakte veranderingen in energieverbruik vereist dat verbruik van alle relevante energiedragers wordt gecorrigeerd voor variaties in de gemiddelde buitentemperatuur. De variatie moet gedefinieerd worden als de jaarlijkse afwijking van het aantal graad-dagen van het gemiddelde aantal, zoals bepaald voor een vaste periode in het verleden. De correcties voor eindverbruikers moeten doorvertaald worden naar veranderingen in het energie-aanbod.

B. Interactie bij energiebesparingeffecten en de bijdrage van besparingsbeleid:

- Interactie tussen diverse besparingseffecten, bijvoorbeeld besparing op elektriciteitsverbuik en een hoger conversierendement van centrales, wordt rekenkundig aangepakt in decompositie analyses. In het MONIT-evaluatiesysteem en de PME-methode komen de besparingseffecten stapsgewijze in de analyse aan bod. De gebruikte volgorde in de analyse bepaalt hoe het gecombineerde besparingseffect wordt toegerekend aan de interacterende besparingsopties.
- De interactie tussen een besparingseffect en andere effecten betreft bijvoorbeeld een grotere besparing van efficientere energieprocessen ingeval de productie van industriele sectoren harder groeit. Dit kan het beste aangepakt worden met standaard decompositie methoden.
- In een omvangrijke set van beleidsmaatregelen zijn er vele mogelijke interacties tussen de besparingseffecten van beleidsmaatregelen. De kwalitatieve matrix methode, gepresenteerd in dit proefschrift, levert een snelle selectie van (vaak beperkte aantallen) combinaties met een substantiele interactie.
- De interactie tussen enkele beleidsmaatregelen ter beperking van huishoudelijk energieverbruik is gekwantificeerd met een bottom-up simulatiemodel dat historische energieontwikkelingen simuleert. De berekende energiebesparing voor de combinatie van heffingen, subsidies en regulering van ruimteverwarming blijkt lager uit te vallen dan de som van apart berekende besparingseffecten. De overlap lijkt toe te nemen in de tijd, hetgeen zou betekenen dat het totale beleid bij huishoudens minder effectief wordt.
- Met hetzelfde simulatiemodel is het mogelijk om de interactie te analyseren tussen beleidsmaatregelen ter stimulering van besparing en energieprijzen. Hieruit blijkt dat de beleidsmaatregelen de prijsgevoeligheid van het energieverbruik van huishoudens doen verlagen, met name voor gasverbruik.

C. Presentatie van evaluatieresultaten in een vorm die voldoet aan de informatie behoeften van beleidsmakers:

- Het MONIT evaluatiesystem kan specifieke beleidsrelevante energie-effecten, zoals de bijdrage van import/export en substitutie tussen brandstoffen aan de verandering van het totale energieverbruik, laten zien. Dit vereist juist gekozen energiegrootheden, energiedata die gebaseerd zijn op volledige energiebalansen (inclusief winning, import en export), voldoende dis-aggregatie van het energieverbruik en een geïntegreerde benadering voor energie-aanbod en eindverbruik.
- De totale energiebesparing en de beleidsmatig gerealiseerde besparing worden vaak apart berekend volgens verschillende methoden. De simulatiemethode, gepresenteerd in dit proefschrift, biedt een geïntegreerde bepaling van de beleidsmatige-, de autonome- en de totale energiebesparing. Er geldt een zelfde formaat (definities energieverbruik en invloedsfactoren) en het effect van alle invloedsfactoren wordt tegelijk geanalyseerd.
- Berekende besparingscijfers hebben een onzekerheidsmarge die deels toe te schrijven is aan de marges in de gebruikte data, maar vooral een gevolg is van fouten bij het bepalen van het referentie energieverbruik. Alleen de PME-method berekent de onzekerheidsmarges, welke bijvoorbeeld 30% bedraagt voor de totale jaarlijks gerealiseerde energiebesparing in Nederland.
- De analyse van onzekerheidsmarges als deel van de PME-method laat ook zien dat de kwaliteit van de evaluatieresultaten verbeterd kan worden door een lager aggregatie ni-

veau te kiezen. Zowel het grotere aantal segmenten in het totale energieverbruik, alswel een 'beter' referentie energieverbruik, reduceren de onzekerheidsmarge in de besparingsresultaten.
- Een eerste voorwaarde voor het kunnen vergelijken van resultaten van verschillende studies is het gebruik van hetzelfde basisjaar. Veel methoden zijn er niet op ingericht om naar behoefte een herberekening uit te voeren voor een ander basisjaar. In MONIT kan een berekening plaats vinden op basis van een willekeurig te kiezen basisjaar vanaf het jaar 1990.

D. Verklaring van de oorzaken van berekende totale en beleidsmatige energiebesparing:

- Sommige mutaties in het totale energieverbruik zijn een gevolg van complexe veranderingen in het energieverbruik door systeem-brede factoren zoals een afnemend aantal personen per huishouden. De verklaring van deze mutaties vereist een methode die om kan gaan met alle secundaire gevolgen van, en interdependenties tussen, diverse ontwikkelingen in het energieverbruik (b.v. een ongunstiger kosten/baten verhouding voor zuinige verwarmingsketels door een lagere warmtevraag per woning). Het gedetailleerde simulatiemodel voor huishoudelijk energieverbruik maakt zo'n analyse mogelijk.
- Simulatie van het historisch energieverbruik, waarbij gebruik wordt gemaakt van modellen met gedragsmatige relaties tussen energieverbruik en bepalende factoren, kan bijdragen aan het verklaren van de ontwikkeling van het energieverbruik en de energiebesparing. Bijvoorbeeld, simulaties voor huishoudens in Nederland laten lage prijselasticiteiten zien (waarde 0,12 - 0,13) die toenemen met de tijd. De kleine invloed van prijzen is te wijten aan het feit dat maar een beperkte fractie van alle besparingsopties gevoelig is voor prijsveranderingen. Ook kost het tijd om te kunnen reageren op prijsveranderingen, vanwege de geleidelijke vervanging van energiesystemen.
- Met simulatiemodellen kan de energiebesparing van afzonderlijke beleidsmaatregelen bepaald worden, los van interactie met andere beleidsmaatregelen. In dit proefschrift is dit voor huishoudens in Nederland gedaan voor de regulerende energiebelasting, investeringssubsidies voor besparingsopties en regulering van gasverbruik voor ruimteverwarming in nieuwe en bestaande woningen.
- Berekeningsmethoden voor gerealiseerde energiebesparing verschillen vaak sterk van de methoden ter bepaling van de verwachte besparing in energiescenario's, die als basis dient voor het formuleren van besparingdoelen. De simulatiemethode, gepresenteerd in dit proefschrift, kan deze methodologische scheiding overbruggen omdat de evaluaties zijn gebaseerd op berekeningen met een (aangepast) bottom-up model dat ook toegepast kan worden voor scenarioberekeningen.
- In het algemeen kan de gerealiseerde energiebesparing niet vergeleken worden met de doelstelling voor besparing, omdat de werkelijke ontwikkelingen afwijken van eerder gemaakte veronderstellingen bij het formuleren van de doelstelling. De simulatie aanpak maakt het mogelijk om hiervoor te corrigeren. Dit geschiedt door hetzij een correctie van de doelstelling (herberekening met werkelijke trends), hetzij een correctie van de gerealiseerde besparing (op basis van originele veronderstellingen over bepalende factoren). Aldus kan een 'eerlijker' vergelijking gemaakt worden.
- Naast energiebesparing dankzij beleidsmaatregelen of autonome trends, kan besparing ook te danken zijn aan eerder gevoerd beleid, dat wil zeggen beleid gevoerd voor het begin van

de analyseperiode. Voor huishoudelijk energieverbruik zou de besparing door ‘eerder beleid’ bepaald kunnen worden met het simulatiemodel; dit is echter nog niet gedemonstreerd.

Observaties

Tegenvallend gebruik van resultaten van monitoring en evaluatie

Voor de bepaling van de totale bereikte energiebesparing op nationaal en sectoraal niveau zijn, ook in dit proefschrift, diverse methoden ontwikkeld. Een aanzienlijk aantal toepassingen van deze methoden kan gevonden worden in de literatuur. Voor de bepaling van beleidsmatige energiebesparing zijn andere methoden beschikbaar, met een nog groter aantal toepassingen in de literatuur.

Echter, het gebruik van de resultaten van monitoring en evaluatiestudies is nog beperkt. Tot enkele jaren geleden speelden kwantitatieve resultaten van deze (ex-post) analyses geen doorslaggevende rol in de formulering van het energiebesparingsbeleid. In Nederland was het besparingsbeleid, vastgelegd in diverse nota’s, gebaseerd op de resultaten van (ex-ante) scenarioanalyses. Pas sinds 2000 heeft de evaluatie van gerealiseerde energiebesparing direct geleid tot veranderingen in de formulering van besparingsdoelstellingen en -beleid.

Op EU-niveau zijn recent ook energiebesparingsdoelstellingen geformuleerd. In de *directive* over energiediensten en energiebesparing wordt gerefereerd aan de Odyssee indicatoren voor het monitoren van energie-efficiency. Echter, dit geldt voor de in de toekomst uit te voeren evaluaties van de dan bereikte energiebesparing. De beschikbare Odyssee-cijfers over in het verleden gerealiseerde besparing worden niet genoemd bij het presenteren van de doelstelling.

Voor ontwikkelde landen zijn de energie (efficiency) trends recentelijk in kaart gebracht door het IEA. Ofschoon de resultaten waarschijnlijk het huidige politieke klimaat voor energiebesparingsbeleid in OECD-landen hebben beïnvloed, worden de IEA-resultaten nergens expliciet genoemd bij het (her)formuleren van energiebesparingsdoelen. Dezelfde waarneming kan gemaakt worden op UN-niveau, waar wereldwijde trends in energievraag en -aanbod in kaart zijn gebracht in de World Energy Assessment studie in 2000.

De redenen voor de zwakke positie van ex-post monitoring en evaluatie zijn reeds belicht in de vraagstelling in het inleidende hoofdstuk van dit proefschrift. De verbetering van bestaande methoden, en de ontwikkeling van nieuwe methoden, zou deze situatie kunnen veranderen.

Manieren om evaluaties te verbeteren

De in dit proefschrift gepresenteerde verbeteringen zouden de tekortkomingen van bestaande evaluatiestudies grotendeels kunnen opheffen. Echter, om de verschillende problemen (zie Tabel 8.2) tegelijk aan te pakken zouden de nieuwe methoden in combinatie moeten worden toegepast. In dit proefschrift is dit gerealiseerd voor de combinatie van de interactie-matrix en simulatie van historische ontwikkelingen in het energieverbruik (zie hoofdstuk 5). Verdere mogelijkheden betreffen de combinatie van de twee varianten op de decompositie aanpak, namelijk de PME-methode en het MONIT-evaluatiesysteem. Tenslotte zou deze gecombineerde methode tesamengenomen moeten worden met de simulatie-aanpak; dit vereist een afstemming van definities, sectorindelingen en rekenregels bij de methoden.

Een tweede voorwaarde voor verbeterde evaluaties op nationaal en sectoraal niveau is een volledige dekking van de eindverbruiksectoren. De interactie-matrix en het simulatiemodel zijn nu beschikbaar voor slechts èèn sector (de huishoudens) en zouden ook beschikbaar moeten zijn voor de sectoren industrie, land- en tuinbouw, transport en diensten. Wat betreft de interactie-matrix zou dit geen probleem hoeven te geven omdat de internationale MURE database informatie verschaft over beleidsmaatregelen in alle eindverbruiksectoren. Wat betreft simulatie voor andere sectoren, kan gebruik worden gemaakt van de bottom-up simulatiemodellen die al beschikbaar zijn in Nederland voor de industrie, land- en tuinbouw en diensten. Hier is een extra inspanning nodig om de modellen aan te passen en om de simulatieresultaten in overeenstemming te brengen met de waargenomen trends. De bottom-up simulatiemethode vereist gedetailleerde informatie over penetratie van besparingsopties en structurele veranderingen. De eisen aan de data hoeven niet de beperkende factor te zijn, mits voldoende tijd en inspanning gestoken wordt in het verzamelen van deze data. De ervaring met het model voor huishoudens toont aan dat een tamelijk kleine maar gerichte jaarlijkse enquete de benodigde informatie kan leveren. Deze inspanningen zullen ook nuttig zijn voor het opzetten en evalueren van de effecten van het (mogelijk) nieuwe beleidsinstrument Witte Certificaten, waarbij certifcaten per gerealiseerde besparingsoptie worden verstrekt. Het werk aan simulatie van voorbije energieontwikkelingen kan ook bijdragen aan het valideren van de simulatiemodellen die gebruikt worden in energiescenario's, omdat het 'fitten' van simulatie-resultaten aan de werkelijkheid informatie oplevert over de te gebruiken modelparameters.

Een derde conditie voor verbeterde evaluaties betreft betrouwbare statistieken aangaande het daadwerkelijke energieverbruik en de variabelen die gebruikt worden om het referentie energieverbruik te bepalen. Momenteel beperken de onzekerheidsmarges in de jaarlijks berekende energiebesparing (30% voor de totale besparing in Nederland) het nut voor beleidsmakers. Volgens de onzekerheidsanalyse in de PME-methode zijn de marges in statistische data vaak van dezelfde orde als de (relatieve) omvang van de jaar-op-jaar gerealiseerde energiebesparing. Daarom kunnen besparingscijfers met een acceptabele onzekerheidsmarge alleen worden gegeven als een gemiddelde over een periode van minstens zeven jaar (zie paragraaf 7.4). Kleinere marges in inputdata maken zowel meer betrouwbare resultaten als een snellere rapportering aan beleidsmakers mogelijk.

Een laatste op te lossen probleem is vergelijkbaarheid van resultaten, allereerst voor verschillende evaluatiestudies op hetzelfde terrein, ten tweede voor ex-post en ex-ante analyses, en ten derde tussen verschillende landen. Het eerste probleem is voor Nederland aangepakt met de ontwikkeling van een algemeen schema voor berekening van gerealiseerde energiebesparing, de zogenaamde PME-methode. Vergelijking van ex-post evaluatieresultaten met doelstellingen gebaseerd op ex-ante scenarioresultaten is al eerder aan de orde geweest. De toepassing van een zelfde simulatiemodel in de analyses van toekomstige en historische ontwikkelingen kan de vergelijkbaarheid van resultaten aanzienlijk verbeteren. Internationale vergelijkbaarheid betreft hoofdzakelijk het EU-niveau, waar het Kyoto verdrag, CO_2-emisiehandel en vooral het nieuwe *directive* over energiebesparing vragen om vergelijkbare cijfers over de gerealiseerde energiebesparing per land. Momenteel worden al Europese energie-efficiency indicatoren geleverd door het Odyssee-project. Deze informatie zou gebruikt kunnen worden om in elk land methoden zoals de PME-methode of MONIT te implementeren. Echter, wegens gebrek aan bottom-up simulatiemodellen in veel landen, blijft vergelijkbaarheid van beleidsmatige energiebesparing een probleem.

Kwantitatieve resultaten voor energiebesparing en effecten

De focus van dit proefschrift ligt op methodologische verbeteringen in evaluatiemethoden. Het belang van deze verbeteringen is kwantitatief onderbouwd in diverse analyses. Echter, de met deze analyses verkregen resultaten zijn ook op zichzelf beschouwd belangrijk voor de beleidsmakers. Hier worden een aantal verkregen resultaten per nieuw ontwikkelde methode samengevat.

De resultaten verkregen met het **simulatiemodel** van *huishoudelijk* energieverbruik in Nederland betreffen de periode *1990-2000*. Deze resultaten zijn als volgt:

- De totale energiebesparing van huishoudens (waarbij elektriciteit is omgerekend naar primair energieverbruik onder aanname van 40% conversierendement) bedraagt ongeveer 2,2% per jaar.
- De regulerende energiebelasting, vanaf 1996 toenemend tot meer dan 30% van de totale gas- of elektriciteitsprijs in 2000, heeft een besparing opgeleverd van ongeveer 2% van het energieverbruik in 2000, zowel voor aardgas als elektriciteit.
- Subsidies die in de meeste jaren voor een groot deel van de besparingsopties zijn verstrekt bedroegen 20-25% van de extra investeringen t.o.v. het referentiesystem. Het berekende besparingseffect in 2000 is gelijk aan ongeveer 3% van het elektriciteitsverbruik en 4% van het gasverbruik.
- Regulering van gasverbruik voor ruimteverwarming heeft geleid tot 4-5% minder gasverbruik in 2000, hoofdzakelijk bereikt in nieuwe woningen. Regulering omvatte met de sociale verhuurders overeengekomen besparingsmaatregelen bij te renoveren woningen, maar vooral normen voor nieuw te bouwen woningen. Tot 1995 betrof dit normen voor isolatie en ketelrendementen, daarna gevolgd door een prestatienorm die regelmatig werd aangescherpt.
- Het gecombineerde besparingseffect van deze beleidsmaatregelen bedroeg 50% van de per 2000 bereikte totale gasbesparing, en 15% van de totale elektriciteitsbesparing. De extra besparing dankzij andere beleidsmaatregelen wordt als klein ingeschat.
- De combinatie van de beleidsmaatregelen regulerende heffing, investeringssubsidies en regulering van ruimteverwarming levert 13-30% minder besparing op (voor gasverbruik) dan de som van de besparingen van elke beleidsmaatregel apart.
- De gevonden prijselasticiteit bedraagt 0,13 voor gasverbruik en 0,11 voor elektriciteitsverbruik. Deze is gebaseerd op de berekende reductie van het energieverbruik in 2000 na een vaste relatieve priisverandering van 20% vanaf 1990.
- De aanwezigheid van de eerder genoemde drie beleidsmaatregelen vermindert de prijsgevoeligheid met 25-30% (periode 1995-2000).
- Structurele veranderingen leiden tot een drie à vier keer grotere toename van het elektriciteitsverbruik dan geldt voor het aardgasverbruik. Dit is deels een gevolg van vervanging van aardgas door elektriciteit bij de warmwatervoorziening en bij koken.

- De berekende brandstofbesparing (in PJ) van efficientere ketels in huishoudens verschilt een factor 1,5 of meer, afhankelijk van de volgorde waarin structuur-effecten (b.v. een hogere thermostaat instelling) en andere besparingsopties (b.v. waterbesparende douchekop) worden meegenomen in de analyse.

Resultaten verkregen met de **PME-methode** voor energiebesparing in Nederland zijn:
- De gemiddelde nationale energiebesparing bedroeg 1,2% per jaar in de periode 1990-2000 en 1,0% per jaar in de periode 1995-2002 (met een marge van +/- 0,3%).
- De gemiddelde jaarlijkse energiebesparing per sector bedroeg 1,5% in huishoudens, 1,3% in de industrie, 0,4% bij transport en 1,8% in de land- en tuinbouw in de periode 1990-2000.
- De totale nationale besparing van 1,2% in de periode 1990-2000 was het resultaat van besparing bij finaal verbruik (0,9%), warmte/kracht productie (0,2%) en een efficientere energiesector (0,1%).

Enige opvallende resultaten uit berekeningen met het **MONIT-evaluatiesysteem** zijn:
- De vermindering in de totale jaarlijkse CO_2-emissies tussen 1998 en 1999 bedroeg ongeveer 3 Mton. Dit resultaat is echter sterk beïnvloed door de verandering bij import van energie (m.n. elektriciteit) welke 6 Mton aan CO_2-emissies van centrales uitspaarde (zie Figuur 3.13).
- In de periode 1990-1998 werd de initiele toename van de energiebesparing bij industriele warmte/kracht productie bijna gehalveerd door verbeterde conversie rendementen van centrales en meer elektriciteitsimport (dus minder uitgespaarde brandstof als gevolg van elektriciteitproductie met warmte/kracht eenheden, zie Figuur 3.14).

De analyse van 15 beleidsmaatregelen gericht op energiebesparing bij huishoudens in Nederland, gebruik makend van de **interactie-matrix methode**, levert de volgende resultaten:
- Slechts 9% van alle 136 mogelijke combinaties van twee maatregelen kent een sterke interactie, waarvan het grootste deel een overlap vertoont.
- Slechts zes combinaties verdienen een verdere kwantitatieve analyse van de interactie, waarbij de volgende beleidsmaatregelen zijn betrokken: normen voor gasverbruik in nieuwe woningen, de regulerende energiebelasting, investeringssubsidies voor besparingsopties, het energiebesparingadvies en labels voor apparaten.

Conclusies en aanbevelingen

Evaluatie van bereikte energiebesparing op nationaal of sectoraal niveau is een reguliere activiteit geworden, zowel voor de totale besparing als voor de beleidsmatige besparing. Echter, het daadwerkelijk gebruik van de resultaten voor het (her)formuleren van energiebesparingsbeleid wordt gehinderd door diverse tekortkomingen van bestaande evaluatiemethoden.

Vele tekortkomingen zijn te wijten aan het feit dat evaluaties niet genoeg aandacht besteden aan de behoeften van de gebruikers van de resultaten, met name de beleidsmakers. Zo sluiten resultaten niet aan bij onderdelen van het geformuleerd beleid (bijvoorbeeld geen aparte besparingscijfers voor warmte/kracht productie). Ook is er een gebrek aan afstemming tussen de berekening van de totale besparing en de bepaling van beleidsmatig bereikte besparing. De cijfers voor de gerealiseerde besparing (ex-post evaluatie) zijn veelal niet vergelijkbaar met de hiervoor geformuleerde doelstellingen, gebaseerd op scenariostudies (ex-ante evaluatie). Gebrek aan algemeen geaccepteerde methoden verhindert ook een goede vergelijking van resultaten tussen landen, met name bij de beleidsmatige energiebesparing.

Verder houden methoden geen rekening met interactie tussen beleidsmaatregelen. De berekende effecten worden gepresenteerd zonder ze te verklaren aan de hand van de ontwikkelingen voor bepalende grootheden. Tenslotte worden beleidsmakers niet geïnformeerd over de (forse) onzekerheidsmarges in de besparingsresultaten.

Andere tekortkomingen zijn een gevolg van gemaakte methodologische keuzes, bijvoorbeeld het gebruik van energiegrootheden waarmee geen analyse mogelijk is van de energiebesparing met warmte/kracht productie. Een ander probleem is het (te) hoge aggregatieniveau in de analyse, leidend tot een berekende energiebesparing die vermengd is met structuur- of substitutie-effecten. Ook problematisch is een te beperkt terrein van analyse, bijvoorbeeld analyses van het eindverbruik los van de gelijktijdige ontwikkelingen bij het energieaanbod, of ananlyses van het nationale energieverbruik zonder rekening te houden met de ontwikkelingen bij de import en export van energiedragers.

Zoals beschreven in dit proefschrift kunnen de meeste tekortkomingen aangepakt worden; sommige door verbeteringen van bestaande methoden, en andere door het toepassen van nieuw ontwikkelde methoden. Nieuwe methoden, gepresenteerd in dit proefschrift, zijn:

- bottom-up simulatie van historische energietrends in eindverbruiksectoren,
- een beleidsgerichte variant op decompositiemethoden (de PME-methode),
- decompositie analyse met geconstrueerde energiebalansen (het MONIT-evaluatiesystem),
- interactie-matrix, ter selectie van combinaties van beleidsmaatregelen waar sprake is van interactie.

Vooral het gebruik van bottom-up simulatiemodellen, welke ook gebruikt worden in energie scenariostudies, kan een belangrijke rol spelen bij het verbeteren van de evaluatie van gerealiseerde energiebesparing. Het gebruik van een overeenkomstig model voor ex-post en ex-ante evaluaties vermijdt de problemen met verschillende formaten of definities. Het vergemakkelijkt de vergelijking van doelstellingen voor energiebesparing met de cijfers voor gerealiseerde energiebesparing. Nog belangrijker is dat het een uitwisseling van informatie stimuleert over factoren die bepalend zijn voor het energieverbruik, hetgeen gunstig is voor zowel historische evaluaties als scenariostudies op energiegebied. Een algemeen bezwaar tegen het gebruik van bottom-up modellen in scenarios, namelijk gebrek aan gedetailleerde kennis over toekomstige trends, geldt niet voor het verleden, waar deze data in beginsel wel beschikbaar zijn.

Het nieuwe EU-*directive*, met o.a. nationale energiebesparingsdoelstellingen, vereist een evaluatie van de totale besparing die dankzij beleid is bereikt en een bottom-up evaluatie van het effect van specifieke beleidsmaatregelen. De verbeteringen en methoden, gepresenteerd in dit proefschrift, kunnen een belangrijke bijdrage leveren aan het voldoen aan de evaluatiebehoeften van de EU.

Om de belofte van verbeterde evaluaties waar te kunnen maken moeten wel een aantal aanvullende werkzaamheden worden uitgevoerd. Allereerst moeten ook simulatiemodellen voor andere eindverbruiksectoren dan huishoudens worden ontwikkeld, of aangepast voor toepassing op het verleden. Verder moeten de PME-methode en het MONIT-evaluatiesysteem geïntegreerd worden, teneinde een sectoroverkoepelend evaluatie-instrument te verkrijgen. Op het gebied van energiedata is behoefte aan betere statistische gegevens voor sommige sectoren, zoals diensten en land- en tuinbouw. Er is ook behoefte aan statistische data over bepaalde grootheden waarmee het referentie energieverbruik wordt bepaald. Het belangrijkste is echter het verzamelen van ‘micro data’ ten aanzien van de penetratie van besparingsopties en structurele veranderingen op een laag aggregatieniveau. Dit kan plaatsvinden middels regelmatig te houden enquetes per sector. Mogelijk komt informatie beschikbaar in het kader van de monitoring voor het besparings*directive* van de EU, of de monitoring van de effecten van het nieuw toe te passen beleidsinstrument Witte Certificaten. Tenslotte zou nader onderzoek kunnen plaatsvinden om de onzekerheidsmarge in de resultaten beter te bepalen, met name het vertalen van de ‘kwaliteit’ van het geconstrueerde referentie energieverbruik naar een onzekerheidsmarge voor dit verbruik.

Zelfs bij toepassing van alle verbeteringen of gebruik van de verbeterde methoden, zoals gepresenteerd in dit proefschrift, kan niet gegarandeerd worden dat de berekende energiebesparing de ‘echte’ bereikte besparing weergeeft. Energiebesparing kan immers niet direct waargenomen worden, maar moet berekend worden als het verschil tussen een berekend referentie energieverbruik en een waargenomen energieverbruik. Onnauwkeurigheidsmarges in de inputdata en resterende beperkingen bij het bepalen van het referentie energieverbruik blijven leiden tot onzekerheidsmarges in de resultaten, welke altijd aangegeven zouden moeten worden.

Bij een lager aggregatieniveau in de analyse van de ontwikkelingen in het energieverbruik worden andere waarden voor de bepaalde energiebesparing gevonden dan op een hoger aggregatieniveau, omdat het cijfer minder vermengd is met structuur-effecten. Voor huishoudens in Nederland laat dit proefschrift zien dat een meer gedetailleerde analyse hogere energiebesparingscijfers oplevert. Voor andere sectoren staat dit echter niet algemeen vast.

De kwantitatieve resultaten die verkregen zijn met de verbeterde methoden maken het mogelijk de volgende conclusies te trekken voor het energie(besparing)beleid in Nederland:

- Beleidsmaatregelen voor energiebesparing in huishoudens hebben behoorlijk bijgedragen aan de gerealiseerde totale besparing in de periode 1990-2000.
- Het effect van energieprijzen op het energieverbruik is bij huishoudens beperkt; bovendien neemt de invloed af door de ingevoerde beleidsmaatregelen.
- Interactie tussen diverse beleidsmaatregelen voor huishoudens betreft soms elkaar versterkende effecten, maar meestal elkaar overlappende effecten. Dit laatste vermindert de effectiviteit van het pakket van beleidsmaatregelen gericht op energiebesparing.
- De ontwikkeling van het gemiddelde jaarlijkse energiebesparingscijfer op nationaal niveau laat zien dat het besparingstempo is afgenomen tussen 2000 en 2002. Echter, gegeven de 30% onzekerheidsmarges, moeten conclusies voorzichtig getrokken worden, met name voor besparing op finaal verbruik.

- Naast de algemeen berekende volume-, structuur- and besparingseffecten zijn ook de veranderingen bij import en export van energie van belang. Vooral in kleine internationaal georienteerde landen zoals Nederland kunnen deze de energietrends sterk beïnvloeden, en moeten dus meegenomen worden in de evaluatie van nationale energietrends en besparing.

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Curriculum Vitae

Piet G.M. Boonekamp was born in Pynacker on September 23th, 1948. After attending the Higher Technical School in The Hague and performing military service he decided to continue his scientific education at the Technical University of Eindhoven, in the faculty of Electrical Engineering. In the final stage of his study he participated in an inter-disciplinary project about analysing the energy supply system of the Netherlands. He finished his study in 1977 with a thesis "Developing a linear programming model of the Dutch energy supply system". In 1978 he worked temporarily at the university in a research project on "long term relationship between energy consumption and production in industrial sectors". Then he joined the just established Energy Study Centre of ECN, which should advise government on future energy policy matters. During his years at ECN he worked on the following subjects:

- Energy model building, both at the national level, cogeneration and end-use sectors (especially households).
- Execution of scenario studies, e.g. the National Energy Outlook, in support of energy and environmental policy makers.
- Electricity supply: capacity planning, load dispatch, load-curves, industrial cogeneration and costs of base-load electricity production.
- Energy demand: calculations with the developed bottom-up simulation model for households, providing energy savings owing to policy measures.
- Monitoring and evaluation of energy and emission trends in the Netherlands, with emphasis on energy savings, both at national and international level.

Next to his work in projects he was, for a number of years, coordinator of unit activities in the field of national energy policy and later group leader of the section National energy policy. Since 2001 he is coordinator of Platform Monitoring Energy savings (PME), consisting of MNP/RIVM, SenterNovem, CBS and ECN, which regularly provides figures about realised energy savings in the Netherlands. Since 2003 he is member of the Technical Coordination committee of the international Odyssee project on energy indicators. Further on, he participates in the national Discussion Platform on Energy issues (Bezinningsgroep Energie).

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