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DYNAMIC ENERGY CONSERVATION MODEL REDUCE

Extension with experience curves, energy efficiency indicators and user's guide

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Abstract

The main objective of the energy conservation model REDUCE is the evaluation of the effectiveness of economical, financial, institutional, and regulatory measures for improving the rational use of energy in end-use sectors. This report presents the results of additional model development activities, partly based on the first experiences in a previous project.

- Energy efficiency indicators have been added as an extra tool for output analysis in REDUCE. The methodology is described and some examples are given.
- The model has been extended with a method for modelling the effects of technical development on production costs, by means of an experience curve.

Finally, the report provides a ‘users guide’, by describing in more detail the input data specification as well as all menus and buttons.

Preface

This project was registered under ECN project 7.7146 in 1998, and 7.7189.01.02 in 1999.

CONTENTS

SUMMARY

The main objective of the energy conservation model REDUCE is the evaluation of the effectiveness of economical, financial, institutional, and regulatory measures for improving the rational use of energy in end-use sectors. This report presents the results of additional model development activities, partly based on the first experiences in a previous project.

The first model extension is the addition of *energy efficiency indicators* as an extra tool for output analysis in REDUCE. This creates the opportunity to compare historical trends with different developments in the future. Furthermore, international comparisons and benchmarking can be performed by using the indicators.

The indicators are implemented as a very flexible tool. For each indicator, the user decides which activity is used, which growth rates and on which level of energy demand the indicator is calculated. This is in line with the overall objective of REDUCE to provide an international framework for comparable energy conservation studies. The case studies show some brief analysis using indicators. They show that, among other things, effects of dematerialization, structural changes and policy measures (here environmental surcharges) can be made visible by comparing energy efficiency indicators.

A potential weakness of the methodology with which the indicators are calculated is that it compares several projections. After all, the future energy consumption is based on projections just like the activity. Only the achieved savings are simulated. This is an important difference compared to the certainty of indicators when looking at the past. Therefore care should be taken that the projections are consistent. On the other hand, an indicator analysis can be regarded as a useful check on the quality of both the projections and the model results, by visualising trends and, possibly, disruptions.

The second model extension consists of a method for modelling the effects of technical development on production costs, by means of an *experience curve*. The use of experience curves can add a degree of realism to the model. Technologies in the demonstration stage are characterised by a small market share, high investment costs but also by a high saving potential. If more units of these options are produced, investment costs will decrease as a result of the learning effect: more experience in the production process will induce a cost decrease. This implies that for technologies still in the demonstration stage, the assumption that the investment costs remain constant over time is not appropriate. For most other saving options the S-curve, a standard feature of REDUCE, sufficiently reflects the different stages of technology development.

The case studies show that the definition of an experience curve does not automatically result in a larger market share. Based on the initial investment costs, some extra units will have to be produced, otherwise the learning effect is not induced. For example, the heatpump has an internal rate of return that is too low during the start year. Policy measures such as regulation will be required to support this technology to overcome its experimental stage. The high-concentration dryer is an example of a technology that is probably better modelled using an experience curve.

Finally, the report provides a 'users guide' to the REDUCE model, by describing in more detail the input data specification as well as all menus and buttons.

1. INTRODUCTION

Although a wide range of internationally applied energy demand models exists, it is not always easy to incorporate energy conservation activities in these models in an appropriate way. Econometric models such as SEEM (Pellekaan et al., 1995)treat energy demand (and thus energy conservation) as a function of economic production and energy prices. These models consider market barriers, consumer behaviour and responses to prices in an aggregated way by means of elasticities, but they are not able to analyse at technology level. Furthermore, calculation of elasticities is based on long time series of data, implicitly assuming unchanged technological and policy environment. In simulation models, such as MEDEE, relationships are typically fixed without description of conservation behaviour of consumers. Apart from these international modelling activities, many national energy conservation models have been developed, such as the Dutch SAVE models (ISIS, 1992). In most cases these models are very detailed and country specific. Up to now, most close to an internationally applicable energy conservation model is MURE (Boonekamp, 1994). The MURE software has been developed within the framework of the DG XVII SAVE programme. It provides information on energy conservation measures that have been carried out in the 15 Member States of the European Union, and enables the simulation and comparison at a national level of the potential impact of such measures.

Given the complex field of energy conservation and the many approaches for modelling and understanding different aspects of conservation, it is impossible to combine all these modelling activities into one energy conservation model. However, scope exists for a model, which can provide a basis for international communication, research activities, and policy making in the field of energy conservation. Therefore, the main reason for developing the energy conservation model REDUCE (Reduction of Energy Demand by Utilisation of Conservation of Energy) is to provide national results that are comparable in an international context[1]. This allows for assessing common aspects as well as understanding country-specific characteristics of energy conservation across Europe. This way, REDUCE provides a common framework for a consistent and comparable transfer between countries of different aspects of energy conservation, such as options, potentials, costs, market penetration and policy instruments. The approach was first used for this purpose in an EU funded project involving seven countries, see Van Harmelen and Uyterlinde (1999).

The main objective of REDUCE is the evaluation of the effectiveness of economical, financial, institutional, and regulatory measures for improving the rational use of energy in end-use sectors. Not only the technical scope and ranking according to a range of criteria for investments in energy savings is assessed, but also the market dynamics of energy saving options are considered, on the short term (immediate policy actions and implementation) and longer term (strategic policy considerations).

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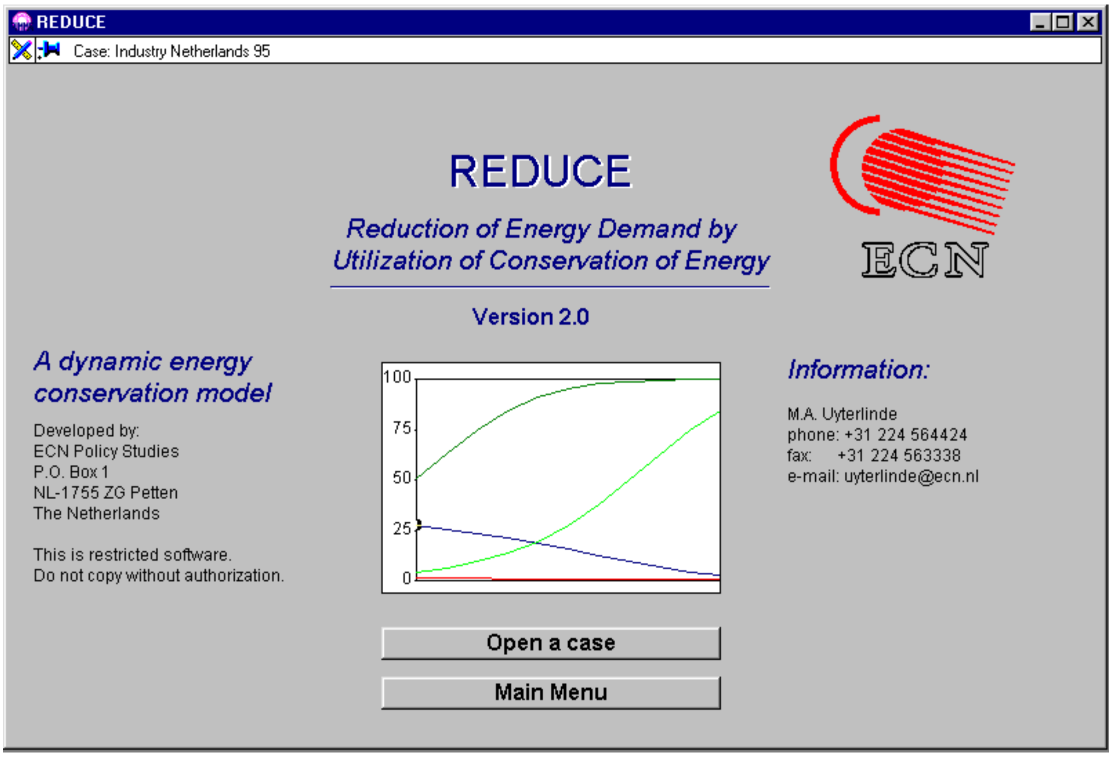
[1] The pioneering work of T. van Harmelen and H. de Kruijk in developing the REDUCE model is gratefully acknowledged.



Case: Industry Netherlands 95

REDUCE

Reduction of Energy Demand by
Utilization of Conservation of Energy

Version 2.0

A dynamic energy
conservation model

Developed by:
ECN Policy Studies
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Figure 1.1 *The opening screen of the REDUCE energy conservation model*

This report presents the results of some additional model development activities, partly based on the first experiences in Van Harmelen and Uyterlinde (1999). Chapter 2 starts with an overview of the structure of the model. Chapter 3 describes the use of energy efficiency indicators as an extra tool for output analysis in REDUCE, and gives some examples. Chapter 4 develops a method for modelling the effects of technical development on production costs, by means of an experience curve. Finally, Annex A provides a ‘users guide’, by describing in more detail the input data specification as well as all menus and buttons.

2. THE REDUCE MODEL

2.1 General approach

The REDUCE model can be characterised as a bottom-up approach, taking into account all techno-economic aspects of energy conservation options. However, market barriers and consumer behaviour with respect to conservation options are taken into account without using elasticities. Therefore, impacts over time of policy instruments influencing market barriers, consumer behaviour and benefit-cost ratios can be assessed given certain technological conditions and dynamic interactions of different conservation options and policy instruments. A schematic representation of the framework is given in Figure 2.1.

The dynamics of market penetration of conservation options are influenced by a number of diverse and complex factors. These factors can be divided into three categories, such as (1) properties of conservation options, (2) dynamic interaction between these options, and (3) driving forces for penetration of options, which will be discussed in the following paragraphs.

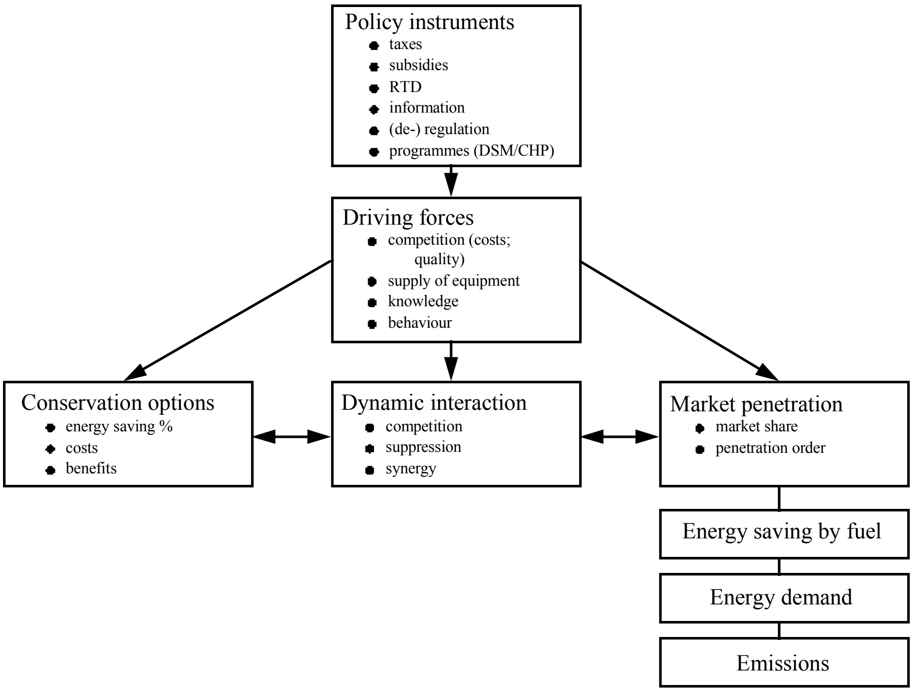


Figure 2.1 *Schematic overview of the analytic framework for evaluation of energy conservation policies*

Conservation options

A conservation option can be characterised by its direct investment costs and operation and maintenance costs, its potential energy saving effect (usually expressed as a percentage of energy consumption) and technical aspects which determine the market niche for possible application of a particular option. A large database on conservation options, based on ICARUS in The Netherlands (De Beer et al., 1994), is starting point for the analysis.

Dynamic interaction

Dynamic interaction between conservation options can take several forms. Certain conservation options are *competing* for application in the same energy service market, for instance a heat pump and a high efficiency boiler compete for heat supply in households. They have to share the market. Penetration of competing options can be more or less ‘permanent’ (options such as wall insulation that stays in place for a very long period), which implies that a conquered market share will not be lost to a competing option. In that case the market share can only increase. Penetration of options can also be ‘temporary’. This applies to options such as appliances and heating systems, which are frequently replaced, implying that the market share can increase but also decrease. This is a typical example of crowding out.

Energy conservation options interact with energy supply options. High savings in end-use decrease attractiveness of supply savings and vice versa. This second form of interaction is not a competition between alternative options but *suppression* of complementary options. An interesting example of suppression of complementary options concerns energy conservation and fuel switch. The fuel price has a large influence on the profitability and therefore also on the market penetration of conservation options. But, if cost differences become large, the market will respond with fuel switch towards the cheaper fuel, herewith reducing the economically attractive saving potential. Therefore, fuel switch is taken into account. This point is often neglected in conservation studies. In the remainder of this report, this last form of interaction is often summarised by the term *interference* of options.

Interaction of options is modelled by means of two simple concepts: groups of options and penetration order. Options in a group compete with each other on the basis of crowding out. Depending on the type of options in a group, permanent penetration and temporary penetration can occur. Furthermore, supply and demand groups have been distinguished to model interaction of options. Calculations are conducted for each year. It is a reasonable assumption that each supply option to be installed will be introduced in a situation where on average a percentage of end-use saving equal to that of the previous year has been reached. When the percentage of end-use savings is high, the energy demand to be reduced by a new supply option will be low, and the profitability of the supply option will also be low.

Driving forces

The driving forces for implementation of conservation options are highly important for understanding market penetration of dynamically interacting conservation options. These driving forces are a schematic representation of consumer behaviour with respect to conservation options. In other words, what makes options attractive? The economic attractiveness (cost-effectiveness, rates of return, payback periods etc.) is an important driving force. But also technology supply constraints, limited knowledge about a technology, and consumer preferences (attitude/awareness) in general or concerning specific options can play a role in the (rate of) uptake of options by a market. Most energy conservation frameworks avoid these hardly quantifiable driving forces and assume exogenously specified restrictions instead. However, driving forces play a key role in evaluating policy instruments, since most instruments place incentives through one or more driving factors.

Market penetration

Although market penetration of options is very complex, especially concerning driving forces, and hard to project, experts agree that market introduction of a new technology tends to follow an S-shaped curve. This gradual penetration of technology accounts for some general, commonly accepted ideas in technology dynamics. According to Fisher and Pry (1971), the stages of technology development, viz. demonstration technology, mass production, and saturation of the market are reflected by this S-curve. Apart from these supply oriented stages, social, economic, and behavioural driving forces play a role in determining the slope of the curve. Fisher-Pry and others (1971), have assessed curves for several technologies which penetrated the market in the past, thereby also quantifying these driving forces. In our approach, this driving force factor is split up in two factors, the first one determined by economic profitability, measured by means of Internal Rate of Return, the second one determined by behavioural and other factors. In this way, the penetration speed factor is not fixed for a technology, but can vary under different economical circumstances. When profitability increases, the penetration speed increases too.

Two different approaches can be used to deal with penetration speed. First, one can try to estimate the technology dependent penetration speed factor with the help of statistical analysis of data time series and surveys. Second, as in techno-economic assessments of national strategies for the longer term, penetration speed factors are being kept equal for each conservation technology. In that case, options are compared and ranked in a sophisticated way as in cost-optimisation models. This new approach, related to for instance the approach used in the renewable energy evaluation model SAFIRE (ESD, 1995) leads to more differentiated technology projections than those produced by the more static economic evaluation.

Policy instruments
The main objective of developing REDUCE is to analyse the expected realised energy conservation and its costs and benefits as induced by certain policy instruments. Furthermore, the interaction of different policies is analysed. In the box 'Policy instruments' in Figure 2.1 a number of policy instruments are mentioned. The arrow from this box indicates that most policy instruments influence the conditions under which driving forces induce certain behaviour. Different policy instruments can act upon one or more different driving forces. The driving forces affected by a type of instrument have to be identified and quantified in terms of marginal changes in market penetration speed. It is important to distinguish the differences and overlap between policy instruments.

The instruments mentioned in Figure 2.1 are all taken into account in REDUCE. Emphasis is put on economic and financial instruments, since the economic driving forces are studied in most detail and are relatively easy to quantify.

Baseline projection
A reference energy demand projection, without additional energy conservation options and policies, is an important starting point for the analysis. The relationship with economic developments must be clearly specified. Special attention has to be given to the split into different fuels, since the differences in fuel costs have a large influence on profitability and thus penetration of conservation options.

2.2 Model description

2.2.1 Economic evaluation

One of the classical ways of performing an economic evaluation of project investments makes use of the Internal Rate of Return (IRR). The IRR can be interpreted as the interest percentage one could receive when the money for investment is not invested, but put on the bank during the period of the economic lifetime.

The internal rate of return IRR is derived from the following standard formula:

$$\sum_{t=1}^{lt} \frac{\text{CashIn}}{(1+\text{IRR})^t} - \text{CashOut} = 0$$

with:

CashOut :	the additional investment for installing an option
CashIn:	the annual benefit of an option
lt:	the lifetime of an option

Other methods for performing an economic evaluation of project investments are the Payback Period (PBP) and the Net Present Value (NPV). The Payback Period focuses on risk, minimising the period for return. The total benefits are not directly taken into account: if the lifetime is long, the payback period becomes also longer, although total benefits may be very high. This aspect is particularly considered by the Net Present Value method. This method focuses on absolute benefits, herewith giving an advantage to large projects above small projects. The Internal Rate of Return has not that property, since it expresses benefits in the form of a profitability percentage. In this case, the absolute benefits are not considered.

An advantage of the IRR above the Payback Period is that it is independent of the economic lifetime. The advantage of the IRR above the Net Present Value is that it is independent on the magnitude of the investment. So, small and large projects with different lifetimes can be compared. A disadvantage of IRR compared to the Net Present Value is that negative additional investments result together with benefits in an infinitely high IRR, regardless of the size of the benefits.

The expression above is the static way of calculating the internal rate of return. Unlike other models in this field, REDUCE is completely based on dynamics and for every year in the period under study, the IRR is calculated. The IRR changes over time because annual benefits can vary over time. They consist of saved fuel expenses minus the options' variable costs. First, the fuel prices vary over time. Second, the saved amount of energy after applying an option will decrease if other options are applied meanwhile. This interference of options has been explained in the previous section. From the IRR, the market share and a behavioural factor, the market penetration of conservation options is calculated.

2.2.2 Market penetration

The penetration of a single energy saving option in its own market is supposed to happen conform the S-curve described cf. Fisher and Pry in the following differential equation:

$$\begin{cases} \partial P / \partial t & = \quad S \times P(t) \times (1 - P(t)) \\ P\,(t_0) & = \quad P_0 \end{cases}$$

The increase in penetration percentage P depends on the actual penetration or market share and the share that is left to be penetrated (1-P). Exactly when half of the market is penetrated, penetration speed is at its highest.

The constant S in the basic Fisher Pry curve is a calibration constant. In REDUCE this constant is used to reflect the driving forces for market penetration of energy saving options: economic attractiveness in terms of IRR and behavioural aspects as discussed earlier. Behaviour is quantified by the parameter α. So an additional equation is:

$$S = \alpha \times IRR$$

The complete above differential equation is approximated by a difference equation:

$$\begin{cases} P(t+1) = P(t) + \alpha \times IRR \times P(t) \cdot (1 - P(t)) \\ P(t_0) = P_0 \end{cases}$$

With a well specified α the penetration in time can be calculated iteratively. In Figure 2.2 three different curves are presented with different values of S and with different initial penetration values. Two observations can be made:

- S, being α and IRR, represents the penetration speed: sensitivity of purchasing behaviour for economic incentives.
- The start share P_0 affects the initial penetration speed.

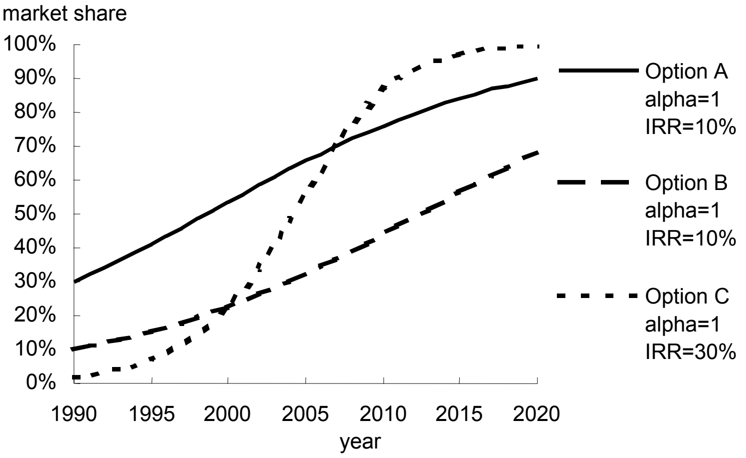


Figure 2.2 *Market penetration of three single options in separate market groups*

2.2.3 Competition between options

With the S-curve concept, market penetration of options can be calculated iteratively. However, it is not as simple as that. In the market of energy conservation, a number of options compete with each other as in any market. The 'market' is to be divided by different options if these options deliver to the same market.

Permanent options

Once an option has penetrated on a certain share of the market, this market share will not be lost to another option. Examples of this kind of options are wall insulation and roof insulation. As a result of the competition, a particular option can not conquer the part of the market which has not installed this single option, but it can only conquer that part of the market which has no options at all.

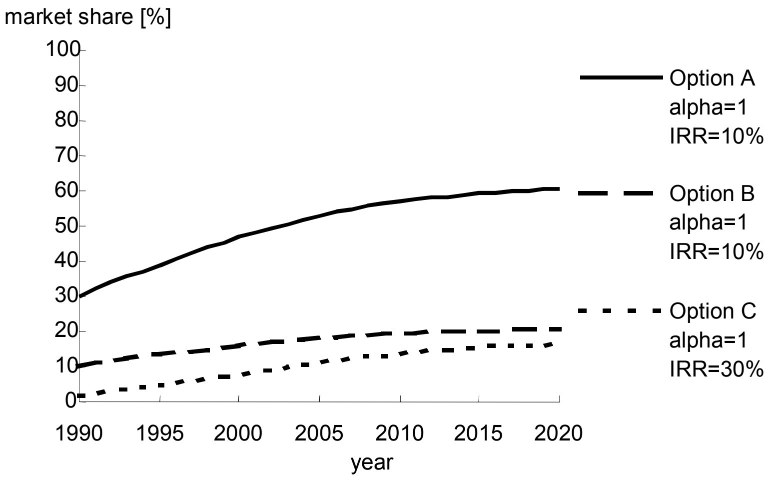


Figure 2.3 *Market penetration of three competing permanent options in one market group*

Temporary competing options

It is also possible that options can replace one another. For instance compact fluorescent lamps or double glassing only last for their lifetime and then will be replaced. In the case of competing options, the influence of an option's penetration share is weighed with the other options' shares, and multiplied with their penetration speed.

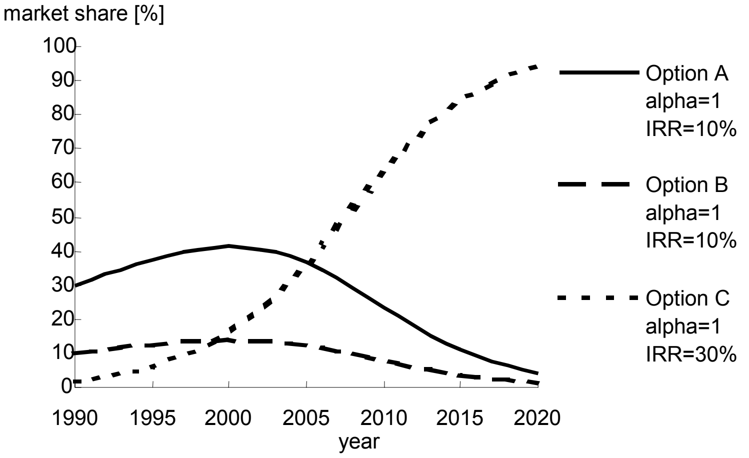
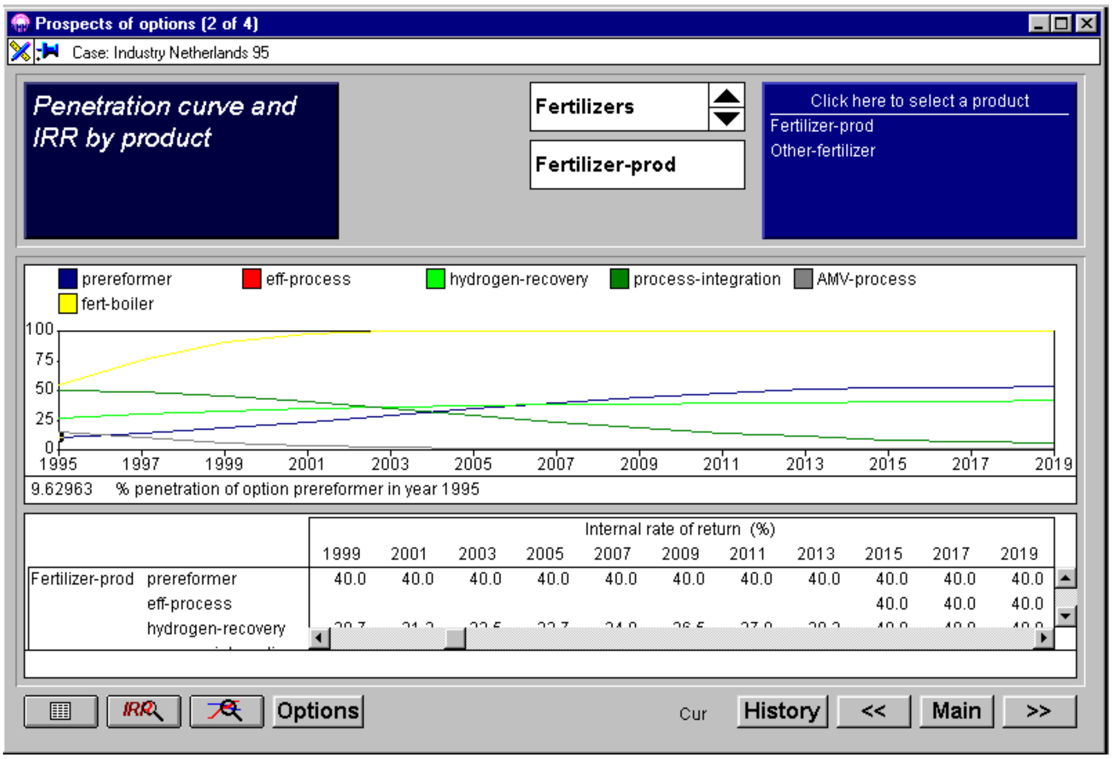


Figure 2.4 *Market penetration of three competing temporary options in one market group*

So, options must be specified to follow permanent or temporary penetration patterns because different penetration curves apply for each type of options. Furthermore, it has to be specified which options exclude or compete with each other and which options can be applied at the same time. For this purpose options are allocated to groups. Within a group, options compete with each other.



9.62963 % penetration of option prereformer in year 1995

		Internal rate of return (%)										
		1999	2001	2003	2005	2007	2009	2011	2013	2015	2017	2019
Fertilizer-prod	prereformer	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
	eff-process									40.0	40.0	40.0
	hydrogen-recovery	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 2.5 *Example of a REDUCE screen on the market penetration of options*

2.2.4 Interference of options

Options are being characterised as supply or demand options. Supply options are by definition temporary. This concerns efficient boilers for heating, heat pumps etc. Demand options concerning heating are for instance insulation of walls, double-glazing, etc.

Supply and demand options are distinguished in order to model interference of options. This is illustrated by the following example. Wall insulation and heat pumps can both be applied in the same house to save energy for heating. Suppose that one house is already provided with wall insulation and another is not. Then in both houses application of a heat pump will cost the same but the return in terms of a lower energy bill will differ. In other words, the IRR of the heat pump depends on the question whether wall insulation is applied or not.

For calculating the interference of supply and demand options, the concepts *demand effectiveness* and *supply effectiveness* are used for every product/energy-carrier combination. The demand effectiveness is the remaining fraction of the energy demand after subtracting the saved fractions reached by already existing supply saving options. The reverse holds for supply effectiveness. These parameters are calculated yearly for all product/energy-carrier combinations. The energy demand is the product of both supply- and demand-effectiveness and the projected energy demand. The difference between the projected energy demand and the energy demand is the energy saving. The energy saving is smaller than the sum of savings of demand options and supply options due to interference of demand and supply options. The effectiveness based on the penetration of options in the previous year is included in calculating the annual benefits and thus the IRR of an option for each year. In time, penetration depends on the penetration in the previous year and the IRR in each year.

2.2.5 Definition of energy consumption

A conceptual issue that has to be settled, is how to define 'baseline developments' in a bottom-up conservation model such as REDUCE. This is schematically illustrated in Figure 2.6. The basic underlying issue is that energy consumption and energy conservation is an ongoing process, metaphorically speaking a train moving on a track. The modelling work has to start at a certain point, the baseyear, where the modeller has to jump on the running train. Obviously, some energy conservation options are already installed and saving energy in the baseyear. At first, only the actual energy consumption in the baseyear is known from the statistics, which takes into account all current energy conservation. In the model this energy consumption is called the 'Actual Energy Consumption', in contrast with the energy consumption corrected for energy conservation reached by conservation equipment installed in the baseyear. This (higher) energy consumption is referred to as 'Energy Use Without Savings' (EUWS).

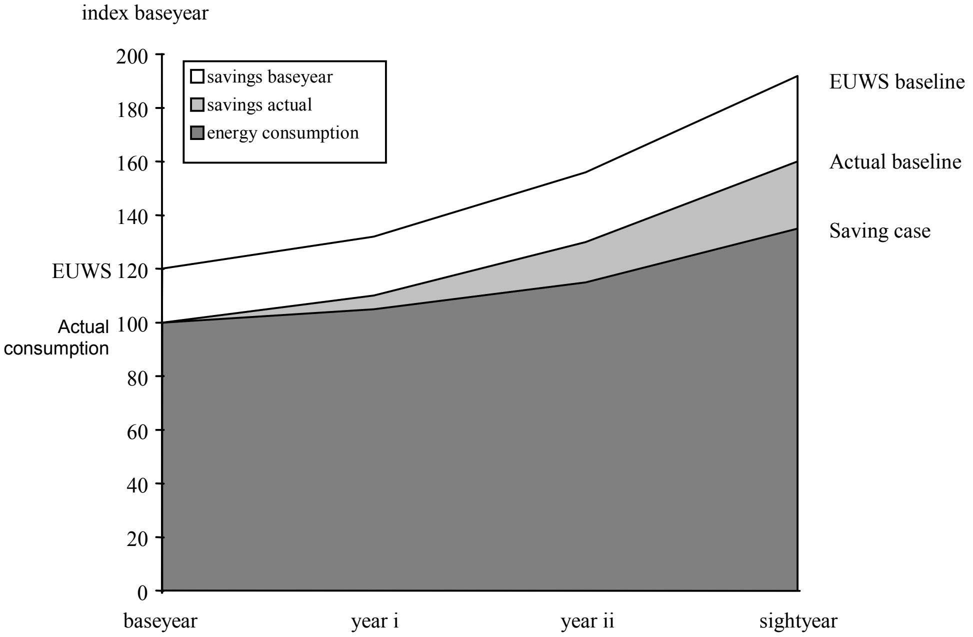


Figure 2.6 *Schematic illustration of the concept of different types of baselines as a reference for the saving impact of the penetration of attractive energy savings*

When a growth path is applied to develop a baseline, this growth path can be applied on both the EUWS and the Actual energy consumption in the baseyear. The difference between these two in the baseyear, notably the energy saved in the baseyear, will grow proportionally to both baselines. This can be interpreted as a volume growth of the baseyear energy savings proportional to the volume growth of energy consumption. In other words, the baseyear situation is considered to be a status quo.

The EUWS baseline is important for the explicit specification for energy conservation options in the baseyear and the (proportional) correction for this energy conservation in the years after. The Actual baseline is taken as the baseline, which is interesting as a 'doing nothing', case with a baseyear perspective, and without any autonomous efficiency improvement. Also, energy conservation after the baseyear should be viewed with reference to the Actual baseline, hence considering energy conservation additional to the baseyear situation.

2.2.6 Overview

Figure 2.7 gives a schematic overview of the REDUCE model. The issues discussed in the previous section, viz. economic evaluation, market penetration, competition and interference of options, their relations and the relations with different types of policy instruments are presented schematically.

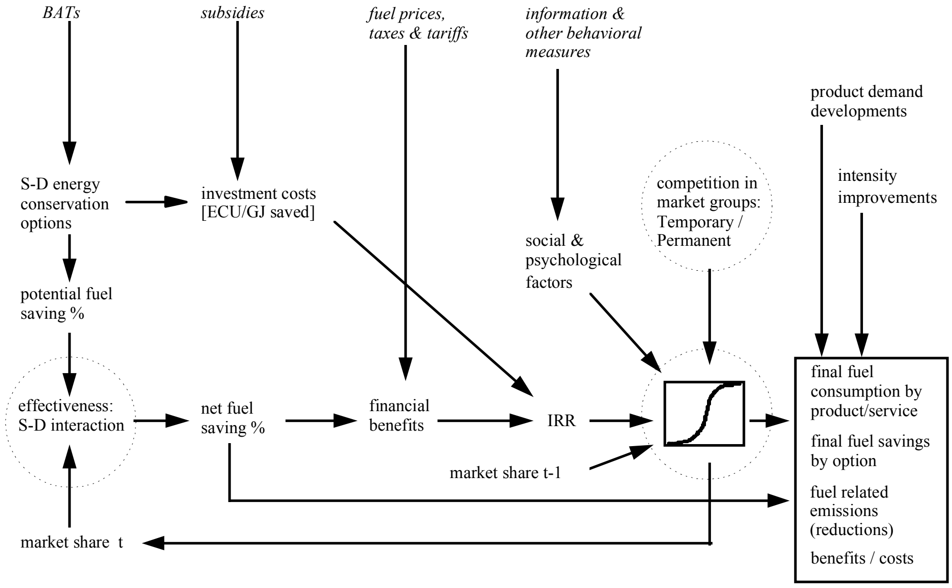


Figure 2.7 *Schematic overview of the REDUCE model (policy relevant parameters are in italic; important model mechanisms are within the circles)*

3. INDICATORS AND BENCHMARKING

3.1 Introduction

This chapter describes the use of energy efficiency indicators as an extra tool for output analysis in REDUCE. In this section the motivation and background of this tool is explained. Next, in Section 3.2 the methodology is outlined. Sections 3.3 to 3.5 illustrate the usefulness of the approach by describing case studies for the Dutch households and manufacturing sectors. Finally, in Section 3.6 some conclusions are drawn.

Several types of energy efficiency indicators can be distinguished, having in common that they consist of time series of the ratio of energy consumption related to a certain activity. This activity can be measured in monetary terms, thus resulting in an economic indicator called 'energy intensity', or in physical terms, yielding a physical indicator often called 'unit consumption' (Bosseboeuf et al., 1999).

What makes indicators a valuable addition to the REDUCE model? In the first place, indicators give the opportunity to translate the model results to more general (economic) terms, and thus improve the transparency of the results. This is particularly important when communicating model results to policy makers, who are often more used to thinking in terms of energy intensities. Secondly, indicators allow for a combination of ex post and ex ante analysis. This is illustrated in Figure 3.1. The historical trend, typically analysed using indicators, can be compared to different developments in the future, depending on certain scenario assumptions or (mixes) of policy measures. Third, indicators are very suitable for country comparison and benchmarking, because they translate absolute (and very different) levels of energy demand to comparable proportions. This is in line with the overall objective of REDUCE, to provide an international framework for comparable energy conservation studies.

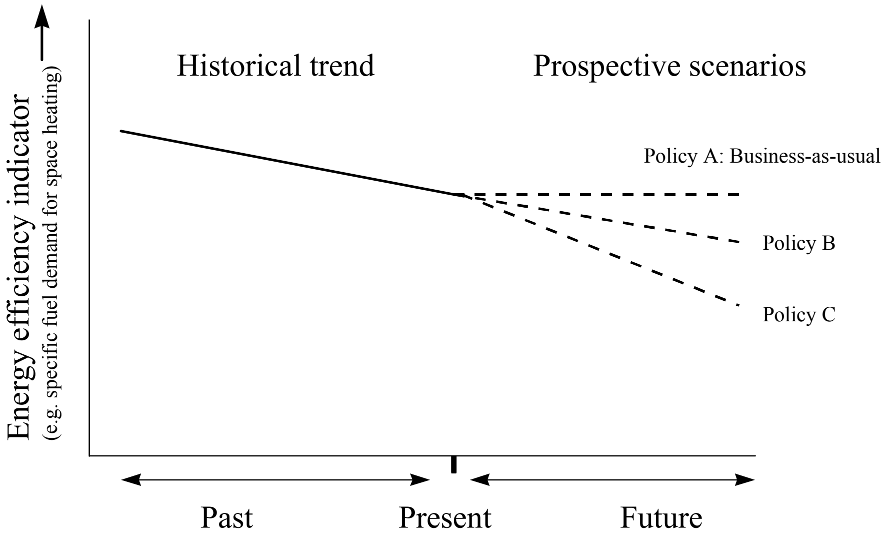


Figure 3.1 *Illustration how indicators can be used to compare ex-post and ex-ante analysis*

Indicators can be calculated on different levels. On the division (sector) level, it is often useful to assess energy efficiency developments from an economic perspective ('energy intensities').

Changes in the indicator values can have different causes:

- Savings achieved in different products and groups.
- Structural changes within the division, for instance when energy intensive subsectors or products are growing faster than other subsectors. This effect can be assessed by calculating the same indicator without structural changes, i.e. running REDUCE again with (some) constant product growth rates.
- Effects of policy measures. Calculating the same indicator based on different policy cases can assess this.

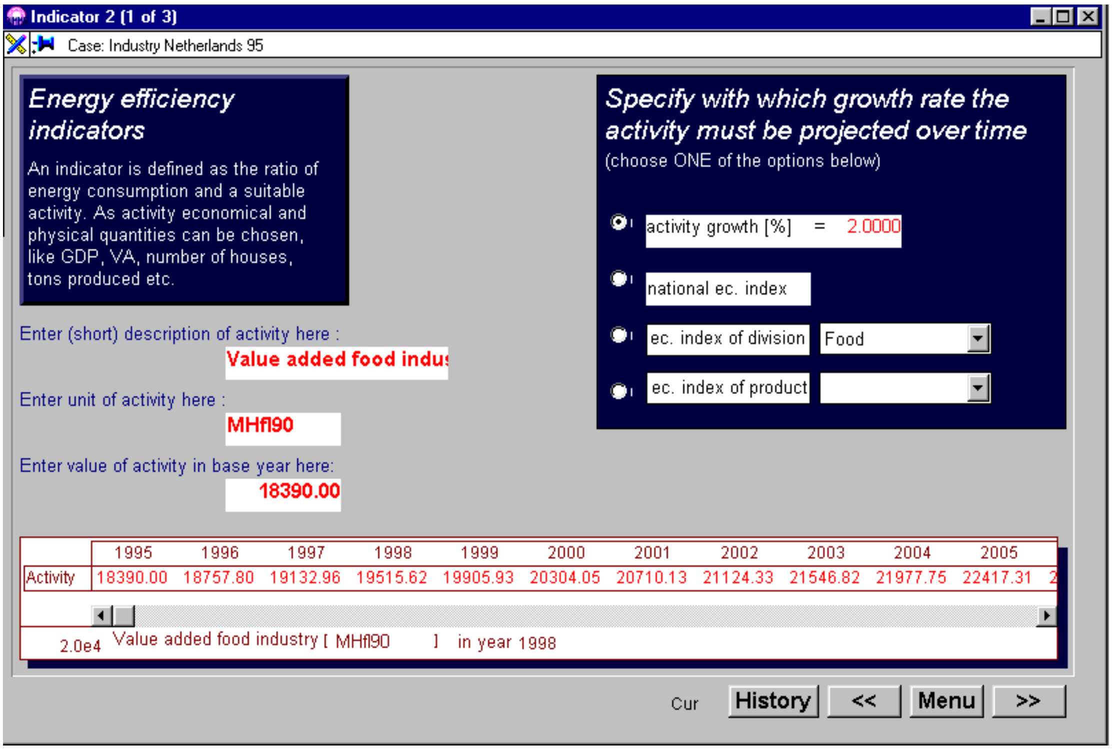
The case studies in Section 3.4 and 3.5 illustrate the role of these factors. For industry, the level 'above' divisions is also interesting, because it summarises the total industry sector. This way, the effects of structural changes on division level (shifts from heavy to lighter industry) can be examined as well.

On product level, the effects of technical developments and behavioural changes are made visible. Here the activity often represents a physical unit. The effect of policy measures and structural changes can be assessed in the same manner as described above.

3.2 Indicators in REDUCE

The calculation of the indicators is based on the final output data of REDUCE. Hence the indicators are actually a processed reproduction of the output. Therefore the specification and calculation of indicators is on the output side of the REDUCE-menu. For each case it is possible to define five different indicators.

The indicators are computed by using a generic methodology, giving the user a lot of freedom regarding the utilisation of indicators. All indicators have the following form: $I_t = E_t/Q_t$. Here E_t is the energy consumption during year t computed by REDUCE. As activity, Q_t, economical (GDP, VA) and physical quantities (number of dwellings, tons produced) can be chosen. For this methodology REDUCE needs the value of the activity during the start year, the growth rate of the activity and the level of energy consumption that must be applied, as inputs. Figure 3.2 shows one of the input screens for defining an indicator. The figure shows that it is possible to define a new growth rate for the activity or to use one of the economic growth rates, which were already defined within REDUCE.



Case: Industry Netherlands 95

Energy efficiency indicators

An indicator is defined as the ratio of energy consumption and a suitable activity. As activity economical and physical quantities can be chosen, like GDP, VA, number of houses, tons produced etc.

Enter (short) description of activity here : **Value added food indus**

Enter unit of activity here : **MHfl90**

Enter value of activity in base year here: **18390.00**

Specify with which growth rate the activity must be projected over time

(choose ONE of the options below)

● activity growth [%] = 2.0000
○ national ec. index
○ ec. index of division Food
○ ec. index of product

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Activity	18390.00	18757.80	19132.96	19515.62	19905.93	20304.05	20710.13	21124.33	21546.82	21977.75	22417.31

2.0e4 Value added food industry [MHfl90] in year 1998

Figure 3.2 *One of the three* R*EDUCE screens on energy efficiency indicators: definition of activity*

3.3 Definition of case studies

The case studies presented in this section are meant to validate and demonstrate the use of indicators in REDUCE. Because of practical reasons, the data sets have been derived from work done in a previous project, and are limited to The Netherlands. The indicators present some extra analysis of the output results of these cases. First, the assumptions and policy cases used are characterised briefly. For a more elaborate description, we refer to Uyterlinde et al. (1999). In Sections 3.4 and 3.5 the results of the case studies are presented.

3.3.1 Assumptions

The baseline developments are based on the Global Competition (GC) scenario, as developed by the Netherlands Bureau For Economic Policy Analysis (CPB) in 1996 for a long-term scenario study for the Dutch economy in the period 1995 - 2020 (CPB, 1997). Global Competition is the scenario featuring the most rapid economic growth, both internationally and nationally. The projected growth of the Dutch GDP is 2.3% on average annually.

Households baseline development

Relevant assumptions for household energy consumption are projections on the population, the number of households and the average household size. These are depicted in Table 3.1. The population is projected to grow moderately with 10% up to the year 2020. The number of households will grow substantially more, namely with 26% up to the year 2020, due to the foreseen decrease in average household size from 2.36 to 2.06 persons per household.

Table 3.1 *The projected number of households, inhabitants and household size*

		1995	2000	2005	2010	2015	2020
Households	[million]	6.54	6.90	7.25	7.58	7.93	8.27
Population	[million inhabitants]	15.47	15.90	16.19	16.52	16.77	17.02
Household size	[persons per household]	2.36	2.30	2.23	2.18	2.11	2.06

The final energy consumption of the various energy services within the Dutch households during 1995 is illustrated in Figure 3.3. It shows that natural gas is a very important energy carrier for the Dutch households as it covers more than 80% of the sectoral energy consumption. Most of the natural gas is used for space heating. A smaller part is used for hot water and cooking. The use of oil and coal in 1995 can be neglected as it covers less than 3% of the total energy consumption, and is expected to decrease further in the future.

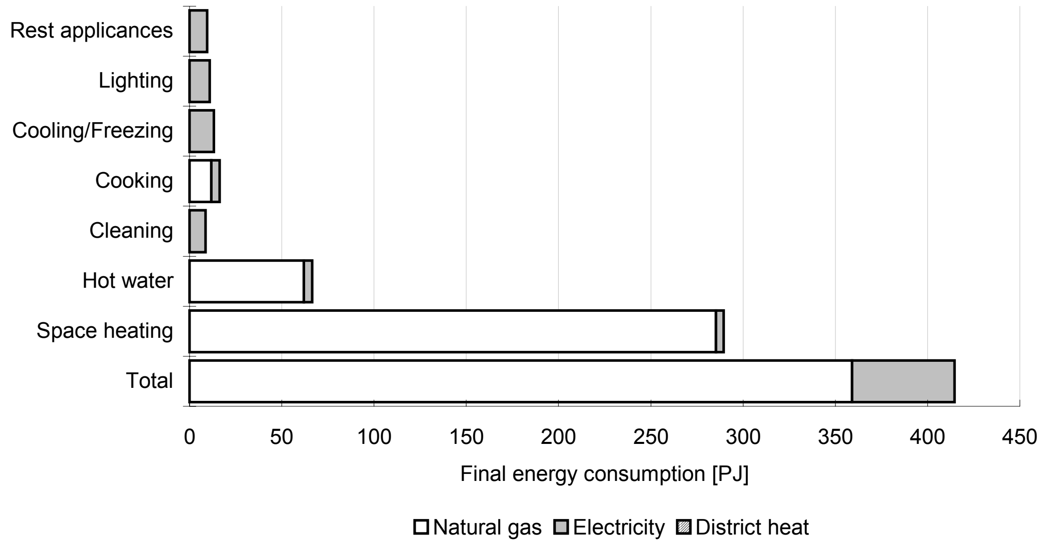


Figure 3.3 *Final energy consumption by energy service and fuel in 1995 (source: Boonekamp, 1995)*

Manufacturing baseline development

Figure 3.4 illustrates the energy consumption by fuel in the baseyear for the Dutch manufacturing sector. These sectoral energy demand figures have been adapted from 1995 realisations (from the Dutch statistical office CBS) by ECN. Natural gas also includes heat, which is almost entirely generated on the basis of natural gas. Natural gas is a very important energy carrier, as it has a share of over 50% in the sectoral energy consumption. Hard coal is mainly used in the basic metal industry. The share of electricity of 12% in the sectoral energy consumption is low compared to other countries. Since it concerns final energy consumption, the conversion losses in the generation of electricity are not taken into account. Figure 3.4 also illustrates the differences between subsectors in share in the final energy consumption in the manufacturing sector.

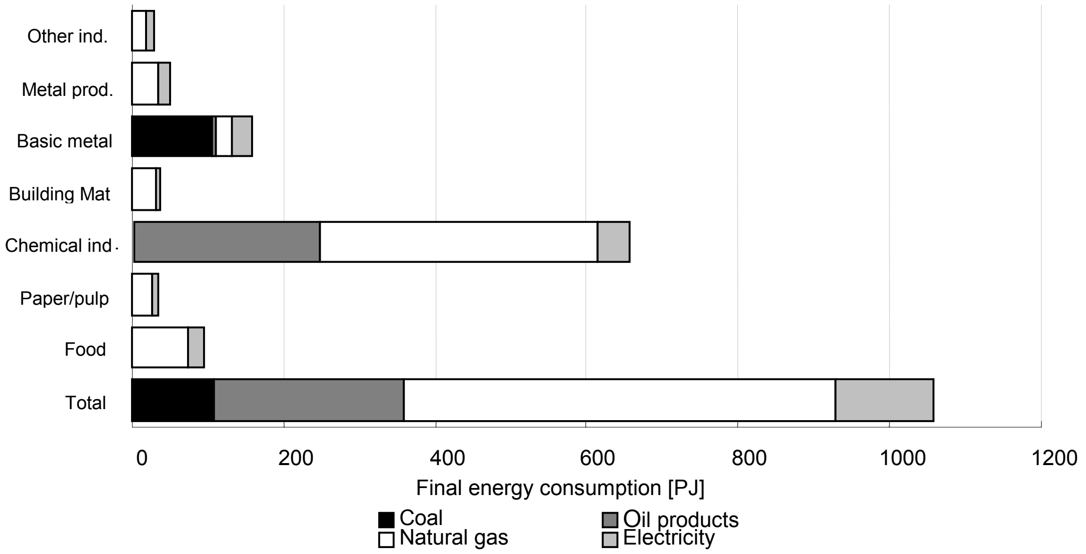


Figure 3.4 *Final energy consumption (end-use) by division and fuel in 1995 [PJ] (source: CBS, climate correction by ECN)*

The 1995 energy demand on branch level has been disaggregated to product level (including energy services) based on the structure of 1990 (De Beer et al., 1994; Van Dril et al., 1994). Figure 3.5 shows the divisional growth figures in the Netherlands, based on economic growth rates from the GC scenario. However, these rates have been adapted to reflect the assumption that energy demand grows proportionally with the physical growth rate which is lower than the economic growth rate and thus includes some dematerialisation. These growth projections result in a (weighted) average growth of 1.9% annually for the manufacturing sector. Within these sectors, various growth projections have been assumed for subsectors (products in REDUCE terminology), see Uyterlinde et al (1999) for a complete description.

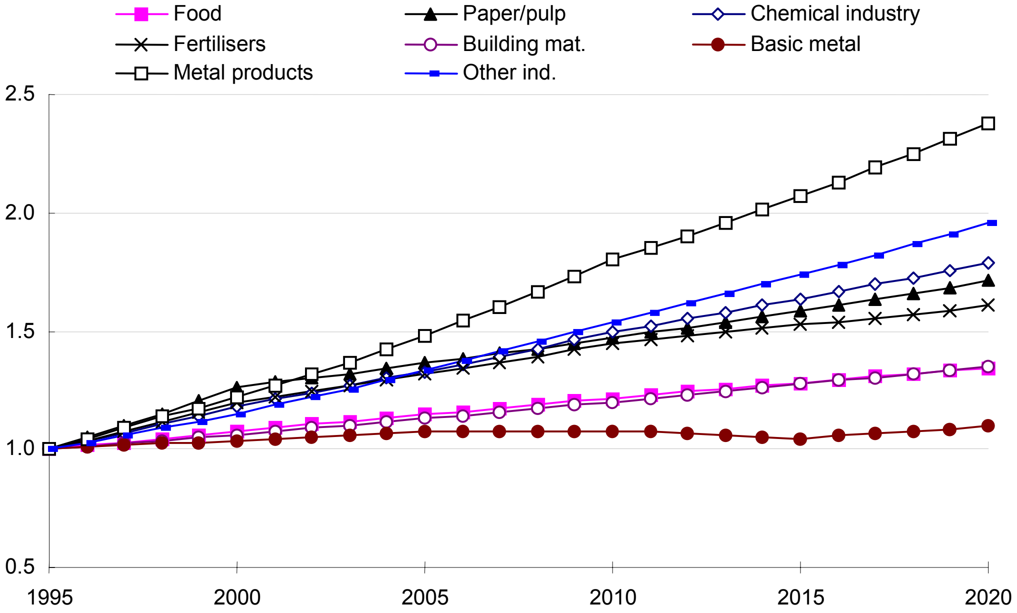


Figure 3.5 *Projected energy consumption growth by division, expressed as index 1995, in the manufacturing sector*

Energy price projections

The world market price projections for primary energy sources have been derived from Capros et al. (1997). From the year 1995, coal prices are projected to grow 0.6% annually, crude oil prices 2.6% and natural gas prices 2.4% per year.

The end-user prices of the year 1995 and the projected end-user prices for the year 2020 of the main energy carriers for households and the manufacturing sector are shown in Table 3.2. End-user prices of all energy carriers are increasing less than world market energy prices. This is particularly true for the household sector where the more or less fixed margin for transportation and distribution costs are relatively high. The industrial prices are to a larger extent determined by world market prices and thus more sensitive to world market price increases.

Table 3.2 *Energy end-user prices [ECU-90/GJ] in 1995 and projected prices for the year 2020 in the Reference scenario*

	Households		Manufacturing	
	1995	2020	1995	2020
Light oil	5.96	9.39	2.75	5.27
Natural gas	6.35	8.58	2.49	4.29
Heat	5.35	5.76	5.40	5.71
Electricity	25.61	28.81	14.29	16.73

Behavioural parameters

As has become clear from Chapter 2, the future market penetration of an energy conservation option depends on the present market share, the IRR of this option and a penetration speed factor α, representing behavioural factors concerning the willingness to make additional investments in return for new efficient technology. Empirical data for α are not available in the special format as defined in REDUCE. More general data on investment behaviour is available but still scarce.

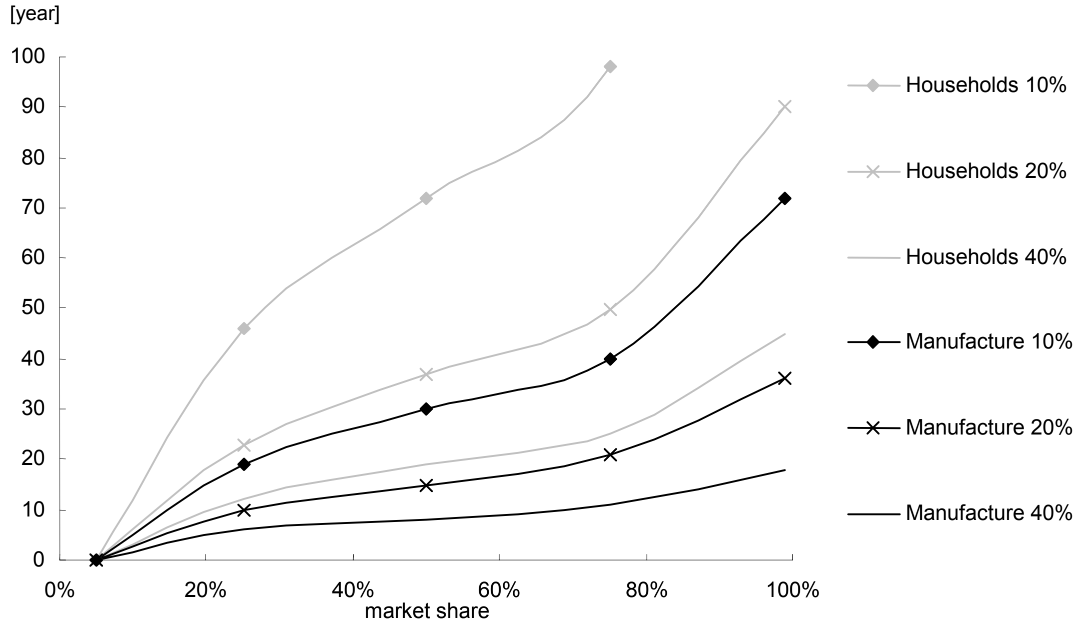


Figure 3.6 *Combinations of market penetration time (years) and market share of options as a function of the Internal Rate of Return for different sensitivity categories (penetration speed α) in households and manufacturing sector*

For the case studies, a straightforward approach has been chosen, more in the style of 'what-if'-scenario-approach. Two different penetration speed α values have been selected to model two categories of behaviour, which have a different sensitivity for cost-effectiveness and economic profitability of new energy conservation options. For each sensitivity category and different values of IRR, Figure 3.6 presents the amount of time required by options to completely conquer a market.

3.3.2 Policy cases

Besides the Reference case, in which the market penetration and effects of energy conservation options under the projected demand, sector and price conditions have been studied, two other policy cases are studied: the Surcharges and Technical cases.

Surcharges case
Environmental surcharges internalise the environmental effects of energy use in end-user prices for different sectors. Surcharges for electricity and heat are calculated on the basis of the fuel mix of the electricity or heat generation system. The surcharges applied for households and manufacturing are presented in Table 3.3.

Table 3.3 *Environmental surcharges [ECU-90/GJ] additional to the Reference energy end-user prices in households and manufacturing, in the year 2020 as applied in the Surcharge case*

Fuel	Level of surcharges	Households Reference tariff	Households Tariff incl. surcharges	Manufacturing Reference tariff	Manufacturing Tariff incl. surcharges
Oil	8.10	9.39	17.49	5.27	13.37
Natural gas	5.30	8.58	13.88	4.29	9.59
Heat	1.71	5.76	7.47	5.71	7.42
Electricity	3.00	28.81	31.81	16.73	19.72

For households, prices of oil almost double and prices of natural gas increase with more than 50% due to environmental surcharges. Oil surcharges are higher than natural gas surcharges, since oil is less environmentally friendly. For manufacturing, prices of oil and gas more than double, due to the lower prices. Electricity remains relatively unaffected by surcharges. The relative price levels of different energy carriers have not changed much.

Technical case
The technical case shows the technically available energy conservation potential present in the REDUCE versions of each sector. It also shows the reduction of energy demand that can theoretically be achieved, regardless of costs, energy prices and investment behaviour. It indicates possibilities for energy conservation which are technically feasible and therefore gives policy makers a long-term strategic perspective. It indicates where the efficiency gap between reality (implementation) and possibility (technically feasible) is large and the scope for policy measures is extensive.

3.4 Results households sector

The major issues playing a role in energy efficiency trends for households are:
- building regulations for new dwellings,
- life style trends, such as increased ownership and use of electrical appliances, less persons per household,
- technical improvement of electrical appliances.

Three indicators have been selected for the Households case studies:

- Energy demand by dwelling for the total division households.
- Specific consumption by refrigerators for the 'product' cooling.
- Energy demand for space heating by dwelling for the products central and local heating together.

By monitoring trends in these indicators the issues above can be studied. Table 3.4 shows the activities used for calculating the indicators.

Table 3.4 *Specification of indicators for the manufacturing sector*

Energy consumption by REDUCE division(s) or product(s) [TJ]	Activity	Indicator
Households	Number of dwellings	Specific consumption [MJ/dwelling]
Cooling	Stock of refrigerators	Specific consumption [MJ/refrigerator]
Central heating, local heating	Number of dwellings	Specific consumption [MJ/dwelling]

3.4.1 Total household sector

The specific consumption of the household sector is defined as the final energy consumption (including supply options) related to the number of dwellings. It is assumed that the number of dwellings increases with an average growth of 0.98% annually. This is consistent with the GC scenario on which the cases are based. The historical data of the household sector are taken from SAVE-module households (Boonekamp, 1995). The simulated unit consumption of households per dwelling is depicted in Figure 3.7.

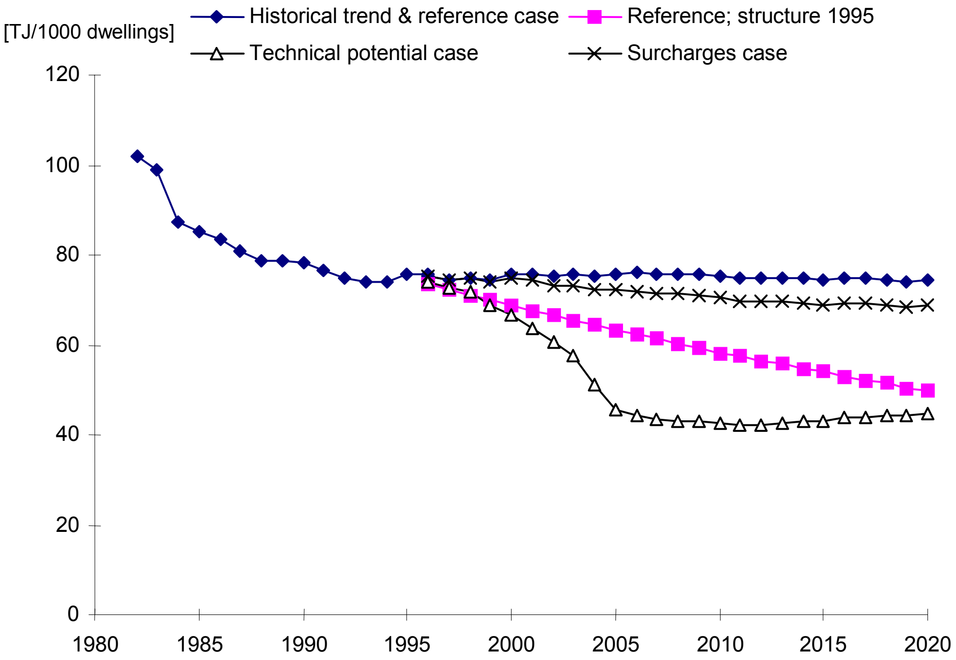


Figure 3.7 *Unit consumption of division households; historical trend and simulation results*

In the reference case the indicator is more or less constant (a small decrease is present) during the period 1995-2020. However, before 1995 a substantial decrease of the indicator is shown. For the most part, this is due to the regulation with respect to insulation of houses, public information of households and high-energy prices during that period. Consequently the total energy consumption declined whereas the number of dwellings increased continuously. During 1990-1995 the decrease of energy consumption stabilises, because the decrease in energy used for space heating was not sufficient to counterbalance the effect of increased energy use for domestic appliances. After 1995 the total energy consumption increases. This growth can partly be explained by an increased penetration of domestic appliances such as dish washers and clothes dryers. Moreover the consumption for space heating is also increasing after 1995.

In the Surcharges case the effect of increased energy prices is investigated. Especially the price of natural gas has increased. Figure 3.7 shows that this case induces improved unit consumption. As natural gas covers the largest part of the energy consumption by households, the higher price makes it more attractive to invest in options that save natural gas. More specific; the energy consumption within the ‘product’ central heating has decreased significantly.

A constant structure, as from 1995, has been modelled by using the same percentage for divisional and product growth, being an annual growth of 0.95%. This percentage is derived from the physical growth of households. The results show that in case of a constant structure the unit consumption decreases according to the same trend as before 1995. It shows that structural changes have a large influence on the energy efficiency within households. As the unit consumption is smaller compared to the reference case, it can be concluded that the structural changes have a ‘de-saving’ effect on households.

The technical potential case differs the most from the reference case. During 1995-2005 a large gap between the unit consumption of the technical and the reference case develops. The decrease of the energy consumption can mainly be ascribed to savings on natural gas consumption. Since most technologies with a high saving potential are introduced in the market around 2001, the unit consumption shows a relatively rapid decrease during that period. Note that because for the technical case costs are no limitation, high potential technologies with high investment costs are able to conquer the market.

In the period 2007-2013 the unit consumption of the technical case is stabilising and after 2013 the indicator even increases slightly. This is a result of the model data. It is almost impossible to predict which future technologies will become available after 2010, hence these technologies are not defined in the model. Consequently after some period there are no new technologies to enter the market and the indicator will stabilise.

3.4.2 Cooling of food

For the product cooling the unit consumption per refrigerator is used as an indicator. The results below are based on an annual growth of 1.89% of the demand for cooling. This includes both an increase in the number of refrigerators and in the size of refrigerators.

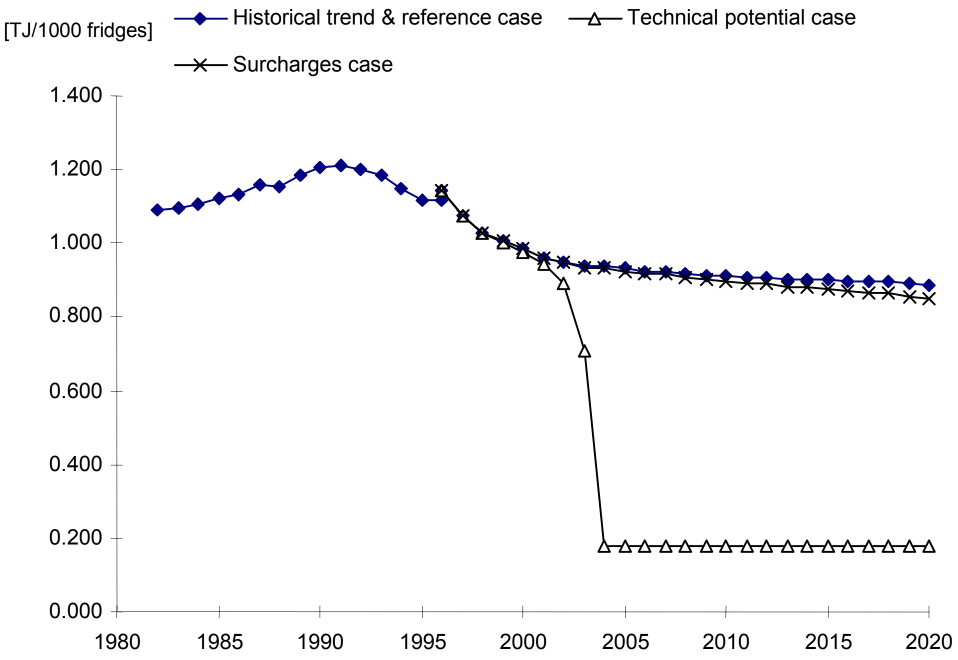


Figure 3.8 *Unit consumption of product cooling; historical trend and simulation results*

The historical trend shows an increase of the energy consumption for cooling per refrigerator. This increase is mainly due to the change of lifestyle within households. In the period before 1992 the trend was to buy larger refrigerators. Looking at the reference case, the more efficient refrigerators start penetrating the market after 1992. This penetration continues the rest of the period, although it slows down after 2004.

Again an enormous gap between the realised efficiency in the technical case and the reference case evolves. The abrupt drop around 2002 is caused by the introduction of a new cooling technology, the vacuum insulated refrigerator, into the market in 2001. This technology has a very high saving potential compared to the other available technologies, but the costs are also very high. For this reason the technology only penetrates the market in the technical case, where costs are not a limiting factor. In Section 4.3.1 an analysis is given of the effect of decreasing production costs (due to the learning effect), and of stimulating this technology with a subsidy. The impossibility to define future technologies on very long term leads to a stabilisation of the indicator. Whereas it is very likely that, in the future, new and more efficient technologies will enter the market.

As the product cooling is based on one growth rate it is not possible to evaluate the effect of structural changes. The effect caused by introducing surcharges upon the fuel prices is minimal, because it concerns only electricity. The small improvement of the unit consumption is due to a substitution of a technology by a more expensive technology which has a higher saving percentage on electricity. Hence the latter technology becomes more profitable due to the increased fuel prices.

3.4.3 Space heating

As indicator for space heating the total consumption for local and central space heating per dwelling is used. Again the stock of dwellings is assumed to grow with an annual rate of 0.98%. To investigate the effect of structural changes, the product growth of local heating and central heating are both fixed on 0.95%.

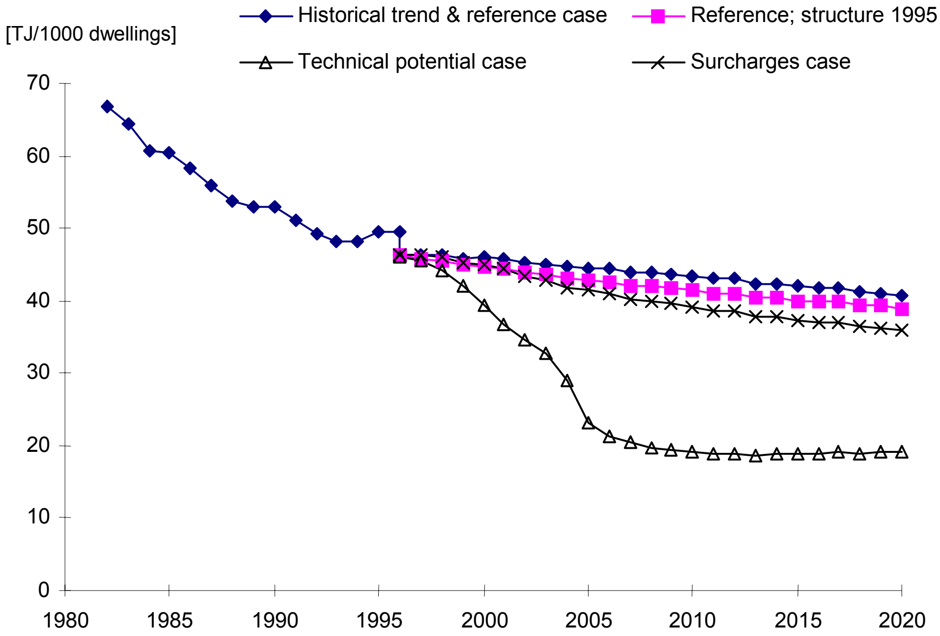


Figure 3.9 *Unit consumption of product space heating; historical trend and simulation results*

Figure 3.9 shows that the historical trend is a decreasing trend. The main reason for the decrease during the whole period is the increased penetration of roof insulation, cavity wall insulation and double glass (Uyterlinde et al., 1997). During the period 1980-2020 the old dwellings are gradually substituted by new, well-insulated dwellings. After 1995 the decrease is weaker as a result of the increase of the average size of dwellings, due to the preference for (semi-) detached houses instead of terraced ones. However the effect of the improved insulation still dominates.

The unit consumption related to a constant structure is smaller than the unit consumption in the Reference case. This means that structural changes have a small de-saving effect on energy consumption for space heating. The Surcharge case produces a much larger deviation from the Reference case. By increasing the fuel prices the penetration of more efficient technologies is accelerated, because they become profitable sooner.

Figure 3.9 shows that during the period 1995-2005 the unit consumption in the Technical potential case is decreasing. Before 2001 the most efficient technologies start penetrating the market irrespective of their costs. Subsequently in 2001 triple glass insulation penetrates the market which results into a further decrease of the unit consumption. After the year 2005 the unit consumption stabilises for the same reason as mentioned in the other two examples. In the end the most efficient technologies will also penetrate in the other cases, hence the reference case slowly converges towards the technical case.

3.5 Results manufacturing sector

Energy efficiency trends in industry are often explained by two factors:

- Structural changes on several levels: between branches (inter industrial structural changes), within branches (intra industrial structural changes, replacement of energy intensive processes or products with less energy intensive ones, or the reverse).
- Technical improvements in production processes.

For an adequate analysis, therefore both monetary and physical indicators should be used. Monetary indicators suggest that there is less energy required to produce one unit of value. This might also mean that there have been structural changes. Physical indicators suggest that there is less energy required to produce one ton of output, but could also indicate dematerialisation.

Three indicators have been selected for the Industry case studies:

- the energy intensity for the total manufacturing sector (a monetary indicator),
- the energy intensity of the food industry (a monetary indicator),
- the specific consumption of the steel industry (a physical indicator).

These indicators give examples of using different types of indicators on different levels. Table 3.5 gives an overview of the activities used to derive indicators.

Table 3.5 *Specification of indicators for the manufacturing sector*

Energy demand for REDUCE division(s) or product(s) [TJ]	Activity	Indicator
Total industry	Value added [M*f*90]	Energy intensity [MJ/*f*90]
Food industry	Value added [M*f*90]	Energy intensity [MJ/*f*90]
Blast furnaces, Blast oxygen furnaces Hot strip mills, Cold rolling mills, Basic metal electricity consumption Electric arc furnaces	Physical output of crude steel [mln. kg]	Unit consumption [MJ/kg]

3.5.1 Total manufacturing sector

The energy intensity for the manufacturing sector is defined as final energy consumption related to the value added (constant prices, factor costs) of this sector. An average growth of 3.2% annually has been assumed for value added, consistent with the GC scenario on which the cases are based. Historical data have been taken from publications of Statistics Netherlands. Figure 3.10 summarises the simulation results.

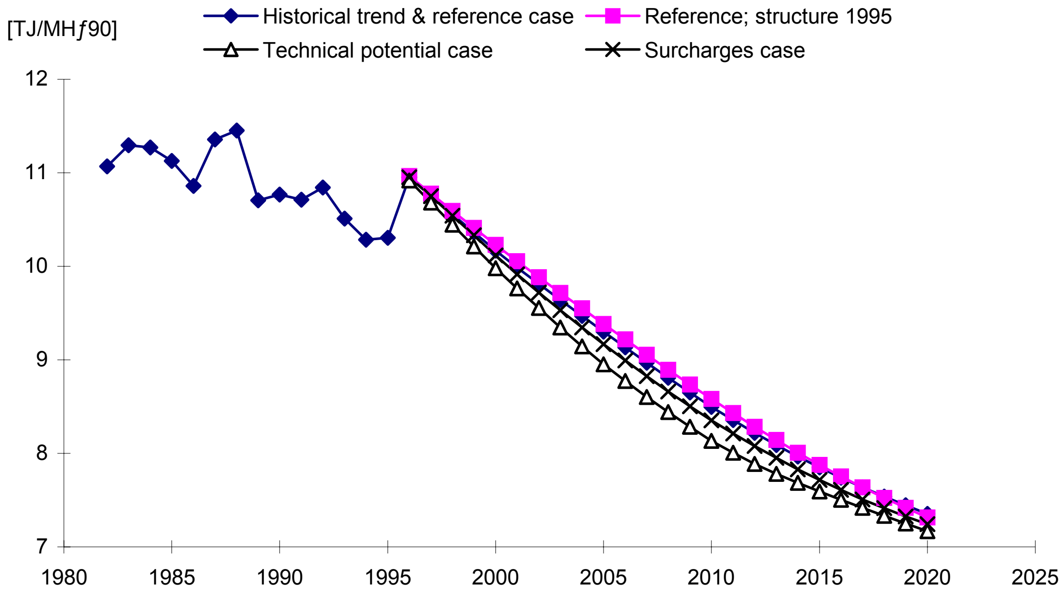


Figure 3.10 *Energy intensity of the manufacturing sector; historical trend and simulation results*

The graph shows a jump in the baseyear 1995. This is partly due to changes in the definition of the statistical classification used for the historical trends. It also explains some of the variation in the historical part of the graph.

For all cases, the energy intensity decreases very fast, also compared to the trend in 1980-1995. The main reason for this is the optimistic growth scenario used for Value Added. In the GC scenario, the assumption is that technological development leads to upgrading of final products, produced out of lesser amounts of basic materials (dematerialisation). However, Figure 3.10 raises the question whether such a growth projection is realistic for a long period.

A constant structure (no structural changes) has been modelled by assuming the average growth projection of 1.9% annually for all divisions and all products. This way, the structure of the industry remains constant compared to 1995. The 'structure 1995' line in Figure 3.10 shows that the influence of inter-industrial structural changes is not very large. The energy intensity is somewhat higher than in the Reference case, which means that structural changes do contribute to energy conservation in the manufacturing sector as a whole.

The surcharges case shows the effect of a general increase in fuel prices, being reflected in an improved energy intensity, compared to the Reference case. The relative competitive advantages of saving options are hardly affected, which is why the overall picture is quite similar to the Reference case.

Most savings are achieved in the technical potential case, which therefore also shows the fastest improvement of the energy intensity. The greatest difference to the other cases is found in the years 2005-2010. This is due to the fact that it is hardly possible to predict now which new technologies will become available after this period, and therefore these technologies cannot be specified in the model. At some point, the technical potential as far as we can specify it now, is completely used. Actually, the technical advantage gained in 2005-2010 in this case is partly lost again in later years when these technologies also gain market share in the other cases.

3.5.2 Food industry

The energy intensity for the food industry is defined as final energy consumption related to the value added (constant prices, factor costs) of this sector. An average growth of 2.1% annually has been assumed for value added, consistent with the GC scenario. The results are shown in Figure 3.11, and the overall trend in the Reference case seems more or less in line with developments since 1980. There appears to be scope for a further improvement of energy efficiency in the Food industry.

Both policy cases add a significant extra improvement compared to the reference case. For the Technical case, the phenomenon described in the previous section plays a role again. The difference with other cases is the largest in the middle years of the simulation horizon.

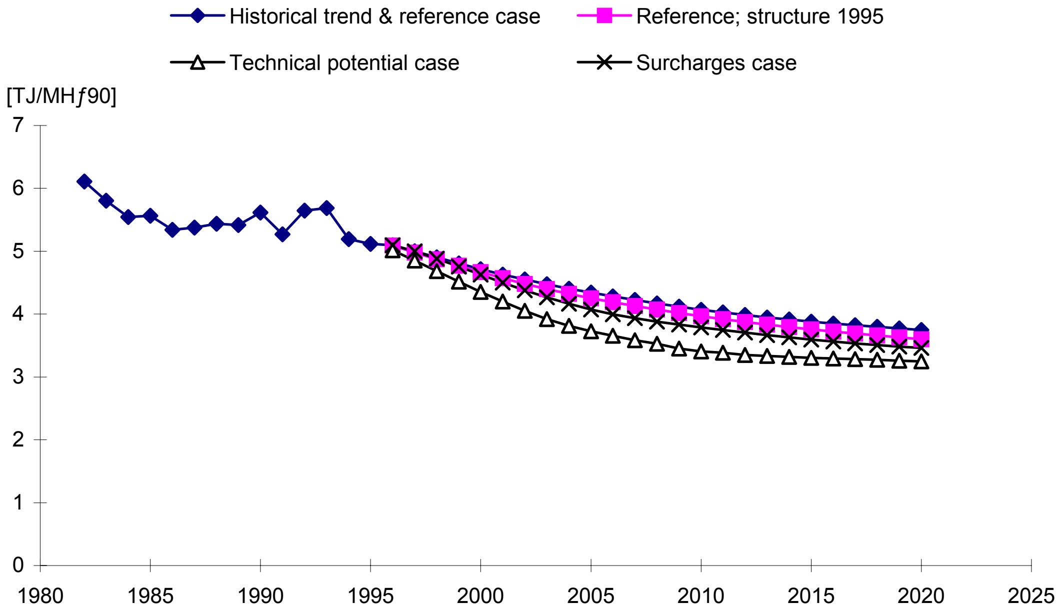


Figure 3.11 *Energy intensity food industry; historical trend and simulation results*

One of the reasons the Food industry was chosen for a case study, is that it comprises of many different subsectors, such as Meat, Dairy, Sugar, Starch, Oils, Fodder and Beer. The growth projections for these subsectors are quite different. The production in dairy and sugar industries is expected to shrink, while growth is expected in the starch, oils and beer industries. Other subsectors, such as meat and fodder are hardly expected to grow.

For the simulation of the 'structure 1995' case, the growth projections for all subsectors were set to their weighted average value used for the Food industry. Structural changes here have an effect opposite to that in the manufacturing sector as a whole. Figure 3.11 shows that the corresponding energy intensity is lower than that in the Reference case, implying that structural changes for the Food industry have a 'de-saving' effect. In other words, the growth of the starch, oils and beer industries counterbalances to some extent the savings achieved in these sectors, and the shrinkage in the dairy and sugar industries.

3.5.3 Steel industry

For the steel industry, the amount of energy required to produce one kg of crude steel has been taken as an indicator of energy efficiency. The following assumptions, derived from the GC scenario, are underlying the growth projections. The basic metal industry is an energy intensive sector, with a share in the total industrial energy consumption of around 20%. In the Netherlands the growth in all basic industries is expected to be lower than the growth in transforming industries. The reason is that the technological development leads to upgrading of final products, produced out of lesser amounts of basic materials (dematerialization). Within the Dutch basic metal industry, the iron and steel industry is expected to grow moderately (index in 2020 of 1.17). The physical output of crude steel is expected to grow with 1.7% annually. For this indicator, it was not possible to examine the effect of structural changes, because one growth figure has been assumed for the complete iron and steel industry.

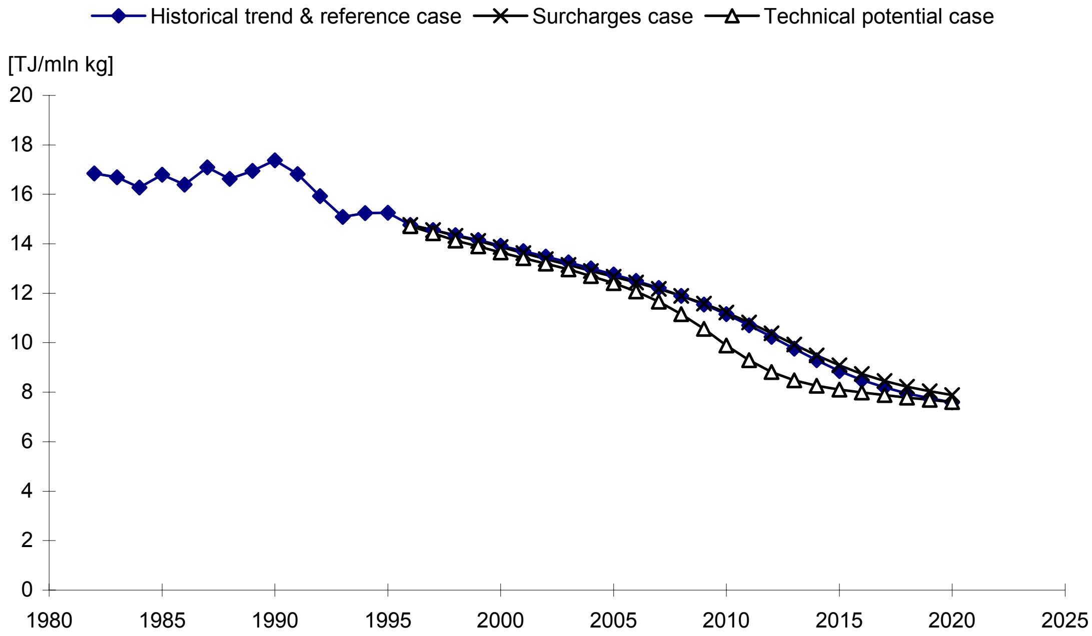


Figure 3.12 *Unit consumption steel industry, historical trend and simulation results*

Figure 3.12 shows a considerable decrease in unit consumption, especially in the second half of the modelling horizon. This is mainly induced by the fast penetration of a very attractive conservation option during this period. This specific conservation option (the *converted blast furnace*) has a saving percentage of 30% and the option is cheaper than its reference technology, whereas the other alternative conservation options have higher investment costs than their reference technologies. Moreover the converted blast furnace belongs to the most energy consuming production process within the steel industry; blast furnaces. As Figure 3.13 shows, this production process covers on average 80% of the total energy consumption of the steel industry. Consequently, the penetration of this option induces a noticeable decrease on the unit consumption of the total steel industry.

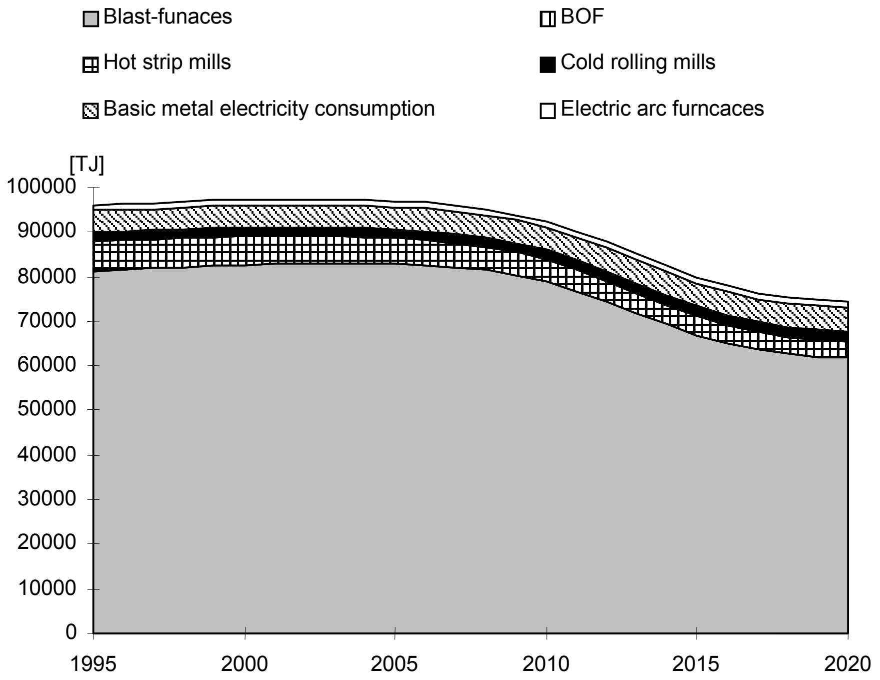


Figure 3.13 *Energy consumption shares of the main production processes within the steel industry*

Just as in the manufacturing sector and the food industry, most savings are achieved during 2005-2015 in the technical potential case. Again the efficiency gap between the technical and the other cases are explained by the phenomenon described at the end of Section 3.5.1. However the efficiency gap is also caused by two attractive, but expensive, options belonging to the blast furnaces process. Since costs are not a limiting factor within the technical case, these two options significantly penetrate into the market. Whereas for the reference case, these options are too expensive. Additionally, the most favourable conservation option of the blast furnace product process penetrates much faster within the technical case, which also contributes to the gap between the technical, and the reference case.

Opposite to the results of the manufacturing sector and the food industry, here the surcharges case does not improve the energy efficiency in relation to the reference case. Before 2010 both cases show the same unit consumption, after 2010 the unit consumption of the surcharges case becomes larger compared to the reference case. This deviation is caused by the principle called ‘second-best-wins’. The increase of fuel prices makes investing in saving options more profitable. As a consequence the options get a larger IRR hence their penetration rate increases as well. Due to this increase in penetration rate it is possible that an average saving option with a significant penetration during the start year will be too competitive for options with a larger saving percentage but a very small penetration in the market during the start year. This situation occurs within the steel industry. The attractive saving option, regarding its saving percentage, is pushed away by a less saving but more competitive option. As a result the unit consumption increases in relation to the reference case.

3.6 Conclusions

The addition of energy efficiency indicators to REDUCE is a very useful one, as it saves time in analysing the output. By using the indicators, the output of REDUCE becomes more general and comparable. This creates the opportunity to compare historical trends with different developments (i.e. cases) in the future. Furthermore, international comparisons and benchmarking can be performed by using the indicators.

The indicators are implemented as a very flexible tool. For each indicator, the user decides which activity is used, which growth rates and on which level of energy demand the indicator is calculated. Consequently any study with energy efficiency indicators can be executed. This is in line with the overall objective of REDUCE to provide an international framework for comparable energy conservation studies. The examples in sections 3.4 and 3.5 show some brief analysis using indicators. They show that, among other things, effects of dematerialization, structural changes and policy measures (here surcharges) can be made visible by comparing energy efficiency indicators.

A potential weakness of the methodology with which the indicators are calculated is that it compares several projections. After all, the future energy consumption is based on projections just like the activity. The only part simulated is the achieved savings. This is an important difference compared to the certainty of indicators when looking at the past. Therefore care should be taken that the projections are consistent. On the other hand, an indicator analysis can be regarded as a useful check on the quality of both the projections and the model results, by visualising trends and, possibly, disruptions.

4. ENDOGENOUS TECHNOLOGY DEVELOPMENT

4.1 Introduction

In previous versions of REDUCE, the effects of technical development on investment costs were not explicitly taken into account. Therefore it was proposed to make investment costs of new, advanced technologies variable in time, in order to allow for a decrease of the production costs through an ‘experience curve’ related to the market share of the particular option. This phenomenon is often referred to as the ‘learning effect’.

First, it must be mentioned that the S-curve in REDUCE does reflect the stages of technology development (among other social and behavioural driving forces), which implicitly include assumptions on production costs. Therefore it seems reasonable to assume that for most options, the S-curve is sufficient to cover the learning effect. However, for technologies with a high potential, a low current market penetration and high investment costs, the assumption that the current costs will remain constant in time is not correct, because the S-curve underestimates their development. For those technologies, a learning curve reflecting a cost decrease as a result of increased production would add some realism to the model.

This chapter describes the use of learning effects on the investment costs of technologies within REDUCE. The next section describes the two alternatives available to use this feature. Subsequently, Section 4.3 discusses four different case studies illustrating the use of an experience curve.

4.2 Modelling learning effects in REDUCE

Two possibilities are offered in REDUCE for modelling learning effects. For each saving option (‘technology’) one of the following methods, described in the next subsections, can be chosen:

- Exogenous variable investment costs.
- Experience curve.

4.2.1 Exogenous variable investment costs

In this alternative, the investment costs are variable in time, but still exogenous. A model user can enter his own estimated cost development (or keep constant costs, as is the current default). This is useful when the market, as considered in REDUCE, is not representative for the total market of a certain option. In addition, it reduces the data requirements compared to the second alternative, i.e. specifying an experience curve (see also Paragraph 4.2.2).

Within REDUCE the variable investment cost function of an option (technology) has the following basic format:

$$\text{Equation 4 1} \qquad Inv_t = Inv_1 \times (1-r)^{t-1},\ r > 0$$

where:

Inv_t = absolute investment costs of option i at time t [currency/GJ saved],
Inv_1 = absolute investment costs of option i in start year [currency/GJ saved],
r = reduction rate,
t = time [years].

This way, the user only needs to specify initial investment costs and a growth rate. REDUCE will calculate the cost curve, which can be still modified by the user afterwards.

To take negative additional investment costs and savings into account the following four combinations are distinguished:

- net savings positive and additional investment costs positive,
- net savings negative and additional investment costs negative,
- net savings negative and additional investment costs positive,
- net savings positive and additional investment costs negative.

Only in case of the first two combinations the defined cost function will actually be used in the presented form. In the last two cases the cost function has to be transposed in order to get an appropriate function. This implies that the investment costs are expected to decrease in time and investment profits (negative investment costs) have to *increase* in time. For example, suppose the net savings of a technology, compared to its reference, are negative. If the technology costs less than its reference, its additional investment costs will be negative although its additional investment costs *per* GJ saved will be positive. This example corresponds with the last case mentioned above. If Equation 4 1 is used to simulate cost reductions for this technology its absolute additional investment costs per GJ saved will decrease. However this implies that the investment costs of the technology tends to the costs of the reference technology, hence the investment costs increase.

4.2.2 Experience curve

The second possibility for modelling learning effects is using an experience curve. The investment costs decrease depending on the cumulative number of units, in turn depending on the market success of the option, as simulated in the model (so the costs are determined endogenously). For this purpose, the following methodology has been developed.

The ‘standard experience curve’ has the following form (Argote et al., 1990):

$$C_t = C_0 \times CUM^b$$

Where:

C_t = production cost per unit at time t
C_0 = production cost of first unit
CUM = cumulative production (total number of units produced)
b = experience index
2^b = progress ratio

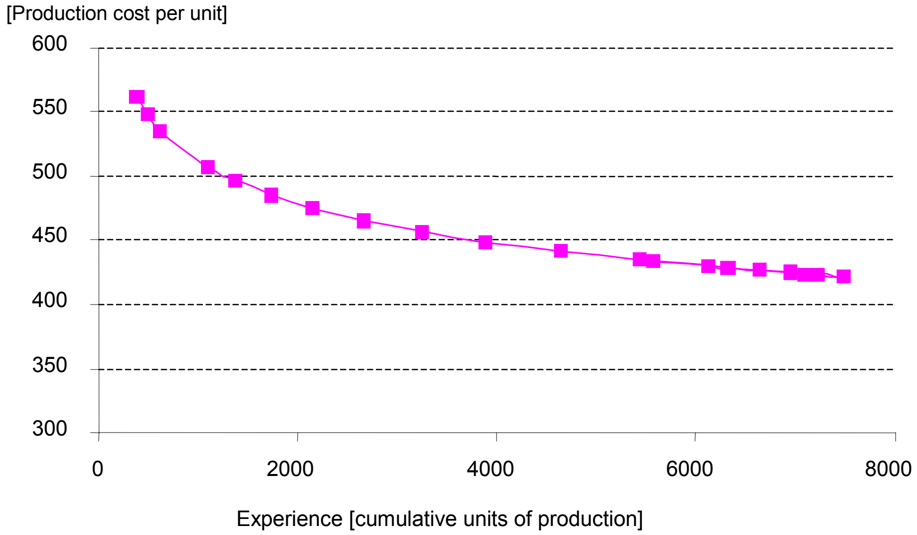


Figure 4.1 *Example of an experience curve with a progress ratio of 80%*

Figure 4.1 shows an example of an experience curve. Characteristic of this function is that cost declines with a constant percentage with each doubling of cumulative production. The experience index is used to calculate the reduction (1-2^b) of production costs. The value of the progress ratio 2^b is typically in the range 70-100%. In literature several classifications by type of technology have been made (Neij, 1997). These should be investigated to provide a first suggestion of data for the model users. Another approach is to use historical trends and assess whether these trends can be expected to continue in the future.

Translated into REDUCE parameters, the cumulative production of a technology is (basically) deduced from the number of units of the technology present in the market during the start year Q_1 and its penetration percentage. The learning curve has the following functional form (using a difference equation for the approximation of cumulative production) for option (technology) i.

$$Inv_t = Inv_1 \times (CUM_t / CUM_1)^b$$

$$CUM_t = CUM_{t-1} + N_t + V_t$$

$$N_t = \max\{0, Q_t - Q_{t-1}\}$$

$$\begin{array}{l} V_t = \quad \text{IF} \quad [Q_t - Q_{t-1}] > 0 \quad \text{THEN} \\ \qquad\qquad\quad N_{t-L} \\ \qquad\quad \text{ELSE} \\ \qquad\qquad\quad \max\{0, N_t - L + Q_t - Q_{t-1}\} \\ \qquad\quad \text{ENDIF} \end{array}$$

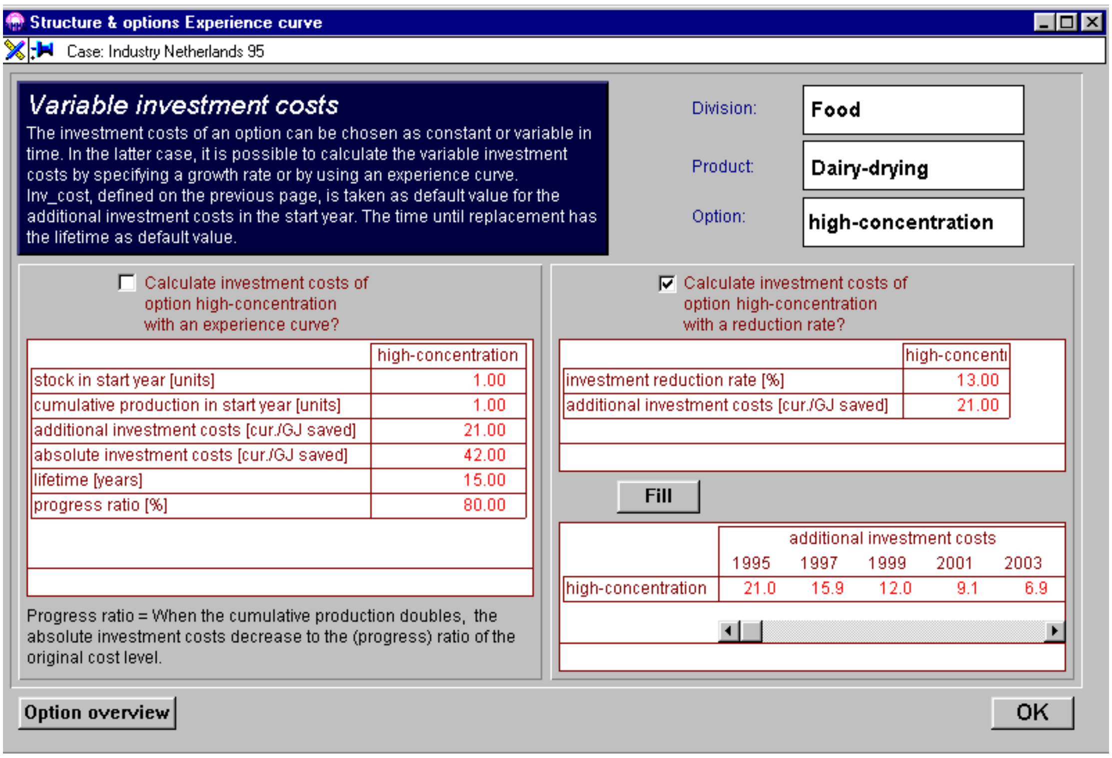
$$Q_t = P_t \times \frac{Q_1}{P_1} \times (1+p)^{(t-1)}$$

where:

Q_t = number of units of option i present in the market during time t,
P_t = market share of option i at time t [%],
Q_1 = stock of option i present in the market during the start year (exogenous),
P_1 = the penetration share of option i in the start year [%] (exogenous),
p = product growth of the product of option i [%] (exogenous),
N_t = increase of the number of units of option i (present in the market) during time t,
V_t = produced number of units of option i during time t for replacement of discharged units,
CUM_t = cumulative number of units of option i produced in all years before (and including) time t,
CUM_1 = cumulative number of units of option i produced in all years before (and including) the start year (exogenous),
L = lifetime until replacement of option i [number of years] (exogenous),
Inv_t = absolute investment costs of option i at time t [currency/GJ saved],
Inv_1 = absolute investment costs of option i in start year [currency/GJ saved] (exogenous),
b = experience index (exogenous).

The same four combinations as with the variable investment cost function can be distinguished to take negative additional investment costs into account. For two combinations the experience curve has to be transposed in order to obtain the appropriate experience curve.

Figure 4.2 shows the screen within REDUCE where the experience curve or variable investment cost-function can be defined. The new data requirements within REDUCE to implement this experience curve are: Q_1, Inv_1, CUM_1 (note that this is larger than or equal to the number Q_1), b and possibly the lifetime until replacement of the option. In REDUCE the ‘economic lifetime’ of an option is used for the calculation of the IRR. When this parameter is directly used for the lifetime until replacement (‘technical lifetime’) the number of units replaced might be overestimated. Therefore the possibility is created to define another lifetime for the replacement of options.



Case: Industry Netherlands 95

Variable investment costs

The investment costs of an option can be chosen as constant or variable in time. In the latter case, it is possible to calculate the variable investment costs by specifying a growth rate or by using an experience curve. Inv_cost, defined on the previous page, is taken as default value for the additional investment costs in the start year. The time until replacement has the lifetime as default value.

Division: Food
Product: Dairy-drying
Option: high-concentration

☐ Calculate investment costs of option high-concentration with an experience curve?

	high-concentration
stock in start year [units]	1.00
cumulative production in start year [units]	1.00
additional investment costs [cur./GJ saved]	21.00
absolute investment costs [cur./GJ saved]	42.00
lifetime [years]	15.00
progress ratio [%]	80.00

Progress ratio = When the cumulative production doubles, the absolute investment costs decrease to the (progress) ratio of the original cost level.

☑ Calculate investment costs of option high-concentration with a reduction rate?

	high-concent
investment reduction rate [%]	13.00
additional investment costs [cur./GJ saved]	21.00

	additional investment costs				
	1995	1997	1999	2001	2003
high-concentration	21.0	15.9	12.0	9.1	6.9

Figure 4.2 *Input screen of* R*EDUCE to define variable investment costs*

The units produced for replacement, V_t, are calculated by using an 'IF-statement'. This statement makes it possible that not every unit will be replaced automatically after its 'lifetime until replacement' is expired, allowing a decreasing market share. Moreover the experience curve is based on the assumption that only units of which the lifetime is expired can leave the market. If the technology belongs to the group of permanent demand options, in no case replacements occur. Hence in those cases the term V_t can be omitted from the formula above.

In REDUCE the investment costs are defined as additional investment costs, relative to the reference technology. However the defined experience curve is based on absolute investment cost. Therefore the additional investment costs through time, as required for the REDUCE calculation, is deduced from the cost decrease resulting from the experience curve. Note that the additional investment costs plotted against time gives another impression of the curve compared to data plotted against experience (cumulative production).

When experience curves are applied, one has to make sure that the correct starting point (CUM_1, Q_1, Inv_1, P_1) is used. By using the wrong starting point to measure experience on a cost component, the previous experience might be underestimated which results in over-optimistic cost projections.

4.3 Case studies

This section presents some case studies in which experience curves are used. The data set used for these cases is deduced from a previous project (Van Harmelen and Uyterlinde, 1999). The underlying assumptions and scenarios have been discussed in Section 3.3. In both the sectors Households and Industry, two technologies have been provided with an experience curve. In the next paragraphs these cases are discussed.

4.3.1 Households

A technology typically should be modelled using an experience curve when it has a high potential, a low current market penetration and high investment costs. Within the sector households the following two technologies complying with these criteria are modelled using an experience curve:

- vacuum insulated refrigerator,
- heat pump.

The additional data required for defining the experience curves are listed in the following table.

Table 4.6 *Additional data requirements for experience curves in sector Households*

		Fridge vacuum insulated	Heatpump
Stock in startyear (Q_1)	[units]	1	9
Cumulative production in and before startyear (CUM_1)	[units]	1	10
Absolute investment costs in startyear (Inv_1)	[D*f*/saved GJ]	1700	9000
Additional investment costs in startyear	[D*f*/saved GJ]	130	76
Lifetime until replacement (L)	[year]	15	15
Progress ratio (2^b)	[%]	80	80
Net savings	[% total demand]	90	74.8

Sources:[5,18]

Vacuum insulated fridge

Experts on domestic appliances expect a prosperous future for the vacuum insulated fridge. The fridge has a high saving percentage compared to the conventional fridge and as the technique is relative simple, hardly any complications are excepted for introduction. As the vacuum fridge is a very new technology the production line of this product is in development, hence the production costs are still very high. As a result the current market share of vacuum insulated fridges is very small. Figure 4.3 shows penetration curves of the vacuum insulated fridge for four different cases simulated with REDUCE. The case without an experience curve and without subsidy can be considered as the base case. The figure shows that as from 2001, when the technology comes into the market, the penetration curve of the vacuum insulated fridge is strictly decreasing.

After defining an experience curve for this technology, the penetration curve remains decreasing. The additional investment costs of the vacuum fridge proves to be too large to penetrate into the market. Because the technology only loses market share as from the start year, there is hardly any production of new units. Accordingly, the definition of an experience curve has no effect.

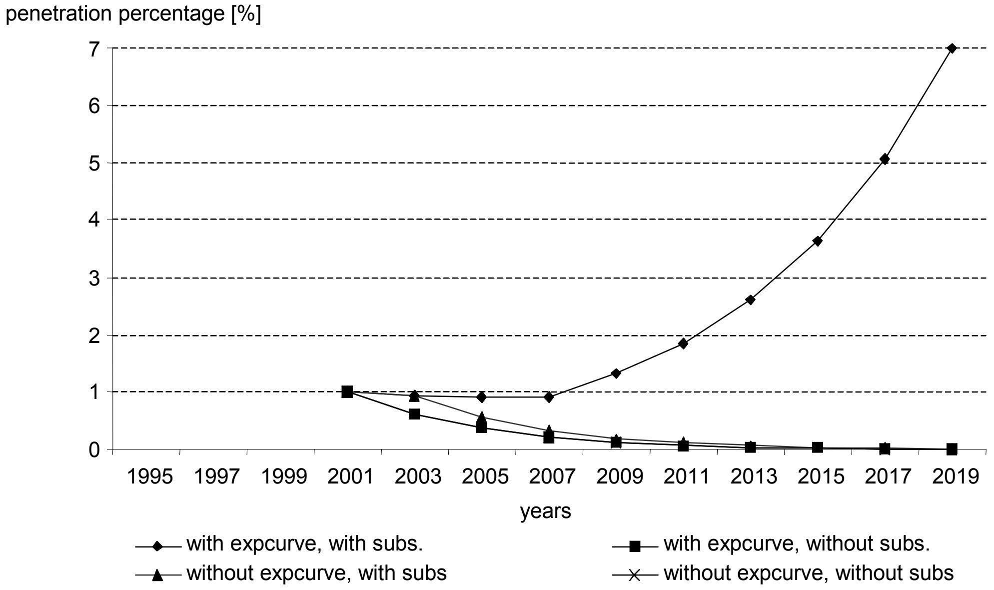


Figure 4.3 *Penetration curves of vacuum insulated fridge*

Suppose authority decides to subsidise the purchase of vacuum insulated fridges with 30% of the investment costs, during the year of introduction (i.e. 2001). This is a policy instrument often applied for stimulating the purchase of energy efficient (A-labelled) appliances. The case, in which also an experience curve is defined, shows that the penetration percentage of the vacuum insulated fridge will increase in time. Hence in this case the learning curve does have an effect on the investment costs of the fridge. Apparently, due to the provision of subsidy during the start year the production of the vacuum fridge is stimulated, and the learning effect takes place. This can also be concluded from the case in which an experience curve is not defined but nevertheless authority decides to subsidise the vacuum insulated fridge with 30% during the start year. In this case the decrease of the penetration percentage is smaller during the start year. However as soon as the provision of subsidy is finished, the curve again approximates the other two decreasing penetration curves.

Heatpump

The future of the heatpump is expected to be less prosperous than that of the vacuum insulated fridge. From pilot projects on heatpumps can be concluded that the technology is still dealing with some unsolved technical problems. As a result the technology still needs large investments for further development, hence the investment costs of a heatpump are still very high. Due to the technical problems and the high investment costs, the market share of the heatpump is small.

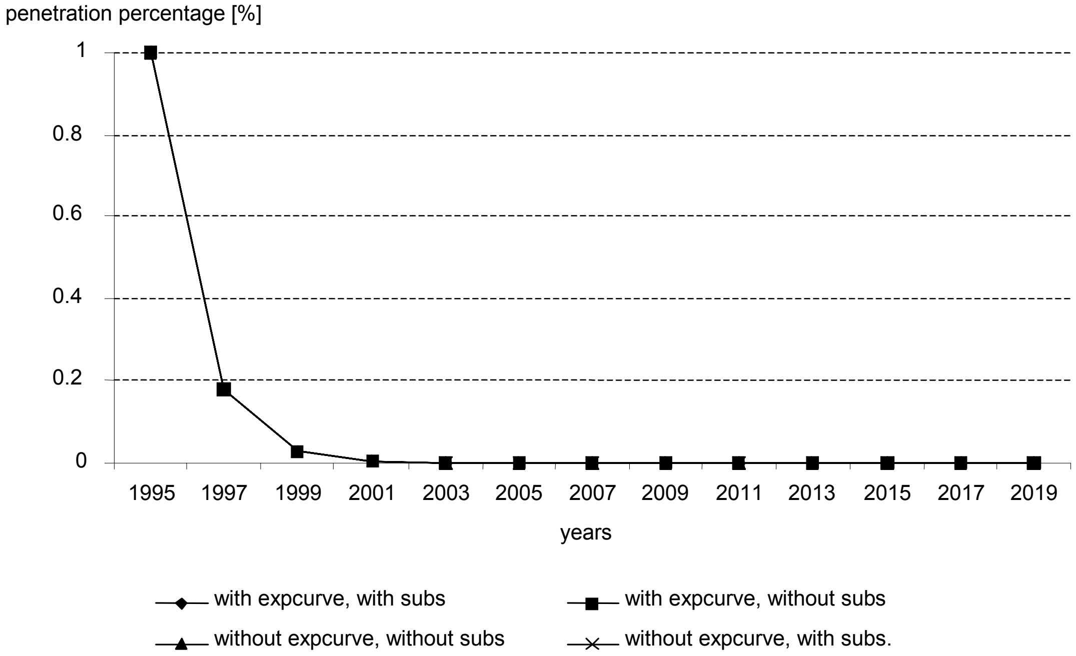


Figure 4.4 *Examples of the penetration curves of the heat pump*

Just as for the vacuum insulated fridge, four different cases are simulated for the heatpump. Figure 4.4 shows the four penetration curves corresponding with these simulations. At the start year the penetration percentage (i.e. market share) of the heatpump is 1%. In all four cases this penetration does not increase. The production of heatpumps is not increasing in such amount that the experience gained affects the production costs. These negative results are not only caused by the strong competition that heatpumps encounter. The savings on gas consumption by the heatpump compared to the reference technology (gas boiler) is positive, however a heatpump consumes electricity instead (but the net amount of energy saved is considerable). The fact that the electricity tariff is five times higher than the gas price, combined with the high additional investment costs of the heatpump result in a negative internal rate of return. A technology with a very negative IRR will never have an increasing market share within REDUCE.

4.3.2 Industry

Within the sector Industry the following two technologies, are used as cases , because they are better modelled with an experience curve:

- High-concentration dryer; a technology that is used within the dairy industry for evaporation of whey.
- AMV-process; a process used within the fertiliser industry.

Table 4.7 *Data requirements of experience curves in the sector Industry.*

		High-concentration dryer	AMV-process
Stock in startyear (Q_1)	[units]	1	1
Cum. Production in and before startyear (CUM_1)	[units]	1	1
Abs. Investment costs in startyear (Inv_1)	[D*f*/saved GJ]	42	3.7E+08
Additional investment costs in startyear	[D*f*/saved GJ]	21	90
Lifetime until replacement (L)	[year]	15	20
Progress ratio (2^b)	[%]	80	80
Net savings	[% total demand]	43	13

Sources: De Beer et al., 1994; Worrell et al., 1997

High-concentration dryer

Figure 4.5 shows the results of the two cases simulated for the high-concentration dryer. In case there is no experience curve defined for the high-concentration dryer, first the penetration is increasing but after ten years the market share of high-concentration decreases. This is caused by the strong competition between dryers within the dairy industry. Finally, another technology that competes with the high-concentration dryer, wins market share and pushes the other alternatives aside.

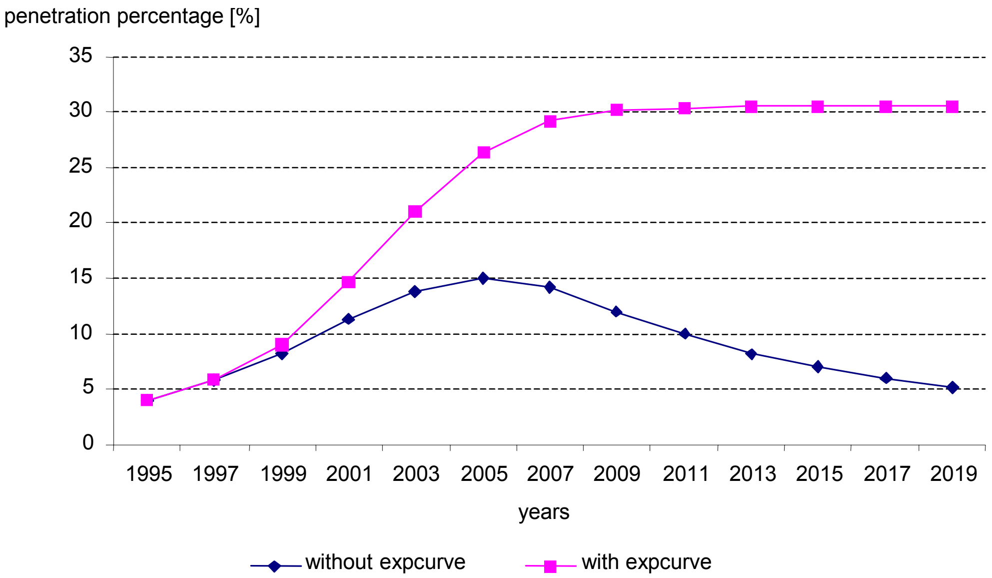


Figure 4.5 *Penetration curves for the high-concentration dryer*

Defining an experience curve on the high-concentration dryer, results into a stabilised market share. Because the market share of the high-concentration dryer is increasing as from the start year, the learning effect will take place in this case. The decreasing investment costs induced by this curve give the high-concentration dryer an economically more attractive position in the market of dryers. Hence the technology is not pushed aside by a competing technology. The technology that would conquer the market in the previous case, is now sharing the market with the high-concentration dryer.

AMV-process

The AMV-process consists of a simple construction change that influences the energy use of ammonia production. Nevertheless its additional investment costs are relatively high compared to its alternatives. In the base case in which no experience curve is defined, the market share of the AMV-process is strictly decreasing. Subsequently, the definition of an experience curve has no effect. Figure 4.6 shows this result (‘with exp.-curve, without subs, with competition’).

Suppose once more that authority decides to subsidise the AMV-process for industries. Then still the market share of the AMV-process is strictly decreasing. Apparently, the process is too expensive. The process has a high saving percentage however the cost-effectiveness is low, compared to its alternatives.

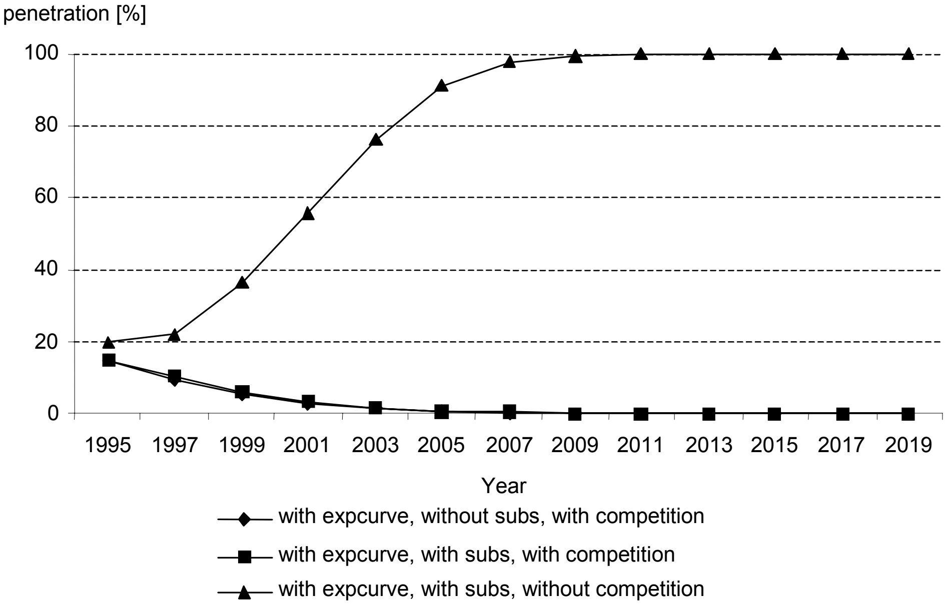


Figure 4.6 *Penetration curves of the AMV-process*

What if there would be no competition for the AMV-process? Figure 4.6 shows that the AMV-process will then conquer the market. Hence, the decreasing penetration is purely caused by strong competition, not by a negative rate of return.

4.4 Conclusions

The use of experience curves can add a degree of realism to the model. Options in the demonstration stage are characterised by a small market share, high investment costs but also by a high potential. If more units of these options are produced, investment costs will decrease as a result of the learning effect: more experience in the production process will induce a cost decrease. This implies that for technologies still in the demonstration stage, the assumption that the investment costs remain constant in time is not appropriate. For most other options the S-curve, a standard feature of REDUCE, reflects the different technology stages sufficiently

The cases discussed in Paragraph 4.3 show that the definition of an experience curve does not automatically result in a larger market share. Based on the initial investment costs, some extra units will have to be produced, otherwise the learning effect is not induced and the experience curve will not be effectuated. For example, the heatpump has a cost-effectiveness that is too low during the start year. Policy measures such as regulation will be required to support this technology to overcome its experimental stage. The high-concentration dryer is an example of a technology that is probably better modelled using an experience curve.

Two short comments on the used definition of ‘experience’ should be given. The production of technologies that are exported to foreign markets is not accounted to the cumulative production, which is used as an indicator of ‘experience’. Moreover REDUCE does not take shared experience (when two ore more technologies share a common resource or component in a similar manner) into account. As REDUCE focuses on national level (it has no links with ex- or imports) the first exception is reasonable. In cases where this assumption is too restricting, such as household appliances which are manufactured for the EU market, the variable production costs should be estimated exogenously (see Section 4.2.1) instead of using an endogenous experience curve. The second exception is more disputable but necessary as the overall objective of REDUCE is to provide an international framework for energy conservation studies. Without the second exception some kind of structure of technologies would have to be fixed within REDUCE, which is undesirable.

Defining an experience curve within REDUCE implies some new data requirements. If proper data on an option are missing, it is recommended to reconsider the use of an experience curve. Especially detection of the progress ratio can be difficult. In the discussed cases a mean value of 80% is used. However, in order to make a proper use of the experience curve it is important to define this ratio correctly. In literature several classifications by type of technology have been made with a corresponding progress ratio (Neij, 1997). These should be investigated to provide a first suggestion. Another approach is to use historical trends and assess whether these trends can be expected to continue in the future.

APPENDIX A USER'S GUIDE

A.1 Input data specification

The guidelines below have been structured in the same way as the pages (screens) in the REDUCE computer model. The names of the subsections correspond to the buttons in the REDUCE Main menu. Each item first will be explained, then some guidelines regarding data definition and specification are given.

A.1.1 Basic data

Energy carriers

On this screen, the user can select which energy carriers are included in the model. The differences in price and CO_2 and SO_2 emission factors of the various energy carriers are important for the cost-effectiveness of energy conservation options and emission reduction. Only those energy carriers that are an option for end-users play a role.

Be aware that an energy demand projection has to be included for each product and for each energy carrier. So, a high level of detail is not practical and feasible. The following standard set of energy carriers is available, and gives the possibility to choose between different aggregation levels:

- coal,
- brown coal,
- light oil,
- heavy oil,
- gasoline,
- gasoil,
- LPG,
- natural gas,
- renewables,
  (geothermal, electricity-wind, solar, photovoltaic)
- electricity,
  (electricity-peak, electricity-base)
- heat.

It is most useful to select a few energy carriers from this list and remove the other ones (see below).

To add an energy carrier from the list above to your data set:

- Click on the '+'
- Type the name of the energy carrier, and optionally, a description.

To remove an energy carrier

- Click on the '-' and always check the option 'remove associated data' to make sure that all data is deleted. Do not remove the 'energy carriers' Total_energy and Saving from this list!

Emission factors

Enter for each energy carrier and each pollutant (CO_2 and SO_2) an emission factor in the table.

Time horizon The model offers a flexible time step, which can be changed on the Basic Data page. In order to save memory, speed, and disk space, it is advised to perform test runs using steps of 2 to 4 years in time. This way, you can see the penetration and impacts of energy saving options on the short term, while the model still runs fast and cases remain compact.

A.1.2 Structure and options

In REDUCE, a hierarchy of different levels has been designed, see Figure A.1. This hierarchy is very flexible; the choice of divisions and products determines the level of detail in the model.

Overview of hierarchy The first page displays an overview of the hierarchy. When entering data, you can click on '>>' to proceed to the next page.

INPUT	LEVEL	OUTPUT
base year / time horizon fuel types emission factors economic growth projection *fuel price projections* *interest rate projections* *penetration speed* *with/without BATs*	**NATIONAL**	
fuel consumption base year *division growth projections* *fuel price / tariff projections* *divisional interest* *divisional penetration speed*	**DIVISION**	***ALL LEVELS*** final demand emissions volume / structure / saving
fuel consumption base year *product growth projections* *product intensity change projections* *product penetration speed*	**PRODUCT** interaction demand / supply	effectiveness fuel saving emission reduction
demand / supply competition temporary / permanent	**MARKET GROUP** FP penetration	benefits / costs investments subsidies
investment / variable costs lifetime start year / market share fuel savings % *BAT* *grant % / time period* *option penetration speed*	**OPTION** IRR calculation PbP calculation	IRR / PbP market penetration of options

Figure A.1 *Overview of hierarchical structure and organisation of input and output on the different hierarchical levels of the REDUCE model*

A.1.2.1 Divisions and products

Divisions

A Division is distinguished in REDUCE for the sake of accounting and comparing with statistics and other models. Therefore, it is important to use clearly defined Division categories. The following example is based on the NACE classification used in many international statistics.

Division	*Subsectors included*
• Food	(Food, beverages and tobacco)
• Clothes	(Textile, Clothes, Leather and Leather products)
• Paper and printing	(Paper and paper products, Publishing and printing)
• Chemical industry	(Manufacture of coke, petroleum products and nuclear fuel, Chemical industry, Rubber and plastic products)
• Building materials	
• Basic metals	
• Metal products	
• Other industries	(Wooden products and furniture, Machinery and office equipment, Electrical machinery and appliances, Medical and optical instruments, Transport industry)
• Households	
• Services	
• Transport	

For each defined division and each energy carrier, enter the Final Energy Consumption in TJ (for the base year) in the red table. It concerns Final Energy Consumption as in the statistics, so present energy savings are included. See Section 2.2.5 for an explanation of the definition of energy consumption.

Conform to most statistics, centrally produced heat is defined as heat, while for decentralised locally produced steam/heat, the fuel that is input for heat generation is used as identification.

Products

The Product level in the hierarchy has a number of meanings. Depending on data availability and the sector modelled, you can use one of the following interpretations. A Product is a designation of energy services, for instance heating or cooling, or processes, such as evaporation, drying, cleaning etc.

Within each division, as many products can be specified as the user likes. On this level, special attention can be given to country specific important types of production or subsectors. In general, the demand for products must be projected in time by energy carrier or mix of energy carriers.

It is recommended to treat different energy carriers in Households as separate Products (viz. gas heating, coal-heating etc.) since energy carrier shares are determined by a number of non-economic factors such as availability of a grid, levels of comfort etc. In this case, fuel switch is made exogenous.

For products in Industrial divisions, a mix of energy carriers could be considered, since fuel switch mainly takes place on the basis of cost-effectiveness of energy carriers. However, the behaviour of the model should be tested in this field, especially if Combined Heat and Power or Heatpump options are included.

Adding a new product

To add a new product, proceed as follows.

- Select a division in the top selection field
- Click the ‘+’ in the second selection field, and type the name of the product (and optionally a description).
- Check the box (with a ‘cross’) to indicate that the new product is in the selected division.

Food-industry

Sugar

☒ Product Sugar is in Food-industry?

For each product and each energy carrier, enter the Final Energy Consumption in TJ (in the base year) in the red table. The difference between the sum of energy consumption of all products in a Division and the level of energy consumption specified for that Division is automatically allocated to a standard product category, reflecting products not explicitly specified. This category is named ‘rest’.

A.1.2.2 Options

A saving option is defined as the difference between a new technology and a reference technology (which is not displayed in REDUCE).

The reference technology can also be constructed as a (weighted) average of the technologies in use in the branch under consideration.

An option is fully characterised by its saving potential as a percentage of total energy consumption, additional investment costs and variable costs, lifetime, and penetration share in the start year (not necessarily the base year of the calculations), subsidy percentage and final year of subsidy (optional).

Saving percentage

The saving percentages are expressed in connection with the *total* energy consumption for a product. Note that this concerns the energy demand corrected for savings in the base year (so probably greater than the energy consumption specified for the product in REDUCE). There are 3 basic situations.

1. One energy carrier, no fuel switch, and thus separate products for different fuels. For instance cooking based on gas or cooking based on electricity. In this case the product demand should only be specified for one fuel, as well as the saving percentage.

	Coal	Gas	Total
Product demand [TJ] (exc. current savings)		250	250
Saving %		20%	20%
Saving [TJ] (total penetration)		50	50

2. Multiple energy carriers, and no fuel switch. This situation applies to demand options that save energy independently of the fuel mix. The total saving percentage is allocated to the fuels in the mix according to fuel shares in energy demand (without savings) for that product. In the example below, the total saving percentage of 20% has been allocated accordingly.

	Coal	Gas	Total
Product demand [TJ] (exc. current savings)	50	200	250
Saving %	4%	16%	20%
Saving [TJ] (total penetration)	10	40	50

3. (Partial) fuel switch. Because of modelling technicalities, this is possible only if the options' reference has a mix of fuels. In the example below, the total saving percentage is positive. In the allocation of saving percentages to the different fuels, the fuel that is not used anymore should have a saving equal to or smaller than the amount demanded, see the example.

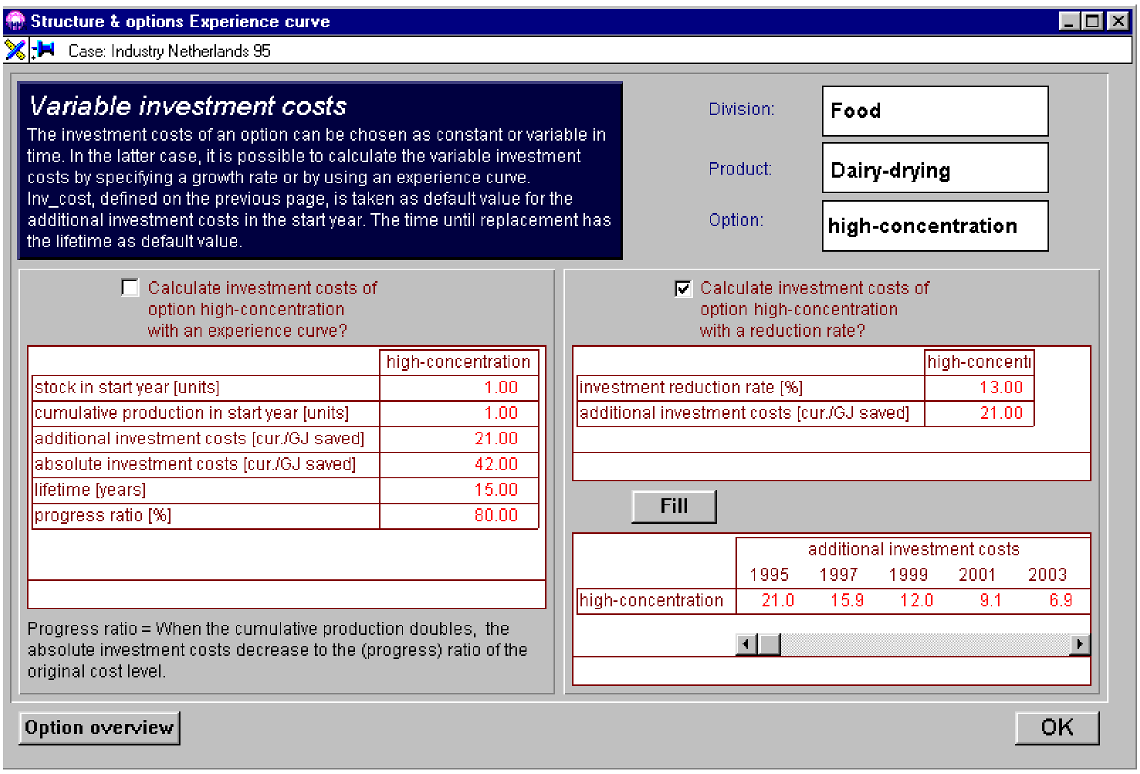
	Coal	Gas	Total
Product demand [TJ] (exc. current savings)	50	200	250
Saving %	20%	-10%	10%
Saving [TJ] (total penetration)	50	-25	25

Fuel switch can even be attractive when the resulting saving is negative (so there is an increase in energy demand), when the switch is towards a cheaper fuel, and the option is cost-effective.

Note that if in the base year conservation options already have penetrated, the fuel mix corrected for energy savings is different from the Product Final Energy Consumption you specified for the base year. The fuel mix corrected for energy savings is the reference for the specification of saving options!

Costs Investment costs and variable (operation and maintenance) costs are defined in currency per GJ *total* energy demand saved. Especially when fuel switch is modelled, it is important to realise that the costs are defined towards the (relatively small) resulting saving percentage. Therefore a negative total saving percentage (a net increase of energy consumption) implies *negative* costs.

Note that only increasing the saving percentage from 10% to 20% will have no effect on the profitability of an option if the costs have remained the same. If you meant to specify that the saving option is twice as effective, you also have to reduce the investment and variable costs (currency/GJ saved) by half, which will result in a higher profitability.



Case: Industry Netherlands 95

Variable investment costs

The investment costs of an option can be chosen as constant or variable in time. In the latter case, it is possible to calculate the variable investment costs by specifying a growth rate or by using an experience curve. Inv_cost, defined on the previous page, is taken as default value for the additional investment costs in the start year. The time until replacement has the lifetime as default value.

Division: Food
Product: Dairy-drying
Option: high-concentration

☐ Calculate investment costs of option high-concentration with an experience curve?

	high-concentration
stock in start year [units]	1.00
cumulative production in start year [units]	1.00
additional investment costs [cur./GJ saved]	21.00
absolute investment costs [cur./GJ saved]	42.00
lifetime [years]	15.00
progress ratio [%]	80.00

Progress ratio = When the cumulative production doubles, the absolute investment costs decrease to the (progress) ratio of the original cost level.

☑ Calculate investment costs of option high-concentration with a reduction rate?

	high-concent
investment reduction rate [%]	13.00
additional investment costs [cur./GJ saved]	21.00

	additional investment costs				
	1995	1997	1999	2001	2003
high-concentration	21.0	15.9	12.0	9.1	6.9

Figure A.2 *Input screen of REDUCE to define variable investment costs*

Variable investment cost

It is possible to define the investment costs variable through time as a result of acquired experience (see also Section 4.2). Click the button labelled ‘Specify…’ to specify variable investment costs for the currently selected option. FigureA.2 shows the two possibilities.

1. Enter your own estimated cost development by using a (positive) growth rate. Use the button labelled ‘Fill’ to calculate the investment costs based on this growth rate. Or, alternatively, enter a certain cost projection directly into the table.
2. The second possibility is using an experience curve. In this case, the investment costs decrease depending on the cumulative number of produced units. Section 4.2.2 contains a more detailed discussion of the experience curve. Some new data requirements are induced if this option is selected:

- Stock in start year: This is the number of units present in the market during the start year.
- Cumulative production in start year: The cumulative number of units produced in all years before (and during) the start year.
- Absolute investment costs: Like the additional investment costs, these costs are defined in currency per GJ total energy demand saved.
- Lifetime: This represents the actual lifetime until replacement (‘technical lifetime’). The default value of this parameter is the (‘economic’) lifetime used in calculating the Internal Rate of Return.
- Progress ratio: The progress ratio is used to express the progress of (investment) cost reduction. For example: A progress ratio of 80% means that costs are reduced by 20% each time the cumulative production is doubled. The value of the progress ratio is typically in the range 70%-100%. It is hard to acquire data on the progress ratio of a specific technology. There is not much literature available, but see for instance (Neij, 1997), hence they will often have to be deduced from historical trends.

Click the button labelled ‘Option overview’ for a list of options for which variable investment costs have been specified.

Further characteristics

Finally, the following characteristics need to be specified for each option.
- The *lifetime* of an option is used in calculating the Internal Rate of Return.
- The option’s *penetration share* in the start year. It is possible to enter a start year different from the base year of the calculations. Please note that, for modelling reasons, it is required to enter a start penetration > 0% to make an option penetrate. If the model runs with a time step, for instance for 4-year periods, then the start year will be rounded downwards to a year included in the set of periods.
- Grants are optional, and can be specified as a percentage of investment costs and are applied starting in the options’ start year until the end year that is also specified for each grant. Again, the start and end years may be rounded downwards if the model runs with time periods of more than one year.

A.1.2.3 Groups

Groups are an important element in the hierarchy, because they are used to model *competition* and *interference* of options. Groups of technologies or options are in fact the markets where technologies or options of the same type are competing with each other. An example: the product ‘heating’ in households can be supplied by different boilers, heatpumps etc. which compete with each other in the group ‘supply’. On the demand side, many different types of technologies exist which all conserve energy: glass in the living room, glass in the bedroom, wall insulation, roof insulation, floor insulation etc. For each type of technology, a separate group is created reflecting that these types of technologies compete type by type, not between different types. Mathematically speaking: the energy savings of different groups have to be added up to get the total energy saving in demand.

Types of groups

The characterisation of groups is based on the type of options in the group. Three kinds of groups are distinguished:
1. Groups of *supply* options. Supply options increase the efficiency of the generation of an energy service (such as heat) and thus save energy. Examples are efficient boilers/heaters/stoves/furnaces and heat pumps. Supply options are by definition temporary; after their lifetime has expired, they are replaced.
2. Groups of *temporary demand* options. Demand options cause a decrease of useful energy demand, while the energy service remains at the same level. Temporary demand options are replaced after a certain period.
3. Groups of *permanent demand* options. These are demand options that stay in place for a very long period, such as wall insulation. Only after demolition of the existing housing stock, so the fade out of the demand for the product heating in existing houses, the installed wall insulation will disappear.

Competition within groups

Interaction within groups concerns *competition* of options. The options within a group are competing for similar types of application in the same energy service market. The distinction between *permanent* and *temporary* options is very important here, because this characteristic determines the shape of the penetration curve in time. Permanent options will not lose a conquered market share to a competing option, while for temporary options, the market share can increase but also decrease. Options competing with each other have to be defined in the same group, so *direct* competition is limited to options of the same type. It is also possible that an option is not competing with any other option. In that case, a group consists of one single option.

Interference between groups

Interaction between groups concerns interference of options, and the distinction between *supply* and *demand* options plays a key role. This is illustrated by the following example. Wall insulation and heat pumps can both be applied in the same house to save energy for heating. Suppose that one house is already provided with wall insulation and another is not. Then in both houses application of a heat pump will cost the same but the return in terms of energy saving and a lower energy bill will differ. In other words, the IRR of the heat pump depends on the question whether wall insulation is applied or not.

Another way to describe this interaction is to state that the effectiveness of demand options is influenced by the presence of supply options, and vice versa. In REDUCE, the *demand effectiveness* is defined as the remaining fraction of the energy demand after subtracting the saved fractions reached by already existing *supply* saving options. An analogous definition holds for the supply effectiveness. This effectiveness is calculated based on the (average) saving percentage and current (in fact, last year’s) penetration of *groups* of options.

Other considerations

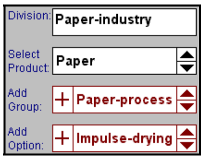
Note that the energy saving share of an option should be specified as the % saving multiplied with the share of the energy demand on which the option is active. If roof losses account for 20% of the total heating losses of a house and roof insulation saves 10% with respect to a Reference roof, the specification of roof insulation would be 2%. This share of the product (e.g. the 20% of total heating losses that is accounted to the roof) is constant over time in the model.

The same applies to large, heterogeneous products such as Household Appliances. All different options such as Microwaves, PCs, Dishwashers etc. have their own group with their own product share. If it is unrealistic, for instance for PCs, to assume a constant share of the Product, there is no other possibility than to specify a separate product ‘PC’, for which you have to project future demand.

This dilemma between Product and Group has to be solved for each type of technology and energy service. Different teams for different countries may make different choices depending on the country situation and data availability. Bear in mind that the size of energy demand for a product is an important factor for distinguishing a product separately.

Adding groups and options

Options and groups can be added and characterised on the page titled ‘Options and Groups’, following the Products page.



Division: Paper-industry

Select Product: Paper

Add Group: + Paper-process

Add Option: + Impulse-drying

Proceed as follows:

- Start with selecting the product. The corresponding division will be selected automatically.
- If the option that you intend to specify belongs to a new group, click ‘+’ on the selection field for groups, just below the list of products. Alternatively, select an existing group.
- Click ‘+’ on the selection field for options to specify a new option. Enter a name for the option, and also some descriptive text to document the option.
- Check the box below the selection field (put a cross in it) to link the option to the group. Once you have done that, the new option will appear in the list of options and groups to the right, and you can add its saving percentage and further characteristics.

Best Available Technologies

Best Available Technologies (BATs) are distinguished as opposed to Locally Available Technologies. Especially in Eastern European countries, not all technologies are available, and it makes sense to analyse the cost effectiveness of these different groups of options. Therefore, REDUCE provides the opportunity to classify some options as BAT, and include or exclude these from the calculation explicitly.

In studies for which this distinction is not very relevant, it still can be useful to compare runs with or without certain options. A very quick way to exclude options without changing their specification, is to mark them as BAT and exclude all BATs from the run.

A.1.3 Behavioural aspects

Policy vector or exogenous penetration speed

The penetration speed is a parameter used to quantify behavioural aspects. The penetration speed and the IRR together form the driving forces for penetration of conservation options. If Speed >1, then the option penetrates faster than would be expected from an economic point of view (IRR). If Speed <1, the reverse holds. See also the description of Figure 3.6.

A.1.4 Financial issues

Energy carrier prices

The energy carrier prices are often based on (inter-)national scenarios. The growth factor can be used to make a projection over the time horizon. Use the button labelled ‘Fill’ to calculate the prices based on the growth rates. The projections can be further adapted by manipulating the table by hand.

Energy carrier tariffs

Here you can specify different tariffs for each energy carrier on divisional level. The tariffs are defined as percentages additional to the national energy prices. Again, the ‘Fill’ button can be used to calculate the values over time.

Interest rate

Most evaluation and cost-benefit analyses implicitly take the interest rate into account, for instance by increasing the required IRR by a certain rate. In REDUCE, it is possible to specify an interest rate value to take explicitly into account the costs of borrowing money. Doing so will especially be relevant when modelling Central and Eastern European countries, to reflect severe capital scarceness.

A.1.5 Demand projections

National economic growth

National economic growth is an index that is used for calculating the *volume* effect on energy conservation. A growth percentage is specified per year and used to make a projection over the time horizon.

Economic growth by division

Divisional growth is an index representing physical product growth and energy consumption growth, expressed in the *structure* effect.

For each division, a growth percentage can be specified. Note that the ‘Fill’ button will only use this percentage if there is an ‘x’ in the second column. This is an extra protection, because for some divisions you may want to enter a non-linear growth path in the second table. In this case you can disable the automatic linear calculation based on a percentage. It is also possible to view and edit the divisional growth in a graph; click the button.

Product growth

Energy consumption is assumed to increase with physical product growth. The difference with the divisional growth is expressed in the 'rest' product. Simulate future demand by adapting the volume growth for a product.

For entering and changing growth rates, the same comments apply as for divisional growth rates. Again, you can use the graph for a quick overview of the growth paths.

Intensity change

Intensity change reflects a change in energy consumption due to a change in product. For instance due to dematerialisation, the demand within a product decreases. Or due to a decreasing number of persons per household, the demand per household for cooking, cooling and lighting could decrease as well. The demand per household decreases, in other words the energy intentsity decreases, which results in a lowered impact of a specific investment in a conservation option. Hence a decrease in energy intensity has not only an constraining impact on the potential which can be technically saved, it also results in a lower profitability and therefore a slower penetration of the saving option.

A.2 Output presentation

A.2.1 Prospects of options

A.2.1.1 Penetration curve

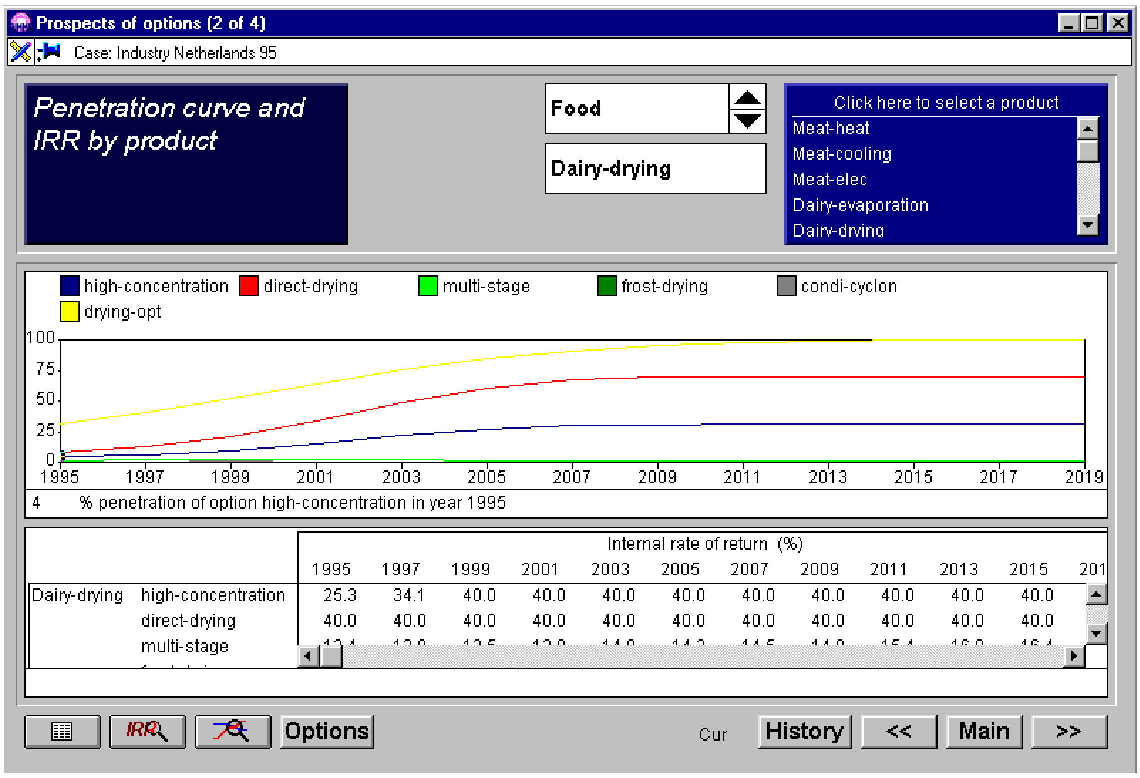
Penetration and IRR

The first two output pages show the penetration curve and the Internal Rate of Return (IRR) of technologies within a product or group. The penetration curve and IRR of an option are strongly related as the penetration speed increases with an increase in the IRR. Illustrations (see Figure A.3) of the penetration curves within one group (i.e. market) show in one instance which options conquer the market and which options are crowded out.

If you like to view the penetration percentages in a table; click this button.

It is also possible to view graphs of the IRR, which facilitates the comparison of IRR's.

After clicking this button an enlargement of the penetration curves is shown.



4 % penetration of option high-concentration in year 1995

		Internal rate of return (%)										
		1995	1997	1999	2001	2003	2005	2007	2009	2011	2013	2015
Dairy-drying	high-concentration	25.3	34.1	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
	direct-drying	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
	multi-stage	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure A.3 *REDUCE screen on the market penetration of options*

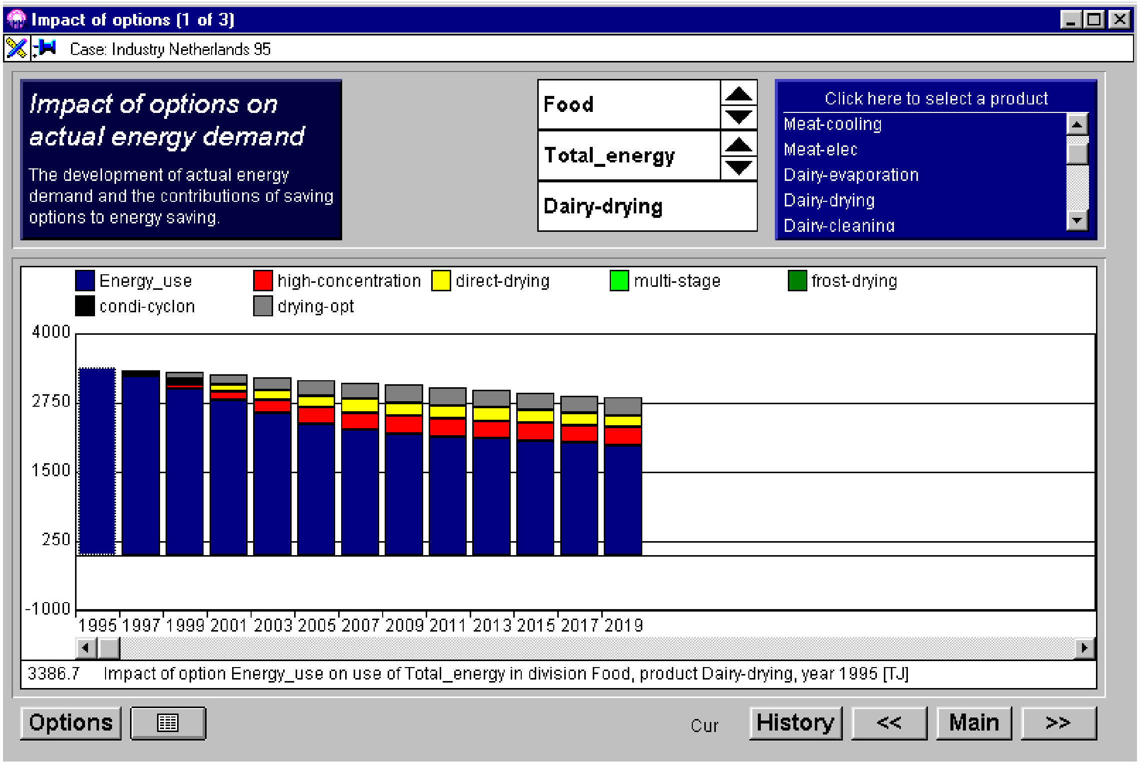
A.2.1.2 Costs versus benefits

Cash in	*Cash in* is a positive number defined in currency, representing the annual benefits of a specific option. It is calculated as the (financial) savings reached during a certain year by using less fuel minus the total variable costs of investing in the option plus the increase of income induced by the investment.
Cash out	The second economic indicator is the *Cash out*, representing the additional investment for installing a specific option. Generally it is a negative number consisting of the additional annual investment costs minus the percentage subsidy received in that year. As investment costs are defined in currency per GJ energy saved, the additional annual investment costs depend on the savings reached during the year.
Payback period	The payback period represents the period for return of investment in years. See section 2.2.1 for a more elaborate discussion.

A.2.1.3 Effectiveness of demand and supply

Interference	The demand and supply effectiveness are used for calculating the interference of supply and demand options. The demand effectiveness is the remaining fraction of the energy demand after subtracting the saved fractions

reached by already existing supply saving options. The reverse holds for supply effectiveness. Hence if demand effectiveness of a certain ‘product - energy carrier’ combination is equal to one, no savings on this energy carrier are reached by supply options belonging to this product. For a further explanation see section 2.2.4.



Case: Industry Netherlands 95

Impact of options on actual energy demand

The development of actual energy demand and the contributions of saving options to energy saving.

3386.7 Impact of option Energy_use on use of Total_energy in division Food, product Dairy-drying, year 1995 [TJ]

Figure A.4 *REDUCE screen on the impact of energy saving options on the energy demand*

A.2.2 Impact of options

On energy demand For each ‘product - energy carrier’ combination within a division the individual contributions of options to the total saving is illustrated. The option ‘Energy_use’ represents the remaining energy consumption by energy carrier. A negative value must be interpreted as a de-saving or in case of the option ‘Energy_use’ as a production of the energy carrier (e.g. in case of a heatpump).

On emissions Also the individual contributions of options to the total avoided emissions within a product are presented. Just as with the impact on energy demand, the option ‘Energy_use’ represents the emitted emissions within the product.

A.2.3 Financial reporting

A.2.3.1 Financial report by product and divisions

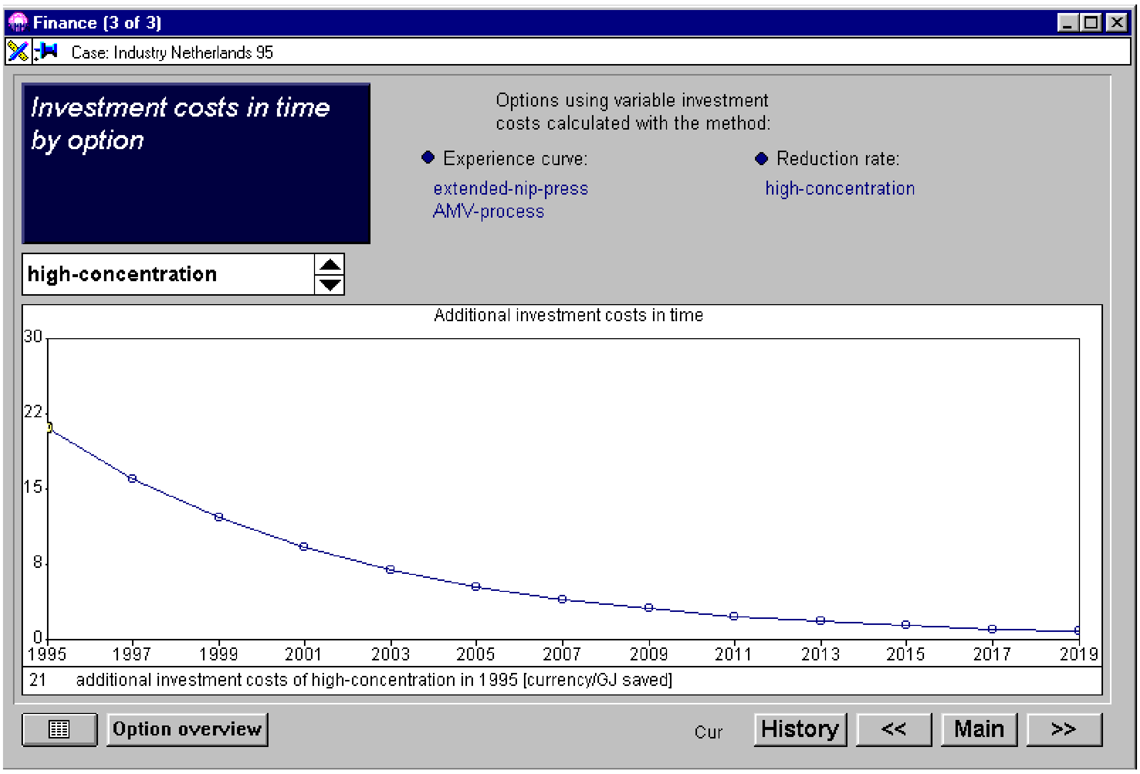
Some annual financial indicators on option, product and division level are reported. The indicators give some global impression of the profitability of an option, product or division.

Additional investment Like the following indicators, the additional investment is defined in currency. The additional investment is the additional capital value of an option or within a product or division. Note that the investment costs are called *additional* because all saving options are defined as the difference between a new technology and a reference technology. Negative additional investments means that the option(s) has a negative (net) saving percentage or that the investment is less than the investment of the reference technology.

Actual investment The actual investment is the *annual* increase of the total additional investment. Even though the user defines a time step larger than one year. In case the increase is negative, the actual investment becomes zero.

Total subsidy The subsidy is defined in percentage of additional investment. Accordingly the total subsidy is calculated by multiplying the additional investment costs with this percentage.

Annual net revenue The avoided fuel costs induced by savings minus the additional variable costs of the option(s) constitute the annual net revenue.



Finance (3 of 3)

Case: Industry Netherlands 95

Investment costs in time by option

Options using variable investment costs calculated with the method:

◆ Experience curve: extended-nip-press, AMV-process

◆ Reduction rate: high-concentration

high-concentration

21 additional investment costs of high-concentration in 1995 [currency/GJ saved]

Figure A.5 *REDUCE screen on variable investment costs in time*

Investment costs in time As described in section 4.2 two possibilities are offered in REDUCE for modelling learning effects. As shown in Figure A.5 the variable additional investment costs along the time horizon are displayed for the options for which an experience curve or an investment reduction rate is specified by the user. Note that the investment costs are plotted against time. In case an experience curve is defined, this plot gives another impression of the curve compared to the data plotted against experience (i.e. cumulative production). By clicking on the button ‘Option overview’, an overview of the specific values assigned to the parameters of the experience curve or to investment reduction rate is shown.

A.2.4 Energy consumption and savings

Section 2.2.5 shortly describes how 'energy consumption' is defined within REDUCE. All consumption is given in TJ.

A.2.4.1 Actual consumption

The actual energy consumption is based on the energy consumption in the baseyear, meaning that all current energy conservation is taken into account. Using the product and division growth index, the projection of the actual energy consumption over the time horizon is determined.

Actual baseline as status quo This projection, the actual baseline, is taken as the baseline, which is interesting as a status quo case with a baseyear, perspective. The savings are induced by the energy conservation options penetrating after the base year. The first page shows the actual consumption by product, the second page displays the total over all divisions.

Saving potentials The savings are shown as percentage of the total actual energy consumption first by division, next by product. The savings are calculated in relation to the actual baseline.

A.2.4.2 Projected consumption

Before saving The energy consumption corrected for savings reached by options installed in the baseyear is called the projected consumption before saving. The projection over the time horizon is based again on the product or division growth index. This projection is important for the specification of energy conservation options in the baseyear and the correction for this energy conservation in the years after.

Including saving Also the projected energy consumption including saving is shown. Actually the bar chart resembles the chart of the projected consumption before saving, however the share of savings is shown. The savings include the savings in the baseyear.

A.2.5 Volume - structure - saving

The difference between the future (actual) energy consumption and the consumption in the baseyear can be ascribed to three factors; the volume, structure and saving effect.

Volume effect Volume effects explain the development of future energy consumption due to (economic) growth. Therefore in REDUCE the volume effect is calculated as the difference between the baseyear actual consumption and the future actual consumption projected with the national economic growth rate, or a physical growth rate, i.e. number of dwellings.

Structure effect The structure effects cause a lower (or sometimes higher) energy consumption than the one induced by the volume effect. These effects are caused by structural changes on product level. For instance dematerialisation, changes in lifestyle, recycling etceteras. In REDUCE the structure effect is defined as the difference between the actual energy consumption excluding savings (the red bars in the corresponding bar chart) and the actual consumption projected with the national economic growth rate (the blue bars).

Saving effect The difference between the actual consumption excluding savings (red bars) and the actual consumption including savings (yellow bars) is ascribed to the saving effect.

A.2.6 Indicators

Indicators main menu For each case it is possible to define five different indicators. This feature has its own submenu from where the five indicators can be accessed. From the other pages it is possible to return to this submenu by clicking on the button Menu. The other buttons have the same functions as in the other pages.

A.2.6.1 Activity

An energy efficiency indicator is defined as the ratio of energy consumption and a suitable activity. As activity economical and physical quantities can be chosen. For example the Gross Domestic Product (GDP), number of dwellings or tons produced. Figure 3.2 shows one of the input screens for defining an indicator

Characteristics The left three text boxes are meant to insert a short description of the activity, the unit and the value in the baseyear. The value is for example the GDP of the baseyear or the number of dwellings present in the market during the baseyear.

Activity growth rate The last feature in order to complete the specification of the activity is the activity growth. The user is able to specify a new growth rate as activity rate or to choose between one of the earlier specified growth rates. It is possible to use the national economic index, a divisional economic index or an index on product level. Make sure that the radio button corresponding to your choice is marked, because the growth rate associated with the marked button will be used for the calculations.

Adapting the projection The table at the bottom of the page shows the activity projection over the time horizon. Changes between growth rates in the values in the table are immediately adapted. This also applies to changing the baseyear value of the activity. The projection can be further adapted by editing the table by hand.

A.2.6.2 Consumption

Specification level The user can choose between different levels of energy consumption for the calculation of the indicator. This choice will be strongly correlated with the specified activity. First the divisional level must be specified. It is possible to choose one of the divisions or to choose all divisions (i.e. to choose ‘Total’ as division). Secondly the user has to select one or more products within the selected division. For example if the user selects three products, the indicator will be based upon the total energy consumption within these three products. Finally the energy carriers that the user wants to include into the calculations have to be selected. Just as with divisions it is possible to select all energy carriers or to select one of the energy carriers.

Calculation indicator As soon as the specification is completed click the button:

to calculate the energy efficiency indicator over the time horizon.

Output The output page shows a graph and a table representing the values of the indicator. The graph can be used to observe the development of the indicator.

A.3 Menus and buttons

REDUCE has been developed in a software package called AIMMS, which has been chosen for its user-friendliness. In this section, a description is given of all menu commands.

A.3.1 Menu 'REDUCE'

Calculate This command starts the calculation of the penetration of options and the development of the IRR through time.

Quit This command ends the REDUCE session.

A.3.2 Menu 'Edit'

Undo This command enables you to undo changes in data. However, there are a few pages in REDUCE where this command is not available, because every change is immediately checked and processed.

Cut, Copy, Paste These commands enable you to copy and paste rows or columns from REDUCE to spreadsheet tables or vice versa. Just drag a rectangular area in a table and issue one of these commands.

A.3.3 Menu 'Case'

Open, Save, Save As, Delete Cases are saved model runs, consisting of the complete set of input data together with model results. Cases are stored in a binary format, only readable within AIMMS. The Open, Save, Save As, and Delete commands in the menu perform the obvious actions. Cases are very useful for comparing different scenarios.

Select Multiple The menu item 'Select Multiple...' allows you to select multiple cases. After such a selection, all tables and some graphs in the output section of REDUCE will display the results of the selected cases side by side. Beware that if you want the active case to be among these results, you have to select that active case again. The acronym, a short case title (max. 10 characters) that you can enter when saving a case, is shown to distinguish the different cases.

Backup Use this command to have an automatic backup copy made of the current case. This backup case is removed when you quit REDUCE.

ASCII Cases In order to facilitate the exchange of case files or data sets, a method has been developed to export all data to a text file. This text file lists the input data in a format readable by AIMMS, but also understandable for a user. Use the Import command to load the data again. You will be prompted to save the imported data as an AIMMS case.

Because of the ASCII format, you can also open the file using the View command, and make modifications to names and descriptions of options, products, groups and divisions. It is not recommended to change values here, because this is more prone to mistakes than changing values in the AIMMS pages.

Output data dump It is also possible to make a dump to an ASCII file of the most important output tables. The Write command in the 'Output Data' submenu writes the results to a file. This file can be opened using the View command, and printed using the Print command.

Files This menu item enables you to select a filename for the export and output data files. Click on the 'Folder' symbol to change this filename.

A.3.4 Menu 'Tools'

The commands in this menu give direct access to a few important pages.

Main Menu Click on one of the titles of the input and output sections to open the data pages.

About REDUCE This is the opening page, containing address and copyright information.

Legend This page gives an overview of the structure and options in the current dataset, including a description (if available).

Redundant Redundant elements are products, groups or options that are not correctly specified in the hierarchy. If such elements are detected, a page is opened in which you can remove these elements from the hierarchy.

A.3.5 Menu 'Window'

The Window menu offers some general utilities.

Grab The Grab command enables you to capture part of the screen as a bitmap. When you issue this command, the cursor will take a '+'-shape, allowing you to drag a rectangle on the screen. This part of the screen is then captured and can be pasted into a word processor or painting programme. Currently, this is the only way to make printouts of the curves and graphs in REDUCE.

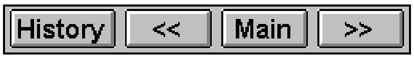
First page This command opens the 'About REDUCE' page.

New editor This command starts an ASCII editor.

Switch windows All open windows are listed here, and you can jump to another window by selecting it from this menu.

A.3.6 Standard buttons

In the bottom right corner of almost every page, you will find the following buttons:



History	This button is a so-called dynamic link; it always returns you to the previous page you visited.
<<	This button is a static link to the previous page in a pre-defined sequence of pages.
Main	This button links all pages to the Main page.
>>	This button is a static link to the next page in a pre-defined sequence of pages.

A.3.7 Data entry techniques

In a table

To enter data in a table, proceed as follows.

- Click in the cell where you want to input a value. The value and a description will appear at the 'status line' at the bottom of the table.
- Type in the value, and press the Enter key.

You can use the up and down arrow keys to move vertically in a table. To move horizontally, use the Tab and Shift+Tab keys.

Entering one value in multiple cells

To input the same value at once in a number of cells:

- Use the mouse to drag a rectangle in the table.
- Type a figure, and press the Enter key. The value is entered in all selected cells.

Furthermore, you can use the commands in the Edit menu to copy and paste rows and columns of data between tables.

Data entry in a graph

Entering data in a graph is very similar to entering data in a table.

- Click in the bar or line where you want to change a value. The value and a description will appear at the 'status line' at the bottom of the table.
- Type in the value, and press the Enter key.

Alternatively, you use the mouse to change values directly by dragging the bars or lines up or down.

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