Actual interaction effects between policy measures for energy efficiency - A qualitative matrix method and quantitative simulation results for households

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Abstract

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

Key words: policy measures; energy savings; interaction; households.

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1. Introduction

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

Remarks on (possible) policy measure interaction are dutifully made in ex-post evaluations, e.g. Vermeulen [37], or discussed for individual cases in Gunningham and Grabosky [15] or Jacobsen [18]. In ex-ante evaluations the interaction between specific combinations of policy measures is analysed too. Recently this subject has attracted new interest because of the set up of an European emission trading system. The interaction mechanism with national policy is extensively analysed in Sorell [33]. However, a general and quantitative method to investigate possible interaction effects is missing so far. The methodological problem of unravelling the effects of various policy measures, which simultaneously affect energy consumption, has not been solved yet. According to Sorrell [33] the analysis of interaction still asks for a systematic approach. In contrast with ex-post evaluations many scenario studies use energy models that can cope with a combination of policy measures, e.g. PRIMES of Capros [9] and the model of Verbruggen and Goetghebuer [36]. But here too the interaction effects between various policy measures are scarcely treated explicitly.

From a policy viewpoint there is a pressing need to look at interaction effects. In most developed countries a great number of policy measures for energy savings was introduced in the nineties. In Europe not only national governments, but the EU as well have become more and more active in this field, as can be seen in the policy measures database MURE [25]. With more measures deployed, interaction between measures can very well become stronger too. If interaction effects become more and more negative, i.e. the total effect is less than the sum of the separate effects, one could say that energy policy as a whole is becoming less effective. New methods to investigate possible interaction effects in sets of policy measures are needed, both in a qualitative and a quantitative manner.

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

In section 2 the mechanisms underlying interaction effects of policy measures for energy savings are analysed. This information is used in section 3 to develop a method to map possible interaction effects qualitatively for combinations policy measures. In section 4 the method is applied to the set of actual policy measures for households in the Netherlands, regarding the period 1990-2003. The next sections are devoted to the quantification of interaction effects. The focus lies on the three most important ones: a regulatory tax on energy consumption, investment subsidies on saving options and regulation of energy use for space heating. In section 5 the key features of the applied bottom-up household simulation model are described. The quantitative interaction results are presented in section 6 for the period 1990-2000. After discussion of the results in section 7 conclusions and policy observations follow.

2. Application of saving options using policy measures

In the following analysis it is assumed that the various policy measures try to realise energy savings by stimulating the application of so-called saving options, which either reduce energy demand or increase the conversion efficiency. Most measures focus on the implementation of these saving options, but some measures (e.g. mandatory maintenance) regard a proper utilization of the energy system. The general framework developed here is applicable to the end-use sectors households, industry, transport and services.

Conditions for a successful implementation of saving options

In literature, e.g. Blok [4], Greene [13], Hennicke and Ramesohl [16], Jochem [19] or Velthuijsen [35], many factors on the implementation of saving options are mentioned. Here the realization is assumed to be dependent on the following set of conditions:

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

As illustrated in figure 1, all four conditions have to be met before the saving option will actually be implemented.

Figure 1

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

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

An important **restriction** for current energy applications is the remaining lifetime of the existing energy using systems. Normally decisions on implementing a more energy efficient system are taken at the 'natural moment' only, when old equipment must be replaced. In Velthuijsen [35] this is one of often mentioned barriers for energy saving, as the earlier investment is not yet depreciated. However, retrofit-options can be installed at any time. Another restriction can be the split between ownership/investment and utilization/benefits. In the case with rented office buildings or shop malls this hinders costly investments in energy savings. Finally a number of specific restrictions can be present, such as lack of space for the system, scarcity of investment money or lack of personnel resources (see Velthuijsen [35]).

Unless legal pressure forces the implementation of saving options, the decision maker should **become motivated** to choose the more efficient system. The most cited motivation is the financial benefit resulting from the implementation of the saving option. This motivation can be enhanced by introducing a tax on energy consumption; the higher financial value of energy saved shortens the pay back time. Another possibility is lowering the investment costs by providing investment subsidies. However, enhancing non-economic motivation to invest is possible too, for instance by increasing the general awareness of the greenhouse problem and its relation with energy use. Another way is the creation of social pressure by public campaigns. Hennicke and Ramesohl [16] mention the role of regional networks and the behaviour of the peer group. Sometimes a saving option creates its own investment motive, as is the case with the extra living comfort that is achieved by installing double-glazing.

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

Influence of policy measures on the conditions

Various policy measure types are used to stimulate the application of saving options. Overviews are given in Braathen and Serret [8], Gunningham and Grabosky [15], Oosterhuis [29], Vermeulen [37] and WRR [40]. In table 1 a list of policy measure types according to

MURE [24] is presented; this set represents common measures in European countries. These policy measures can be split into different types, from very pressing (legislation on implementation) to no engagement whatsoever (public campaigns on behaviour). Financial measures consist of energy taxes, investment subsidies or other types of financial support, such as tax deductions or low interest rates. Information measures range from client-specific advice and education of fitters to TV-campaigns to raise awareness on the subject of energy savings. Agreements between government and energy users or other parties generally do not focus at specific saving options but at total energy use in a sector. The obligatory character depends on the formulation of the agreement and country specific habits. Procurement focuses on co-ordinated action of the various parties involved with respect to a specific saving option. Both agreements and procurement are often used in combination with other measures. Stimulation of research and development (R&D) was added to the list of MURE-measures; it must be stressed that this regards not fundamental research but demonstration projects or additional development to provide a market ready product. Finally the policy measure 'emission trading', which was recently introduced in the EU, was added to the list of policy measures (see Sijm and Sorell [32]).

Table 1

The columns in table 1 represent the conditions; the contribution of each policy measure in meeting the conditions is indicated with crosses. A general observation, which can be drawn from the table, is that most common policy measures are designed to influence investment decisions, especially motivation. It is clear too that there are few measures that affect both implementation (first four conditions) and utilization (fifth condition). Only energy taxes will by nature affect both. The effect of policy measures on each condition will now be highlighted into more detail.

The **availability** of new market ready saving options often is dependent on additional R&D to deliver a marketable option. In the latter stages of development, legislation (e.g. standards) can speed up the development process too according to Newell [27]. Financial measures can stimulate the creation of marketable options too, provided that they are considered to last over a long period. With the exception of high taxes on transport fuels, sustained for decades in various countries, this has not been the case for energy taxes in general. As Newell [27] shows, even the very high energy prices due to the oil crises were only partly responsible for increased energy efficiency. Finally procurement can speed up actual availability. The **knowledge** as to saving options, not only about the concept but also about the actual performance, is most effectively increased by dedicated information, such as mandatory labels. Other possibilities are free information on specific saving options. Audits, agreements and procurement combine the search for saving opportunities with the provision of information on saving options. Vermeulen [37] and Blok [4] state that subsidies often focus attention of energy users to saving options and thus serve as an information source too. Regional and branch networks of entrepreneurs are a means to provide knowledge as well, as parties often imitate each other's decisions (see Hennicke and Ramesohl [16]). The level of implementation already achieved contributes to knowledge of other users too. Actually all measures that stimulate the take-off of a new saving option contribute to it becoming more widely known. Finally, as stated earlier, legislation on the implementation of the saving option is an alternative because it cancels the need for information. **Restrictions** that hamper the implementation of saving options often are of a non-economic nature; therefore they cannot be lifted easily by financial measures according to Vermeulen [37]. Restrictions on performance can be overcome partly by adaptations to the saving option with additional R&D. For instance the development of a high-efficiency boiler with 'closed air circulation' has diminished the problems of placement to a great extent. Restrictions with respect to the decision making process sometimes can be circumvented with tailored policy measures. For rented dwellings this can be an agreement between housing associations, representatives of occupants and the government on the division of costs and benefits. But hardly any measure is able to influence the replacement moment when there is an opportunity to realise energy savings. Even legislation on more efficient systems does not influence directly the actual lifetime of the old systems (see policy measure descriptions in MURE [25]). Almost all measures can contribute to the **motivation** to invest in new saving options. Some provide an economic motivation, such as subsidies or taxes. Other measures, such as information campaigns and voluntary agreements, can create a social motivation. Legislation creates by definition the strongest “motivation”. In the longer run this can be accomplished too in an indirect way, by some other measures mentioned that lead to the disappearance of less efficient options altogether. Influencing the **proper utilization** of energy systems asks for continuous action, as opposed to the one-time investment decision. Moreover, the users of the systems are more difficult to reach. In practice relatively few measures are available to ensure a proper utilization, for instance legislation on maintenance and monitoring of performance. Regular feedback can lead to avoiding unnecessary energy use for space heating according to Jensen [21], but for practical applications feedback costs have to be low. Groot [14] states that energy taxes lead to limited energy savings on daily energy use given the rather low short term price elasticities

As Sorrell [33] shows, it must be pointed out that the influence of policy measures does not only regard government and the energy users, but other actors in an implementation network as well. Shop owners that are pressed to sell more efficient appliances to their customers form an example of these other actors. The network of researchers, suppliers of technologies, energy advisers, user associations, public interest groups and subsidizing agencies, each with their own interests, defines the relationship between policy measures and implementation too. This means that the different conditions for realising saving options are not tied to the same actor. For instance the condition ‘availability’ often will be associated with the manufacturing of new appliances or systems, while the condition ‘motivation’ mostly regards the energy user. In this analysis the role of these other parties is taken into account when analysing possible interaction between policy measures.

Optimal combinations of policy measure types

Looking to the rows in table 1 it is clear that most policy measures do not cover all conditions. The influence of taxes is limited to one of the implementation conditions only; information and subsidies cover two implementation conditions. Legislation can affect all conditions for implementation but is not always acceptable or applicable. Therefore a combination of policy measures appears necessary to comply with all conditions. However, the importance of each condition differs per saving option. For instance, when a saving option is readily available and restrictions are minor, financial and information measures alone can do the job. Therefore the optimal set of policy measures to be applied is dependent on the type of saving option. With respect to the application of saving options one can formulate general rules to reach an optimal set of policy measures. From the preceding analysis the following general criteria for an optimal set follow:

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

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

As touched upon later in chapter 4, in practice the overall optimality of a combination of policy measures will depend on other factors too. Not all types of policy measures present are applicable to every saving option. In energy policy formulation many other factors play a role when choosing a policy measure type. For instance, legislation demands extensive ex-ante knowledge about the appropriateness of the regulated saving option; this knowledge is not always easy to provide. Subsidies often affect actors not belonging to the target group; too much free riders diminish the effectiveness of the measure (see Blok [4] and Vermeulen [37]).

3. Rating of possible interaction between two policy measures

The theoretical approach from section 2 is translated into a method that estimates, for any set of policy measures, the interaction effect between two measures. To this end the concept of optimal combinations is used to formulate a qualitative rating of the possible interaction effect between two measures.

Qualitative rating of the possible interaction effect between two measures

In this analysis the interaction effect regards the direct influence of one policy measure on the saving effect of another measure. Measures from an earlier period, such as R&D-programmes, can influence the effect of present policy measures but are not taken into account. Second order effects, such as the past agreement on industrial energy efficiency in the Netherlands which has provided for a structure that was beneficial to the new measure benchmarking, are not taken into account either.

The qualitative rating of the possible interaction effect proceeds as follows. The more two measures exert influence at the same condition(s) for implementation, the more they mitigate each other's effect. Depending on the specific situation this results in a relative rating:

marginal-, modest- or strong mitigating ('-', '- -' or '- - -'). The last rating can be characterised as 'too much of the same kind'. An example is the combination 'standards and subsidies' which provides more motivation to invest into a saving option than is actually needed. Their combined effect is less than the sum of the separate effects of both measures apart. These cases are also called 'overlapping' or, as in Braathen and Serret [8], 'counterproductive'. In the extreme opposite case two measures complement each other in such a way that the combined effect is much greater than the total effect of both measures apart. This synergetic combination is rated as strong reinforcing ('+++'). A Dutch example is the label system for appliances and the energy premium scheme. The evaluation in Belastingdienst [1] shows that this combination has led, in a few years only, to people purchasing efficient or very efficient appliances only. If the mutual reinforcement of two measures is less optimal the rating is modest or marginally reinforcing ('++'or '+'). In cases where it can be reasoned that one measure does not affect the saving effect of the other the rating '0' is given.

It must be stressed that the interaction analysis regards the common scope of two measures, e.g. in case of appliance standards and subsidies only the part of the subsidy scheme that is devoted to appliances. Because the quantification of interaction effects in literature often gives rise to confusion, the outcomes of interaction analysis for two measures A and B are illustrated in figure 2. For the mitigating combination the total saving effect is less than the sum of both effects; for the reinforcing combination this is the other way around. A neutral combination provides (almost) the same total savings as the sum of both measures. In Braathen and Serret [8] the combination of performance standards and labels for appliances is called 'complementary, as both measures contribute to more efficient appliances in their own way. Gunningham and Grabosky [15] present the fact that the saving effect of a measure is enhanced by another measure as positive. However figure 2 shows that an increase in total savings due to a second measure is valid for all combinations, even the mitigating one. The point is: how relates the combined effect to the sum of the effects of both measures on their own?

Figure 2

Non-existing interactions

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

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

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

Indirect interaction effects

In a few cases measures interact at another point than the implementation of saving options or the stimulation of a proper utilization. Post-implementation effects regard interaction between the resulting saving effects of two measures. E.g. insulation decreases heat demand; this lowers the benefits of installing a more efficient boiler, which is detrimental to the success of a policy measure directed at efficient boilers (see Sezgen [31]). Pre-implementation interaction regards a measure that affects another measure's potential to realise energy efficiency. For instance, Johannsen [22] finds that voluntary agreements have the (implicit) goal to forestall other policy measures, such as a CO_2 tax. Therefore the combination with a tax measure will touch the content of the agreement. The combination will deliver less effect than can be determined from the original content of both measures. In the few relevant cases the rating in the matrix is corrected as to these effects.

Summary of the rating method

The ratings of possible interaction effects in a set of policy measures can be:

- Mitigating: (-), (- -) or (- - -)
- Reinforcing: (+), (++) or (+++)
- Neutral: (0)
- Not possible (x).

The rules to construct an interaction matrix can be summarised as follows:

1. Define the different measure-types,
2. Define (mutually excluding) applications in the sector that is analysed,
3. Attach to every policy measure the type, the application and year-in/year-out,
4. If necessary split measures with a broad scope into different applications,
5. If necessary split broadly defined measures into different types,
6. Determine the matrix-cells which show no overlap in time for the measures,
7. Determine the matrix-cells where the two measures focus on different applications or different actors,
8. For other cells, rate the possible interaction effect, taking into account the relevant conditions for successful implementation or proper utilization, the influence of both measures on these conditions and the overlap or synergy,
9. Correct for a relatively short overlap in time as to the period for both measures,
10. Correct for indirect interaction, such as the overlap in the resulting savings.

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

The method has been applied to the set of policy measures to promote energy efficiency in households in the Netherlands. In table 2 all measures in the period from 1990 on, and with a non-trivial saving effect, are presented. Some measures regard local activities as well (e.g. climate campaign) and others regard EU-wide legislation (mandatory appliance labels), but most measures are part of national energy policy. A description of these measures is given in MURE [25] and, into more detail for some measures, in Oosterhuis [29]. Some policy measures (energy tax, various subsidy schemes, building codes, performance standards and agreement) are described more extensively in chapter 6. The first ten measures aim at three specific applications: new dwellings (measures 1-6), existing dwellings (7-9) and appliances (10). The other measures (12-15) relate to various or all applications; this category 'General' encompasses taxes, agreements and general subsidy schemes.

Table 2

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

The influence of the policy measures on the various conditions is shown in the Appendix in table A.1. These results have been based on an extensive analysis of the content of the policy measures, the available evaluation reports and general literature mentioned earlier. The Environmental Action Plan (MAP) of energy distributors forms a special case because of its very broad scope. To facilitate the interaction analysis, this measure was split into three segments, directed at new dwellings (11a), existing dwellings (11b) and appliances (11c).

In figure 3 the matrix of possible interaction effects is shown, with the measures grouped according to application. The total number of combinations of two measures is (15+2)*(14+2)/2 = 136. The two extra measures in the formula originate from splitting the MAP-measure. The division by two is because only one half of the matrix should be specified. First attention is paid to the cells of the matrix where interaction is not possible because of different applications (dark shaded, with x). These cells encompass all combinations of measures aimed at respectively new versus old dwellings (columns {1-6,11a} & rows {7-9,11b}), new dwellings versus appliances ({columns 1-6,11a} & rows {10,11c}) or old dwellings versus appliances (columns {7-9,11b} & rows {10,11c}). Combinations regarding all dwellings versus appliances (columns {10,11c} & row {14}) cannot show interaction either. Secondly there are cells where interaction is not possible because measures do not overlap in time (light shaded, with x). For instance all measures starting after 1996 cannot interact with measure 7 ending in 1996. It shows that 58 cells (43%) of the matrix are not relevant with regard to interaction between policy measures. For the remaining cells the detailed results of the interaction analysis are presented in table A.2 in the Appendix.

Figure 3

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

- old or new building code and performance standard (column 1 & row 2 and column 2 & row 6);
- new building code and sustainable building options (column 3 & row 6);

- energy performance standard and sustainable building options (column 2 & row 3).

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

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

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

The last and greatest part of the matrix concerns the interaction effects between general measures and the measures focused on specific applications. The broadly defined general measures interact easily with dedicated measures. A strong mitigating effect exists between the performance standard and energy tax (column 2 & row 12); the tax is not needed to stimulate decisions on saving options when standards already force to save energy. A second example is the retrofit-programme that overlaps with the agreement with the housing associations on energy savings in existing dwellings (column 8 & row 14). Further, subsidized energy advices are devoted to dwellings of housing associations, which have already agreed to take action; again this creates a strong mitigating effect (column 9 & row 14). Strong reinforcing interaction effects are present between advice and subsidies (column 9 & row 15), or labels and subsidies (column 10 & row15), because of the combination of motivation and information. Other mitigating interactions, such as between MAP-subsidies and energy tax (columns 11b/11c and row 12) are not rated strongly mitigating because consumer are generally not knowledgeable about energy prices and taxes when deciding on saving options. For the same reason the combination labels and energy tax (column 10 & row 12) is rated less mitigating than labels and subsidies.

The interaction for the remaining combinations is rated to be small or even zero. Small effects are found because the influence of the two measures on conditions shows overlap for some conditions, but complementary effects on other conditions as well. The zero effect cases comprise eight combinations where further investigation has shown that both measures do no focus on common saving options (see table A.2 in the Appendix).

Top six interacting combinations

The preceding analysis shows 12 strong interacting combinations (9% of all combinations). However, a strong interaction effect between two measures is not always of the same importance. When both measures have a very limited saving effect only, the combination will not be decisive for the effectiveness of savings-policy. The most important measures were selected based on various evaluation studies, such as Berenschot [2], IBO [17], Jeeninga [20], Berkhout [3], Das [11] and Oudshof [30]. These measures are:

- Building codes (version 1991 and 2002) regarding insulation,
- Energy performance standard (EPN), started in 1995,
- MAP-subsidies (period 1992 -1999),
- Regulatory energy tax (REB), started in 1996,

- Labels for various appliances, introduced between 1996 and 2002,
- Energy premium scheme (EPR), started in 2000,
- Energy advice (EPA), started in 2000.

The strong interaction effects between these measures are given in table 3; three combinations are rated as mitigating and three combinations as reinforcing.

Table 3

In case A the performance standard (EPN) comes on top of the building codes that define minimum specifications for the different technical measures. The overlap is a deliberate choice of policy makers; the performance standard assures that energy efficiency can be realised at the lowest costs. But the building codes restrict the EPN-choices with respect to insulation because the consequences stretch very long into the future. This deliberate choice is not true in case B with performance standard and energy tax. Given the strong demands of the performance standard the energy tax does not lead to implementation of extra energy efficiency measures in new dwellings; however it is practically impossible to exclude occupiers of new dwellings from paying the energy tax. In case C the combination of MAP-subsidies and energy tax reinforces the total effect for saving options (in new dwellings) that are not yet proved and rather expensive. Subsidies focus the attention of users at specific saving options as well; this task cannot be accomplished by the energy tax alone according to Daamen [10]. In case D, again with subsidies and energy tax, the interaction effect was rated as mitigating. This differs from case C because energy premiums were submitted from the start to proven saving options, especially appliances. Moreover, the level of the tax was much higher than at the time of the MAP-subsidies. The ineffective spending of energy premiums has been justified with the argument that the subsidies facilitated the acceptance of the ever-higher energy tax. People were given the opportunity to avoid part of the high tax by investing in (subsidized) saving options. In Menkveld [23] an analysis was made of energy premiums restricted to options saving the most and being relatively expensive. With regard to the reinforcing cases E and F one would expect lasting support of energy policy; especially the reinforcing combination of labels and energy premiums was found to be very successful. This combination led to such a rapid transformation of the appliance market that, in a few years, a great part of appliances for sale consisted of high-efficiency appliances. However, due to budget constraints the energy premium was cancelled in 2004 for most saving options. According to Boonekamp [6] this will diminish the saving effect of labels and (still subsidized) energy advice to a great extent.

5. Quantitative analysis of interaction effects with a simulation model

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

- regulatory energy tax,
- all subsidies (energy premiums, MAP and renovation)
- regulation of gas use for space heating (building code and performance standards for new dwellings and agreement with housing associations on existing dwellings).

As mentioned in the first section, the models used in policy scenario studies often are designed to cope with interaction between policy measures. Therefore it seems beneficial to use such a model to investigate interaction effects between policy measures in the past. To this end an adapted version of such a model, described in Boonekamp [5] and used earlier in national scenario studies such as NEO [26], was applied to quantify the interaction effects. For practical reasons this analysis was not done for the period until 2003 but for 1990-2000 only. First the key properties of the model, which are important for interaction analysis, are presented. Then the model adaptations are summarised and some background results are given for the analysis which is described in section 6.

Main structure of the simulation model

In figure 4 the broad design of the household energy model is presented. Demographic, social, economic and life style trends are the driving factors that determine the demand for so-called energy-functions, for instance the heating and lighting of dwellings, cleaning, cooking, etc.. This demand is met with a number of appliances and other energy using systems (boilers, etc.). Energy prices, technological developments and policy measures affect energy use of these systems and appliances.

Determination of energy consumption developments

The model contains a detailed description of energy consumption in the base year. Total energy consumption from statistics is first disaggregated to the level of energy functions (e.g. space heating or lighting) and than to the energy input of all adjoining systems or appliances. When appropriate, a distinction between type of dwelling and type of household is made as well. Most details are based on extensive information on electricity and natural gas consumption, from surveys by EnergieNed [12]. Energy consumption over time of each of the systems or appliances is determined by three factors:

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

Figure 4

The **total number of systems or appliances** is equal to number of households/dwellings times the ownership rate, i.e. the fraction of households which uses the system or appliance.

For ‘standard’ appliances such as washing machines the number is dependent on the number of households only. For dishwashers and dryers the number is dependent on socio-demographic-economic trends as well. The second factor, **intensity of use**, is mainly dependent on socio-demographic trends (see Weber [38]). For instance a higher fraction of households with two jobs, an important trend in the Netherlands in the nineties, has decreased the occupation rate of dwellings and thus space heating demand. But it has increased the demand for cooled food storage. The third factor, **change in energy efficiency**, is dependent on quite different factors. It is supposed that energy efficiency is realised by purchasing systems or appliances having higher conversion efficiencies, or by application of demand reducing technologies such as wall insulation. This decision is restricted by the fixed gradual replacement of the existing stock of appliances or energy using systems.

Calculation of change in energy efficiency

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

$$CBR = [(Inv - Subs) * Ann + O\&M] / [Saving * (Price + Tax)] \qquad (1)$$

Inv = Investment in saving option (€)

Subs = Subsidy on saving option (€)

Ann = Fixed annuity factor to calculate yearly investment costs

O&M = Yearly operation & maintenance costs (if present)

Saving = Annual energy savings realized with option (GJ)

Price = Price of energy excluding tax (€/GJ)

Tax = Tax on energy (€/GJ)

The relation between the penetration of saving options and the cost/benefit ratio is modelled in the form of an S-shaped curve (see Figure 5). The S-curve prohibits an "all-or-nothing' decision for a CBR-value near 1. It allows for different investment decisions at the same CBR because actual circumstances differ per household: greatly varying intensities of use, varying costs of saving options, etcetera.

Figure 5

The relationship is defined such that in 50% of the decision cases the saving option will be chosen, provided that the cost/benefit-ratio is equal to the "acceptable" ratio" (see equation 2).

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

P = Penetration level of saving option (fraction of replaced systems)

Stp = Steepness of S-curve

CBR50 = acceptable cost/benefit ratio

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

Model adaptations to simulate past energy use

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

- Replacement of all scenario inputs by historical values for 1990-2000
- Fitting calculated penetration levels of saving options to known historical levels by adjusting the parameters of the S-curve equations. Most of this work regarded the determination of the acceptable cost/benefit ratio CBR50 for every saving option. Values found are shown in table A.2 in Boonekamp [7].
- Correcting the resulting energy consumption per energy function by adjusting the activity levels (time devoted to cooking, number of showers per day, etc.) to the observed levels from surveys.
- Correcting total energy consumption for space heating by adjusting the parameter 'average indoor temperature' to estimated patterns in past years.

Inputs used

Inputs used in the simulation of past energy use can be split into:

- socio-demographic and life style trends,
- penetration rates of energy systems or appliances,
- energy prices,
- policy measures.

The economic inputs for the past have been incorporated in the other inputs and are therefore not presented here (see discussion in Boonekamp [7]). The development of main socio-demographic trends and penetration of important energy using systems or appliances are given in table 4.

Table 4

Figure 6 presents gas- and electricity prices for households in the period 1990-2000. Total gas and electricity prices increase; however without the regulatory tax after 1996 the prices would have been substantially lower in 2000 than in 1990. The policy measures are described in section 6.

Figure 6

Overall results for household energy consumption

Table 5 shows the actual energy consumption of households in 1990 (first row) and in 2000 (last row). Total electricity consumption increases by one-third but total gas consumption, being 97% of total fuel use, proves to be quite stable. The ‘consumption-excluding-savings’ in 2000, or ‘frozen technology consumption’, was determined by stalling, from 1990 on, all improvement of conversion efficiencies or insulation levels in the model (see for methodology Boonekamp [5]). The difference with observed consumption in 2000 is equal to total savings in the period 1990-2000. These total savings are the result of either policy measures or other developments such as price-induced savings or autonomous efficiency improvements. The difference with the 1990-level, called the “Growth 1990-2000” effect, is the result of more households, higher ownership rates for appliances, more consumption of hot water and many other factors.

Table 5

6. Energy savings from combinations of policy measures

The simulation model described reproduces past energy developments, using the relationship between various policy measures and the penetration of saving options. This approach enables the analysis of alternative developments for deviating policy inputs. These variants describe a (theoretical) past trend without one or more of the three policy measures of interest: regulatory tax, investment subsidies and regulation of gas use for space heating. When these variants are compared with the actual development case (with the three policy measures), negative saving effects will be found. For presentation reasons it was decided to compare the results of all variants with that of the simulation without the three measures, the so-called 'base case'. In this base case the calculated level of fuel and electricity consumption is higher than the observed consumption, indicating that the policy measures save energy. However, the base case consumption is lower than the 'consumption-excluding-savings' level from table 5. Only 50% of all fuel savings and 15% of all electricity savings can be attributed to these three measures. Starting from this base case the efficiency gains were determined for each of three policy measures, followed by all combinations of these measures.

Saving effect of the energy tax

The regulatory tax increases the benefits of energy saved, and thus lowers the cost/benefit-ratio for investments in saving options (see equation 1 in section 5); this in turn leads to lower energy consumption. The regulatory tax on fuels and electricity was gradually introduced from 1996 on. In 2000 the energy tax amounted to 36% of the total gas price and 32% of the total electricity price (see figure 6). Because of the five year interval an average value for 1996-2000 was used to determine the total saving effect in 2000 (16-18% of the total energy price). In table 6 the difference with base case energy use is shown as the saving effect for "tax only". The energy tax decreases the base case consumption in 2000 by 2.0% for gas and

1.9% for electricity. Because the energy tax was introduced after 1995 there is no effect in 1995.

Table 6

Saving effect of investment subsidies

Subsidies decrease the additional investment into the saving options, and therefore the cost/benefit-ratio, which results in lower energy consumption. Investment subsidies (MAP-subsidy, renovation subsidies and energy premium, see section 4) were available in the entire period 1990-2000 for all important saving options, such as various insulation measures, high-efficiency boilers and heat pumps. Subsidies often amounted to 20-25% of the extra investments in more energy efficient options. The simulation run with subsidies shows that gas and electricity consumption decrease compared to the base case (see table 6, "subsidies only"). In 2000 gas use is 4.3% lower and electricity consumption decreases with 3.2%

Saving effect of regulation

In the period 1990-2000 regulation has mainly focused on fuel use in new dwellings. Until 1995 the building code defined minimum insulation levels for wall, roof, floor and windows. From 1996 on the energy performance standard (EPN) limited total energy consumption of new dwellings. The choice of saving measures, additional to the building codes, was left to the builder. However, the builder had to prove beforehand, by means of a prescribed calculation method, that the performance standard was met. The yearly surveys by EnergieNed [12] provided information on the saving options actually applied. The total number of new dwellings with regulation of gas use amounted to 13% of the total housing stock in 2000. In the model runs with regulation the actually chosen options because of the performance standard were forced into the simulation by replacing the calculated cost/benefit-ratio with a very low fixed ratio.

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

For the case without regulation the usual cost/benefit formula (see section 5) was used to calculate penetration rates of the saving options concerned. For new dwellings the regulated saving options often were not economically attractive. But for the existing dwellings of housing associations the simulations without regulation showed almost the same amount of saving options in most cases. After introducing regulation in the base case the gas consumption decreased with 4.6% in 2000; the electricity consumption was not affected (see table 6).

Combined effect of three policy measures

In the previous analysis only one policy measure at a time was introduced in the simulation of past energy use. With all three measures present one can expect the sum of the three effects given earlier. However, from table 6 it follows that the combined effect often is lower than the sum of the three effects, and only in one case equal. This means that there is an overlap in the effects of the three measures, up to a maximum of 10% for gas in the period 1990-2000. However, before drawing conclusions, an analysis is made of the interaction effects between each combination of two measures.

Combined effect of two policy measures

With three different measures at hand there exist three combinations of two measures only. For each of these combinations a simulation run with the model was made. In figure 7a results are presented for gas and in figure 7b for electricity.

Figure 7a

Figure 7b

Results are given for the period 1995-2000 because all three measures were active in this period only. All changes are given as a percentage of total gas or electricity consumption in the base case. The results for a single policy measure are shown in the rectangles. These values correspond to the "tax-only', etc. cases in table 6; the increase in savings from 1995 to 2000 translates into the percentages given. Combined saving effects for two measures are shown between the rectangles in figure 7. These saving effects are larger than that of each of the corresponding single measures. This is because two policy measures will have more influence than one. However, in case of electricity the saving of 'tax & regulation" is equal to that of "tax" because the electricity savings owing to regulation are practically zero. The same is valid for "subsidies & regulation" and "subsidies".

The qualitative results presented in section 4 show mainly mitigating combinations of the three policy measures. Therefore one may expect that the combined saving effect of two measures often is lower than the sum of the separate savings; the two policy measures will overlap with regard to their influence on saving options. For instance, in the case of both regulation and tax, the extra effect of the tax on top of regulation will be negligible. This is confirmed in figure 7a: the combined effect of "tax & regulation" is -4.5% against -5.1% for the sum of the two effects. Thus the amount of overlap between these measures is almost 13%. For the combination "subsidies & regulation" the amount of overlap is less profound (8%). From figure 7b it follows that for electricity the overlap for "tax & subsidies" is 4%.

However, in the case of gas and “tax & subsidies” the combined effect is **not** lower than the sum of the two separate effects. This combination proves to be of a reinforcing nature. Further analysis reveals that this is due to the fact that in the period 1995-2000 part of the subsidies is given to advanced, and expensive, saving options. In these cases the combined financial stimulation of the two measures was needed to force the start of the implementation process (see also analysis in Boonekamp [7]). The other part of the subsidies was spent on proven options, leading to a mitigating combined effect. This case resembles the reinforcing and mitigating combinations C and D described in section 4.

The overlap for the three measures together is more than 13% for gas and 4% for electricity. The 4%-figure is equal to that found earlier for the combination “tax & subsidies”. Because the other combinations of two measures show no overlap, the three-measure overlap is equal to the only existing two-measure overlap. For gas the three-measure overlap is slightly greater than the overlap for the two measure combination “tax & regulation”. The other overlap for “subsidies & regulation” does scarcely provide an extra contribution to the total overlap for three measures. One of the rare cases to compare these results with is provided by Vaisanen [34] for energy savings in the Finnish industry. The overlap of approximately 20% for the combination of audits, subsidies and voluntary agreements has the same order of magnitude as was found here.

7. Discussion on interaction results

The new approach in analysing interaction between policy measures raises a number of questions that will be addressed in the following paragraphs.

Effect of measures not regarded

Besides the measures used in the preceding analysis, the following policy measures were present in the period 1990-2000 as well (see table 2) : OEI (optimal energy infrastructure), DUBO (sustainable building options), EPA advice and energy efficiency labels for appliances. The infrastructural measures (OEI) have contributed to a 50% increase for the number of dwellings connected to a town-heating system. However, this type of dwellings still regards only 3% of the total number in 2000. Sustainable building options related to energy use can be ignored too, as they overlap to a very great extent with the insulation standards already dealt with in the preceding analysis. In section 4 the energy advice was mentioned as an important measure in the qualitative analysis of possible interaction for 1990-2003. However, it was introduced in the last year of the simulation period only. The effect of labelling was substantial in the Netherlands according to Winward [39]. Moreover, the combination of labels and subsidies was mentioned earlier as an important combination. However, most MAP-subsidies did not coincide with labels, and the consecutive energy premium was introduced in the last year of the simulation period. This is not true for labelling and the energy tax, which both were introduced step by step after 1996. Although this combination is rated less reinforcing than that of labelling and subsidies (see figure 3) a synergetic effect cannot be excluded. However, it regards electricity consumption only. Given these notes it is concluded that the measures, which were not selected in the quantitative analysis for 1990-2000, are of limited importance with respect to the overall results.

Contribution of substitution between gas and electricity

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

Interaction effects in the longer term

As the three policy measures analysed have been continued after 2000 it can be expected that the interaction effect have increased further. More and more new dwellings will have an energetic design according to regulation that mitigates the potential saving effect of the energy tax on new dwellings. The same is true for the combination "tax & subsidies" or "subsidies & regulation", at least when lowered subsidies in 2004 rise again in the future. However, an analysis with simulation runs for the period 2000-2005 is not possible, as realisations for 2005 are not available yet. To provide some raw estimate about the further increase in the size of interaction effects, past household energy use was simulated with artificially enforced measures. The tax level for 1995-2000 was doubled, bringing the average value at 30-35% of the total energy price. Investment subsidies were doubled as well, and the scope of regulation of gas use in new dwellings was expanded according to current policy. The effects on total energy use were calculated for the three enhanced measures and for the combination. The results for intensified policy show 25-30% lower energy savings for the combination of three measures compared to the sum of effects for each measure apart. The overlap is more than two times higher than that found earlier for three measures (see table 6).

Interaction effects between subsets of more than two measures

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

Uncertainty in the results of the analysis

In the so-called top-down calculation of realised savings an uncertain reference trend is compared with an uncertain actual trend. The relative small difference representing energy savings could have a quite substantial uncertainty margin. However, the simulation method presented here regards a bottom-up method where total energy savings are the result of increased penetration of a great number of saving options. The energy savings per saving option are fairly well known from research (e.g. executed as part of new subsidy schemes). The increase in penetration rates is known very well from yearly surveys. The simulation model calculates total energy use with actual penetration rates and penetration rates of the base year. The difference, being total energy savings, takes account of interaction between the saving effects of various options as well (see chapter 3). Further, the (limited) uncertainties in the amount of savings per option have a small effect on the uncertainty in total savings, due to the law of large numbers for the numerous saving options. So, it is believed that the calculated total energy savings are considerably accurate. However, the more important issue is the quality of calculated savings in the simulation variants with and without policy measures. The energy savings owing to one or more policy measures are equal to the difference between the results of two simulations. Uncertainty in observed quantities does not play a role here, as both results regard calculated figures based on the same inputs. The only deciding factor is how the simulation model accounts for changes in deployed policy measures. Given the penetration-algorithms for every saving option (that were fitted to actual detailed developments in the period 1990-2000), it is supposed that these algorithms also describe saving developments in case one or more of these policy measures are absent. Again, the total change in savings is the result of a number of changes for the penetration of various saving options. This approach is used as well in most models that predict future trends, and which are validated by fitting the parameters to historical trends (e.g. economic models with price- and income-elasticities).

Other effects left aside

The analysis focused on the direct effect of (combinations of) three policy measures on the penetration of saving options. Not regarded are the **direct effect on use** of the energy systems or appliances of these policy measures, and the **indirect effects** of implementing saving options. The policy measures "regulation" and "subsidies" do not have a direct effect on the use of systems or appliances, but energy taxes can. However, according to Groot [14] this effect is quite small due to the low price elasticity values in the Netherlands. The first indirect effect constitutes interaction between the saving effects of different saving options. However, these specific interactions, such as less profitable high-efficiency boilers due to subsidized insulation measures, are taken into account in the simulation model. Another indirect effect is the rebound-effect which can show up in three forms: more intense use of the efficient system, purchasing extra energy using equipment or spending the money saved on products that demand energy when produced. The most important example of the first form is a higher thermostat setting after implementing saving measures. As energy poverty is hardly a policy problem in the Netherlands, thermostat settings have always been such high that this rebound-effect will be small. An example of the second form of rebound effect are new lighting applications. According to literature the introduction of very efficient bulbs (CFL's) has probably contributed to increased use of light in gardens and against burglary. This effect was not accounted for in the simulations with the policy measures "subsidies" and "energy taxes". The spending of money on other products or services (that cause extra energy use) falls outside the scope of this analysis.

8. Conclusions and observations

New framework for investigating possible interaction effects between measures

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

Qualitative interaction results for actual policy measures in households

The method has been applied to the actual set of 15 policy measures on energy efficiency for households in the Netherlands, in the period 1990-2003. The matrix of possible interaction effects shows that interaction is non-existing for 43% of all measure combinations. Only 9% can be rated as strongly interacting, of which the greater part mitigating. Taking into account measures with a substantial saving effect only, the important interaction effects are between:

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

Quantitative interaction results for the most important policy measures

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

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

Observations for optimal policy

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

The matrix-method has been applied to sets of policy measures for EU-15 countries. From Odyssee [28] it can be concluded that the method offers a quick overview of possible interaction effects in actual sets of policy measures. In case of a structural and extensive use of many types of policy measures the matrix-method can be useful to avoid overlapping effects for policy measures. Moreover, the analysis can show opportunities for reinforcing combinations of measures. However, some interaction effects have to be accepted for practical reasons, e.g. the part of energy use which is affected by standards cannot be exempted from taxation. Sometimes the overlapping combination is effective yet in relation to the government efforts demanded. Finally, other criteria influence the choice of policy measures, for instance policy expenditures or public acceptance.

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Appendix 1 Rating of interaction between policy measures for households

In table A.1 the contribution of the various policy measures in meeting the conditions for implementation of saving options in Dutch households are shown. The Action Plan of the distribution companies, mentioned in table 2, was split into three different measures. For the policy measures building codes (1991 and 2002) and the performance standard, the mandatory character forces that all conditions for implementation are met. As to motivation, it must be mentioned that it can follow from legal measures (obligations), financial measures (subsidies and taxes) or social pressure. This last type of motivation is valid for 'Optimal Infrastructure' and 'Climate campaign'.

Table A.1.

In table A.2 the factors that contribute to the rating of the interaction between combinations of policy measures are given:

- the common saving options affected by the two measures,
- overlapping/complementary effects as to the conditions for implementation (A = availability, K = known, R = restrictions, M = motivation and P = proper utilization),
- the overlap in time (average fraction as both periods).

Under the heading "comments" individual factors are given for some combinations; these have contributed to the overall rating of the interaction too. In case of absence of common saving options the interaction was rated zero.

Table A.2

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Figure 1: Conditions for a successful implementation of a saving option

Figure 2: Cases for the saving effect of two measures with interaction (example)

Figure 3: Relative ratings possible interaction effects between 15 policy measures for energy savings in households in the Netherlands 1990-2003

Figure 4: Set up of the simulation model of household energy consumption

Figure 5: Relationship between cost/benefit ratio and penetration level for saving options (example)

Figure 6: Gas- and electricity prices and regulatory tax for households 1990-2000 (€-ct1990 per m^3 or kWh)

Figure 7a: Savings on gas 1995-2000 for combinations of policy measures (% of base case consumption)

Figure 7b: Savings on electricity 1995-2000 for combinations of policy measures (% of base case consumption)

Figure 1: Conditions for a successful implementation of a saving option

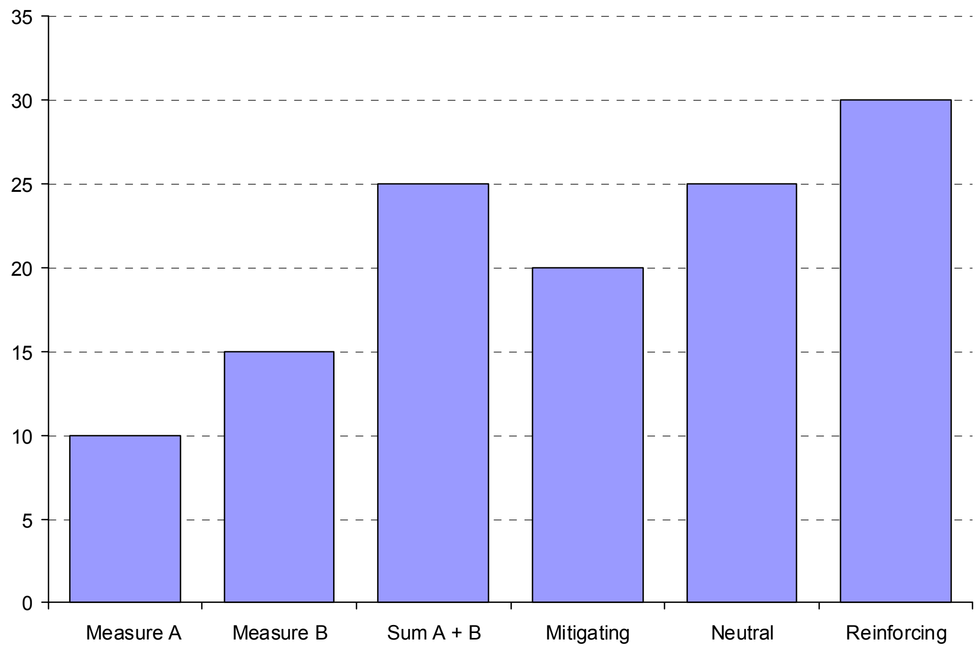


Figure 2: Cases for the saving effect of two measures with interaction (example)

	Active period Start	End	1 **BD1991** new	2 **EPN** new	3 **DuBo** new	4 **EPL** new	5 **Demon.** new	6 **BD2002** new	11a **MAP** new	7 **Renov.** old	8 **Retrofit** old	9 **EPA** old	11b **MAP** old	11c **MAP** appl.	10 **Labels** appl.	12 **REB**	13 **Camp.**	14 **LTA**	15 **EPR**
1	1992	2001																	
2	1996		- - -																
3	1995		- -	- - -															
4	1997		0	- -	0														
5	1985		0	0	0	0													
6	2002		x	- - -	- - -	0	0												
11a	1991	*2000*	0	- -	+	0	+	x											
7	1993	1996	x	x	x	x	x	x	x										
8	1994	2000	x	x	x	x	x	x	x	+++									
9	2000		x	x	x	x	x	x	x	x	-								
11b	1991	2000	x	x	x	x	x	x	x	0	++	+							
11c	1991	2000	x	x	x	x	x	x	x	x	x	x	x						
10	1996		x	x	x	x	x	x	x	x	x	x	x	+					
12	1996		-	- - -	+	+	+	0	+++	0	+	+	- -	- -	+ +				
13	1991		0	0	+	0	0	0	0	0	0	- -	+	+	+	++			
14	1998	2000	0	0	0	0	0	x	0	x	- - -	- - -	- -	x	x	- -	0		
15	2000	2003	0	-	0	0	+ +	0	0	x	0	+++	0	0	+++	- - -	+	-	

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

Figure 3: Relative ratings of possible interaction effect between 15 policy measures for energy savings in households in the Netherlands 1990-2003

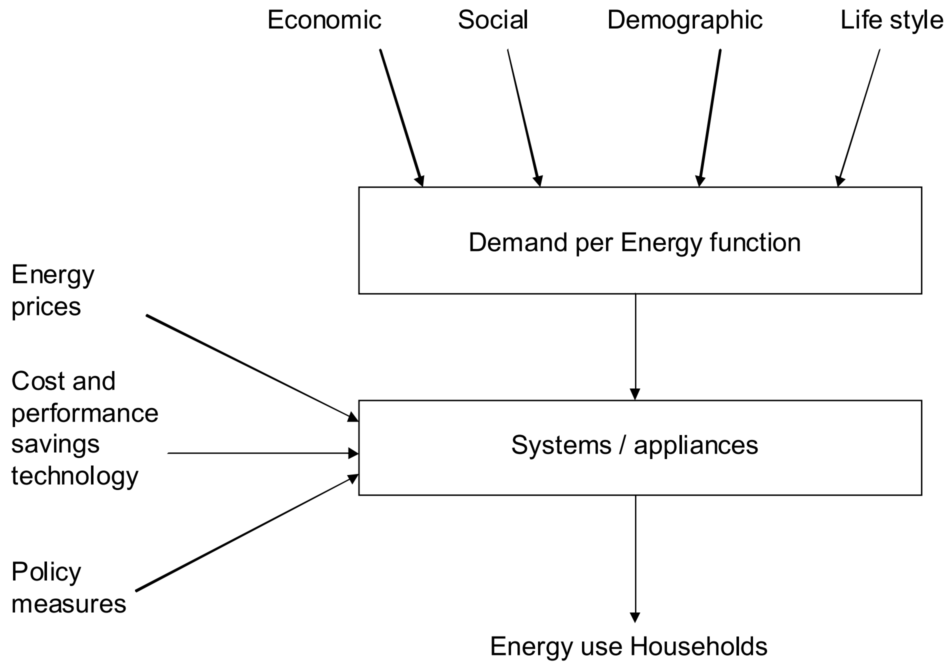


Figure 4 : Set up of the simulation model of household energy consumption

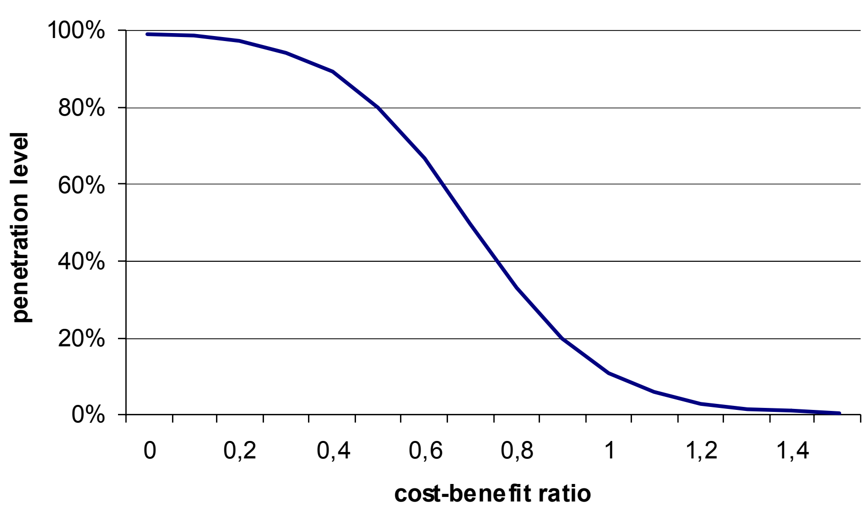


Figure 5 : Relationship between cost/benefit ratio and penetration level for saving options (example)

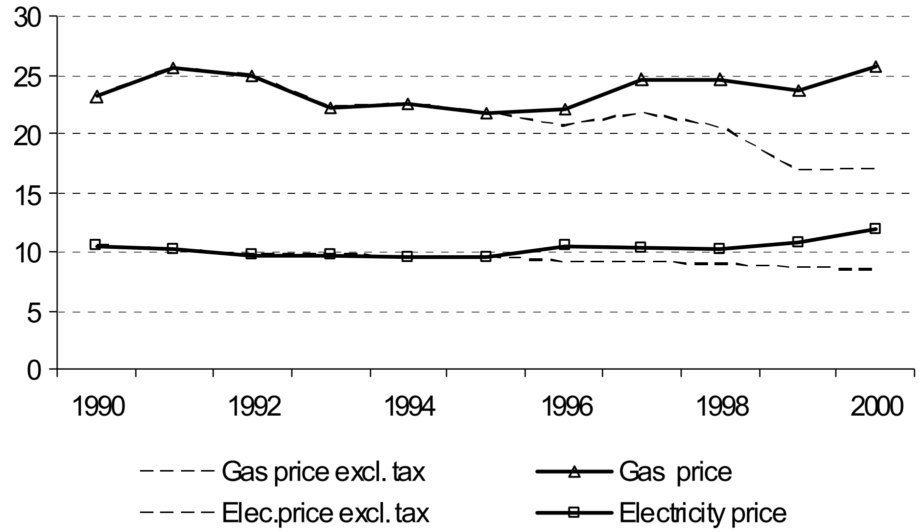


Figure 6: Gas- and electricity prices and regulatory tax for households 1990-2000 (€-ct1990 per m³ or kWh)

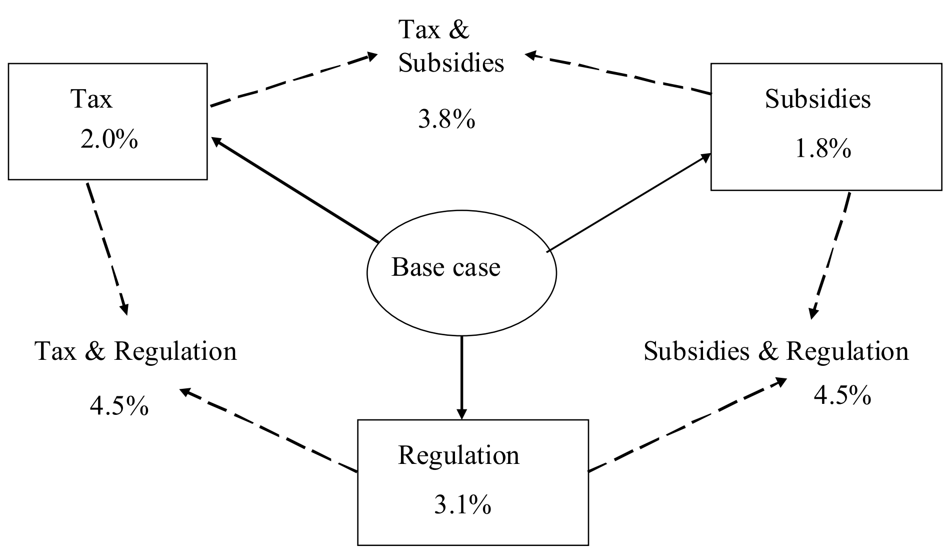


Figure 7a: Savings on gas 1995-2000 for combinations of policy measures (% of base case consumption)

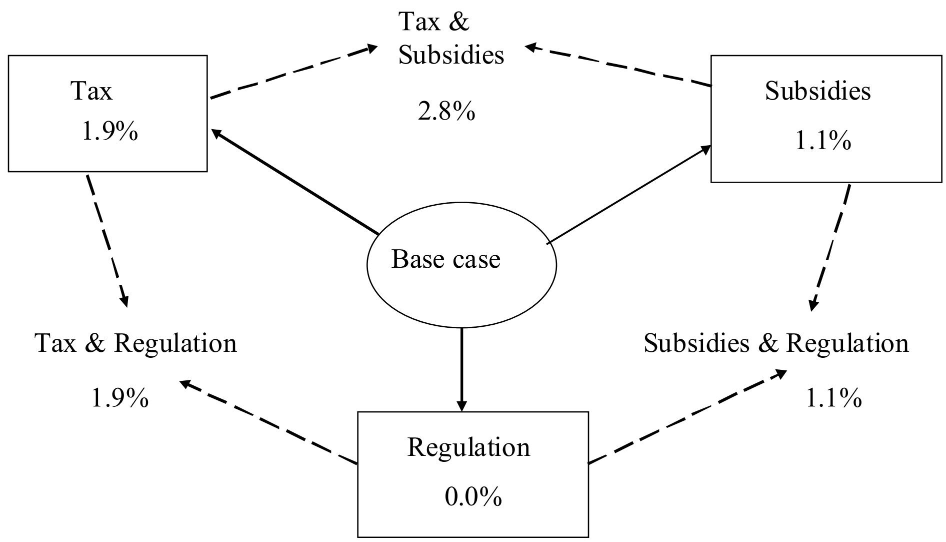


Figure 7b: Savings on electricity 1995-2000 for combinations of policy measures (% of base case consumption)

Table 1: Contribution of measure types with respect to the conditions for implementation and proper utilization of saving options

	Implementation				Proper utilization
	Available for application	Known to appliers	Restrictions lifted	Motivation to invest	
Measure type:					
Legislation					
- implementation	X	X	X	X	
- utilization					X
- labels		X		X	
Taxes				X	X
Support					
- financial		X		X	
- audits		X			
Information					
- options		X		X	
- utilization					X
Agreements		X	X	X	
Procurement	X	X		X	
R&D-facilities	X		X	X	
Emission-trading				X	

Table 2: Overview of policy measures for household energy efficiency in the Netherlands 1990-2003

	Policy measure	Application	Target group
1	Building Code insulation 1991	New dwelling	Builders
2	Energy Performance New dwelling (EPN)	" "	Builders
3	Sustainable Building options (DuBo)	" "	Builders
4	Optimal Energy Infrastructure (EPL/OEI)	" "	Builders
5	Novem demonstration programmes	" "	Builders
6	Building Code insulation 2002	" "	Builders
7	Renovation/saving subsidies	Old dwelling	Housing associations
8	Retrofitting program rented houses	" "	Housing associations
9	Advice energy savings (EPA)	" "	Owner/Associations
10	Energy efficiency labels	Appliances	Consumers
11	Action Plan distribution sector (MAP)	Various	All parties
12	Regulatory Energy Tax (REB)	General	Consumer/Owner
13	Climate Campaign '21	General	Consumers/Municipality
14	Agreement housing associations (LTA)	Dwellings	Housing associations
15	Energy Premium Scheme (EPR)	General	Consumer/Owner

Table 3: Strong interaction effects between important policy measures in Dutch households

	First measure	Second measure	Type of interaction
A	Building codes	Performance standard	Mitigating
B	Performance standard	Energy tax	Mitigating
C	MAP-subsidies	Energy tax	Reinforcing
D	Energy tax	Energy premiums	Mitigating
E	Advice energy savings	Energy premiums	Reinforcing
F	Labels appliances	Energy premiums	Reinforcing

Table 4 Development of main input variables for simulation of household energy consumption

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

Table 5: Overview of household energy consumption developments 1990-2000 (*)

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

(*) Corrected for yearly variations in temperature during the heating season

Table 6: Energy savings owing to a regulatory tax, investment subsidies, regulation, and the combination for 1995 and 2000

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

Table A.1: Contribution of policy measures with respect to meeting the conditions for implementation and proper utilization of saving options for households in the Netherlands

	Measure type	Implementation				Proper utilization
		Available for application	Known to appliers	Res-trictions lifted	Motivation to invest	
1	Building code-1991	X	X	X	X	
2	Performance standard	X	X	X	X	
3	Sustainable options	X	X			
4	Optimal infrastructure		X	X	X	
5	Demonstration programs	X	X		X	
6	Building code-2002	X	X	X	X	
7	Renovation subsidies				X	
8	Retrofit-program		X	X		
9	Advice energy savings		X			
10	Labels appliances		X			
11a	MAP-new dwellings		X	X	X	
11b	MAP-old dwellings		X	X	X	X
11c	MAP-appliances		X		X	
12	Energy tax				X	X
13	Climate campaign		X		X	X
14	Agreement housing		X	X	X	
15	Energy premiums		X		X	

Table A.2: Rating of the interaction between policy measures to stimulate energy savings in Dutch households in the period 1990-2003

No	First measure	Second measure	Common saving options	Effect on conditions overlap	complement	Time overlap	Total rating	Comments	Indirect
1	EPN	BD1991	insulation	A/K/R/M	x	61%	- - -		
2	DuBO	BD1991	insulation	A/K	x	66%	- -		
3	DuBo	EPN	insulation, boiler, heat-recovery	A/K	x	89%	- - -		
4	EPL	BD1991	X				0	Different options	
5	EPL	EPN	epc-measures	K/R/M	x	94%	- -		Post-mitigating
6	EPL	DuBo	large heat distr.projects	K	R/M-A	89%	0		
7	Demonstr	BD1991	insulation	A/K/M	x	79%	0	Time lag	Pre-reinforcing
8	Demonstr	EPN	insulation, boiler, heat-recovery	A/K/M	x	57%	0	Time lag	Pre-reinforcing
9	Demonstr	DuBo	insulation, boiler, heat pump/rec.	A/K	x	64%	0	Time lag	Pre-reinforcing
10	Demonstr	EPL	heat pump, etc.	K/M	A-R	50%	0	Time lag	
11	BD2002	EPN	insulation	A/K/R/M	x	63%	- - -		
12	BD2002	DuBo	insulation	A/K	x	61%	- - -		
13	BD2002	EPL	X				0	Different options	
14	BD2002	Demonstr	insulation	A/K/M	x	57%	0	Time lag	Pre-reinforcing
15	MAP-new	BD1991	X				0	Different options	
16	MAP-new	EPN	options for lower epc	K/R/M	x	44%	- -		Pre-reinforcing
17	MAP-new	DuBO	heat pump/recovery/distribution	K	R/M-A	53%	+		
18	MAP-new	EPL	large heat distrib.projects	K/R/M	x	35%	0	MAP-new >1997 = 0	
19	MAP-new	Demonstr	heat pump, etc.	K/M	R-A	86%	+	Overlap M needed	
20	Retrofit	Renovate	insulation, boiler social rented	x	K/R-M	40%	+++		
21	EPA	Retrofit	insulation, boiler	K	x	18%	-		
22	MAP-old	Renovate	insulation, boiler rented	(M)	K/R-M	40%	0	Mutual excl.subsidies	
23	MAP-old	Retrofit	insulation, boiler social rented	(K/R)	M - K	70%	++	No overlap K/R	
24	MAP-old	EPA	insulation, boiler	(K)	R/M-K	9%	+	No overlap K in time	
25	Labels	MAP-appl.	white appliances	x	K-M	50%	+	Few subsidies	
26	REB	BD1991	insulation	M	x	61%	-	BD-overlap << EPN (27)	
27	REB	EPN	insulation, boiler, heat-recovery	M	x	100%	- - -		
28	REB	DuBO	all DuBo-options	x	M - A/K	94%	+		
29	REB	EPL	heat pump/distribution	M	M-K/R	88%	+	Overlap M needed	
30	REB	Demonstr	advanced options	M	M-A/K	79%	+	Overlap M needed	
31	REB	BD2002	insulation	M	x	25%	0	BD-overlap << EPN (27)	
32	REB	MAP-new	heat pump/recovery/distribution	M	M-K/R	50%	+++	Overlap M needed	
33	REB	Renovate	insulation, boiler	M	x	11%	0		

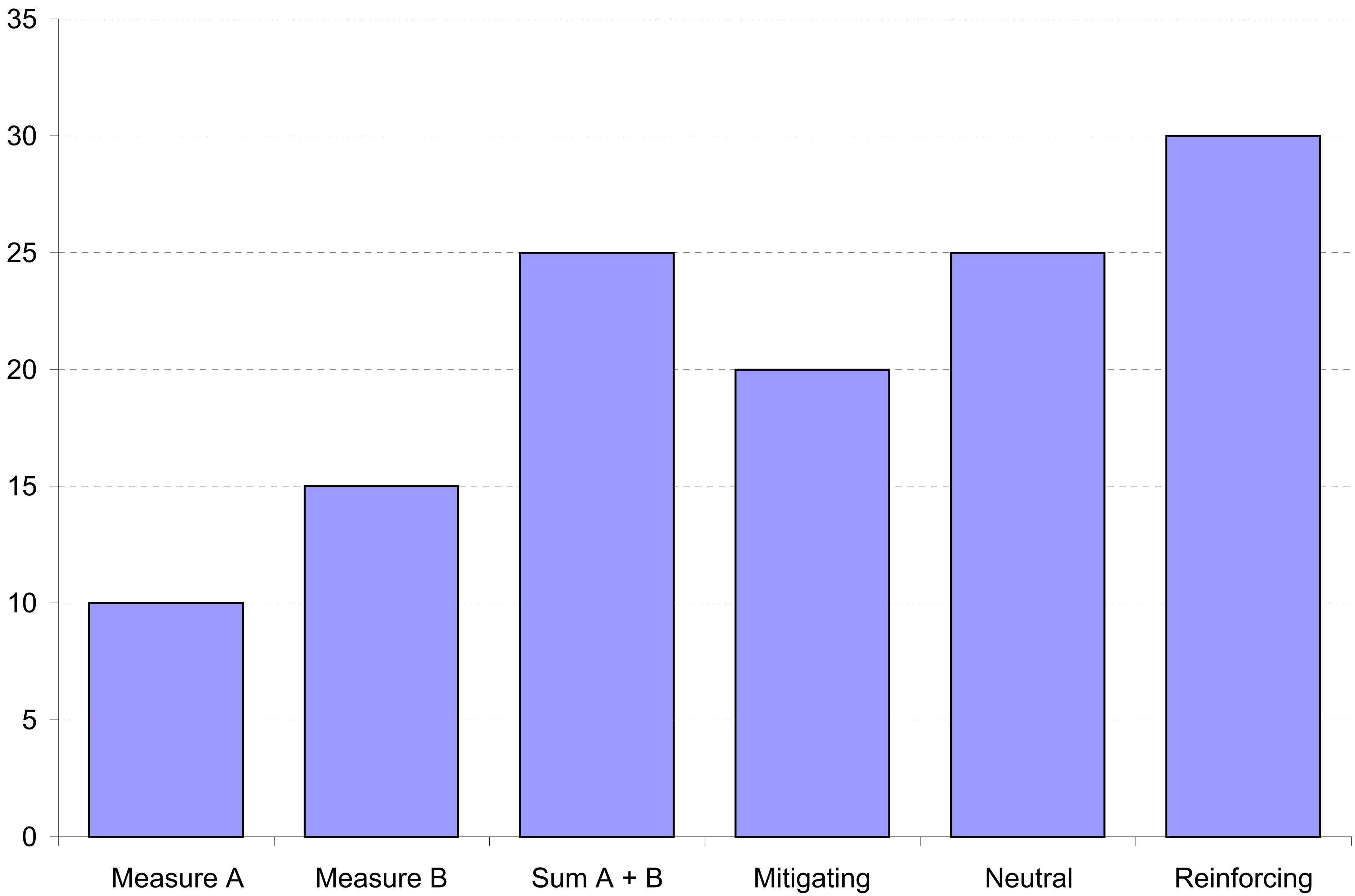
34	REB	Retrofit	insulation, boiler	x	M-K/R	56%	+	
35	REB	EPA	insulation, boiler	x	M-K	50%	+	
36	REB	MAP-old	insulation, boiler	M/P	M-K/R	50%	- -	Overlap stronger
37	REB	MAP-appl.	appliances	M	M-K	50%	- -	Overlap stronger
38	REB	Labels	appliances	x	M-K	100%	++	
39	Campaign	BD1991	insulation	K/M	x	55%	0	Focus on different actors
40	Campaign	EPN	insulation, boiler, heat-recovery	K/M	x	94%	0	Focus on different actors
41	Campaign	DuBO	all DuBo-options	K	M - A	89%	+	
42	Campaign	EPL	heat pump/distribution	K/M	x	100%	0	Focus on different actors
43	Campaign	Demonstr	heat pump/distribution	K/M	M - A	75%	0	Different M
44	Campaign	BD2002	insulation	K/M	x	29%	0	Focus on different actors
45	Campaign	MAP-new	heat pump/distribution	K/M	x	44%	0	Focus on different actors
46	Campaign	Renovate	insulation, boiler rented	M	x	31%	0	Focus on different actors
47	Campaign	Retrofit	insulation, boiler rented	K	M - R	49%	0	Focus on different actors
48	Campaign	EPA	insulation, boiler	K	x	57%	- -	
49	Campaign	MAP-old	insulation, boiler	K/M/P	M-R	44%	+	Different M
50	Campaign	MAP-appl.	appliances	K/M	M-K	44%	+	Different M
51	Campaign	Labels	appliances	K	M-K	94%	+	
52	LTA	BD1991	X				0	Overlap LTA-new = 0
53	LTA	EPN	X				0	LTA-options new = EPN+
54	LTA	DuBO	advanced options rented new	K	R/M-A	67%	0	Few same applications
55	LTA	EPL	heat distribution new rented	K/R/M	x	71%	0	Few same applications
56	LTA	Demonstr	new options rented	K/M	R-A	61%	0	Few same applications
57	LTA	MAP-new	advanced options new rented	(M)/K/R	x	65%	0	No overlap M for LTA-new
58	LTA	Retrofit	insulation, boiler rented (old)	K/R	x	71%	- - -	Overriding M-LTA
59	LTA	EPA	insulation, boiler rented (old)	K	x	25%	- - -	Overriding M-LTA
60	LTA	MAP-old	insulation, boiler rented (old)	K/R	x	65%	- -	Overriding M-LTA
61	EPR	BD1991	X				0	Different options
62	EPR	EPN	heat pump new dwellings	K/M	x	75%	-	EPR-new very few
63	EPR	DuBO	heat pump new dwellings	K	M-A	72%	0	
64	EPR	EPL	heat pump new dwellings	K/M	x	79%	0	Different actors
65	EPR	Demonstr	various options new dwellings	K/M	M-A	64%	++	Complement stronger
66	EPR	BD2002	X				0	Different options
67	EPR	MAP-new	X				0	EPR from 2002 > 2000
68	EPR	Retrofit	insulation, boiler old dwellings	K	M-R	18%	0	
69	EPR	EPA	insulation, boiler old dwellings	K	M-K	100%	+++	Complement stronger
70	EPR	MAP-old	options old dwellings	K/M	x	16%	0	

71	EPR	MAP-appl.	some appliances	K/M	x	16%	0	
72	EPR	Labels	most efficient appliances	K	M-K	75%	+++	Complement stronger
73	EPR	REB	appliances, insulation old	M	x	75%	- - -	
74	EPR	Campaign	appliances, insulation	K/M	M-K	79%	+	Different M
75	EPR	LTA	insulation rented old	K/M	x	21%	-	
76	Campaign	REB	all Campaign issues	M/P	K-M	94%	++	Complem.much stronger
77	LTA	REB	options rented dwellings	M	x	69%	- -	
78	LTA	Campaign	options rented dwellings	K/M	x	71%	0	Focus on different actors

Figure(s)


Available for application
Known to appliers
Restrictions lifted
Motivation to invest
Imple-mentation

Figure(s)



35
30
25
20
15
10
5
0
Measure A
Measure B
Sum A + B
Mitigating
Neutral
Reinforcing

	Measure A	Measure B	Sum A + B	Mitigating	Neutral	Reinforcing
Effect	**10**	**15**	**25**	**20**	**25**	**30**

Figure(s)

	Active period Start	End	1 **BD1991** new	2 **EPN** new	3 **DuBo** new	4 **EPL** new	5 **Demon.** new	6 **BD2002** new	11a **MAP** new	7 **Renov.** old	8 **Retrofit** old	9 **EPA** old	11b **MAP** old	11c **MAP** appl.	10 **Labels** appl.	12 **REB**	13 **Camp.**	14 **LTA**	15 **EPR**
1	1992	2001																	
2	1996		- - -																
3	1995		- -	- - -															
4	1997		0	- -	0														
5	1985		0	0	0	0													
6	2002		x	- - -	- - -	0	0												
11a	1991	*2000*	0	- -	+	0	+	x											
7	1993	1996	x	x	x	x	x	x	x										
8	1994	2000	x	x	x	x	x	x	x	+++									
9	2000		x	x	x	x	x	x	x	x	-								
11b	1991	2000	x	x	x	x	x	x	x	0	++	+							
11c	1991	2000	x	x	x	x	x	x	x	x	x	x	x						
10	1996		x	x	x	x	x	x	x	x	x	x	x	+					
12	1996		-	- - -	+	+	+	0	+++	0	+	+	- -	- -	+ +				
13	1991		0	0	+	0	0	0	0	0	0	- -	+	+	+	++			
14	1998	2000	0	0	0	0	0	x	0	x	- - -	- - -	- -	x	x	- -	0		
15	2000	2003	0	-	0	0	+ +	0	0	x	0	+++	0	0	+++	- - -	+	-	

Figure(s)

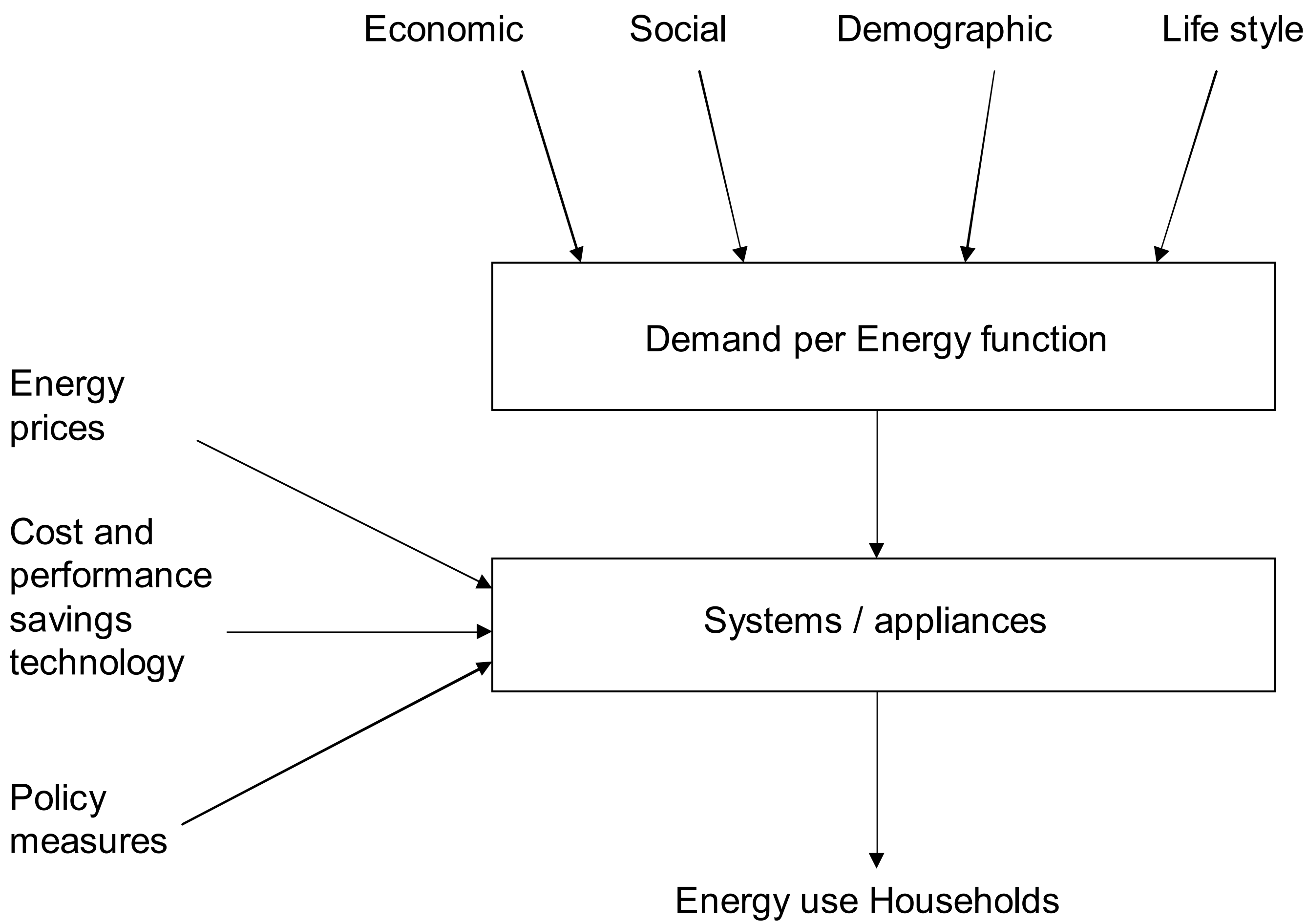
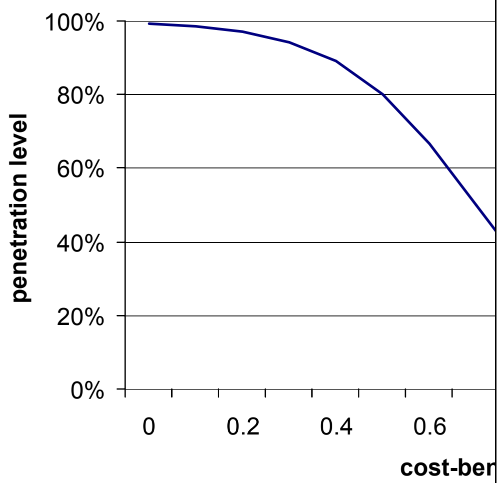

Economic
Social
Demographic
Life style
Demand per Energy function
Energy prices
Cost and performance savings technology
Policy measures
Systems / appliances
Energy use Households

Figure-5-curve

S-curve penetratie bij gegeven kosten/baten-verhouding	
Kantelpunt (k/b-v->50	0.7
Steilheid (fractie)	7
cost/benefit-ratio	penetration
-0.3	100%
-0.2	100%
-0.1	100%
0	99%
0.1	99%
0.2	97%
0.3	94%
0.4	89%
0.5	80%
0.6	67%
0.7	50%
0.8	33%
0.9	20%
1	11%
1.1	6%
1.2	3%
1.3	1%
1.4	1%
1.5	0%



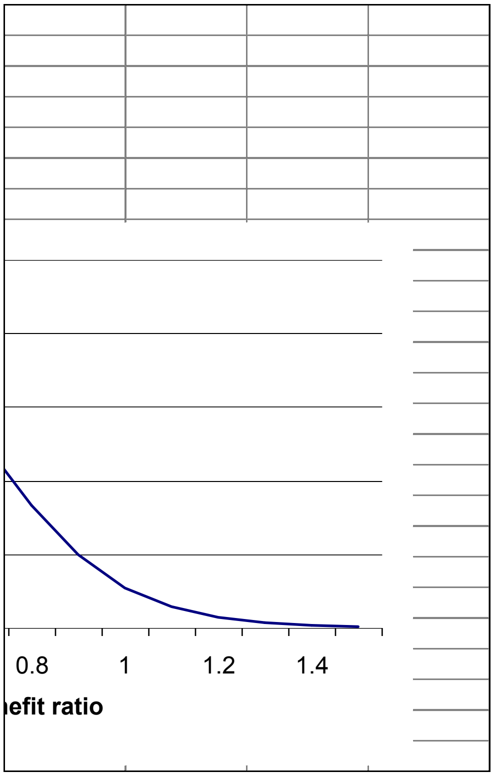
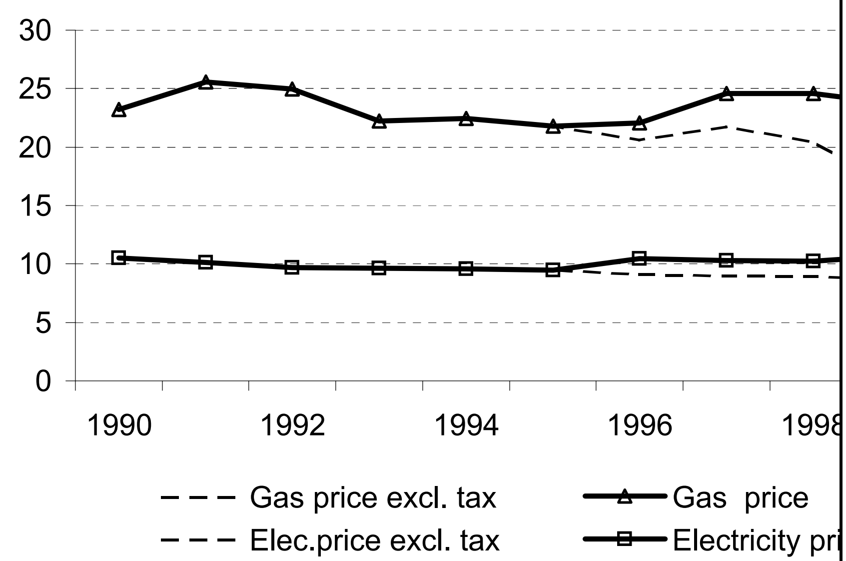
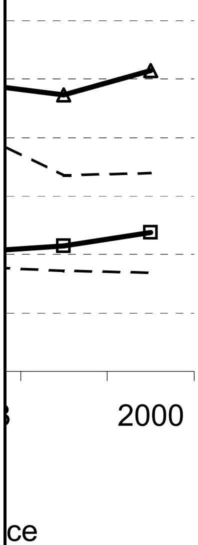

0.8
1
1.2
1.4
efit ratio

Figure-6-prices

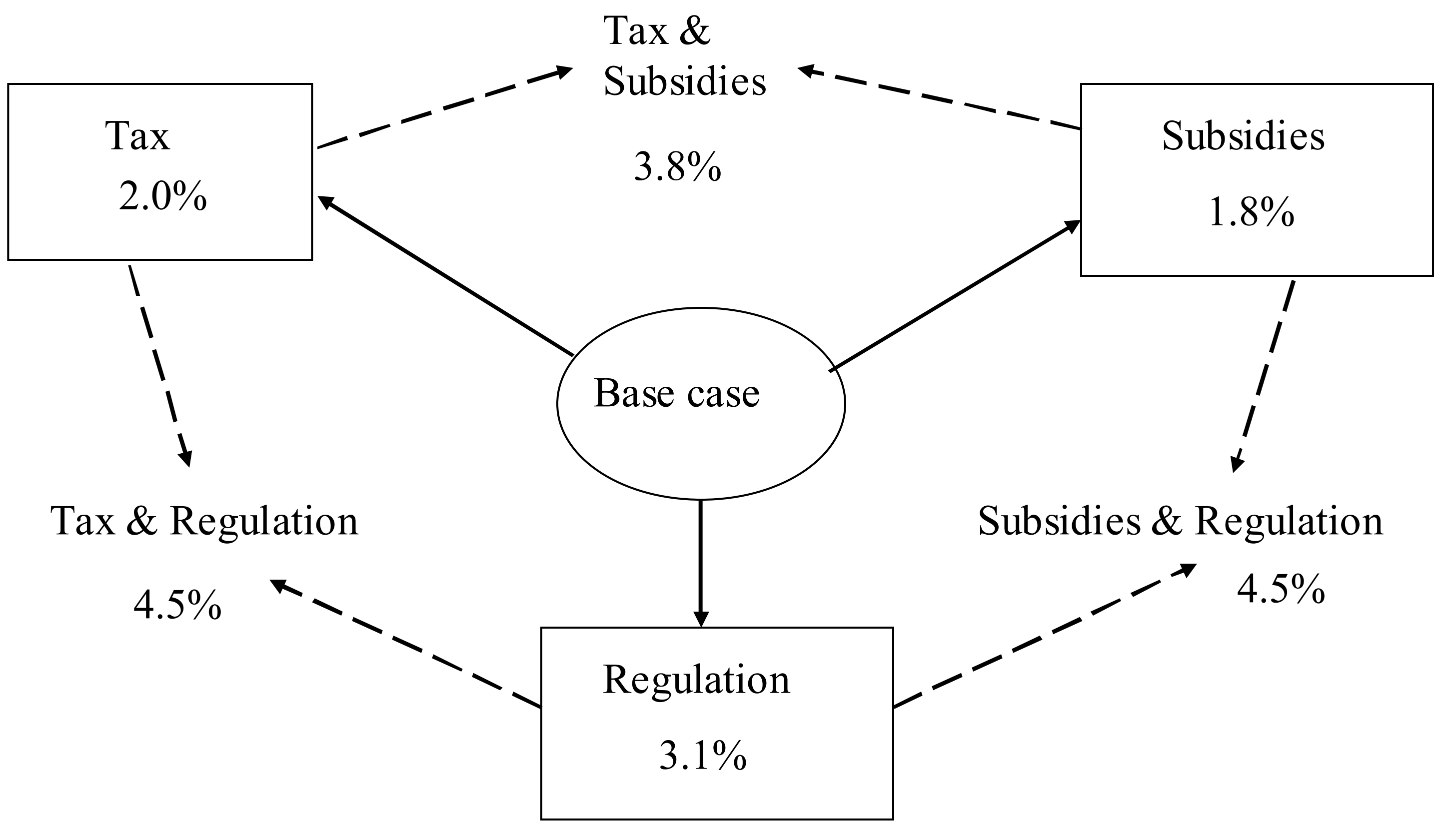
Ct-1990	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Gasprice	**51.19**	**56.37**	**55.02**	**48.94**	**49.52**	**48.03**	**45.38**	**47.87**
Gasprice incl. Taxes	**51.19**	**56.37**	**55.02**	**48.94**	**49.52**	**48.03**	**48.62**	**54.22**
Electricity price	**23.11**	**22.32**	**21.32**	**21.24**	**21.09**	**20.92**	**20.01**	**19.77**
Elec.price incl. Taxes	**23.11**	**22.32**	**21.32**	**21.24**	**21.09**	**20.92**	**22.99**	**22.70**
Tax gas	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**3.24**	**6.34**
Tax electricity	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**2.99**	**2.92**
Ct-1990								
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Gas price excl. tax	23.23	25.58	24.97	22.21	22.47	21.80	20.59	21.72
Gas price	23.23	25.58	24.97	22.21	22.47	21.80	22.06	24.60
Elec.price excl. tax	10.49	10.13	9.67	9.64	9.57	9.49	9.08	8.97
Electricity price	10.49	10.13	9.67	9.64	9.57	9.49	10.43	10.30



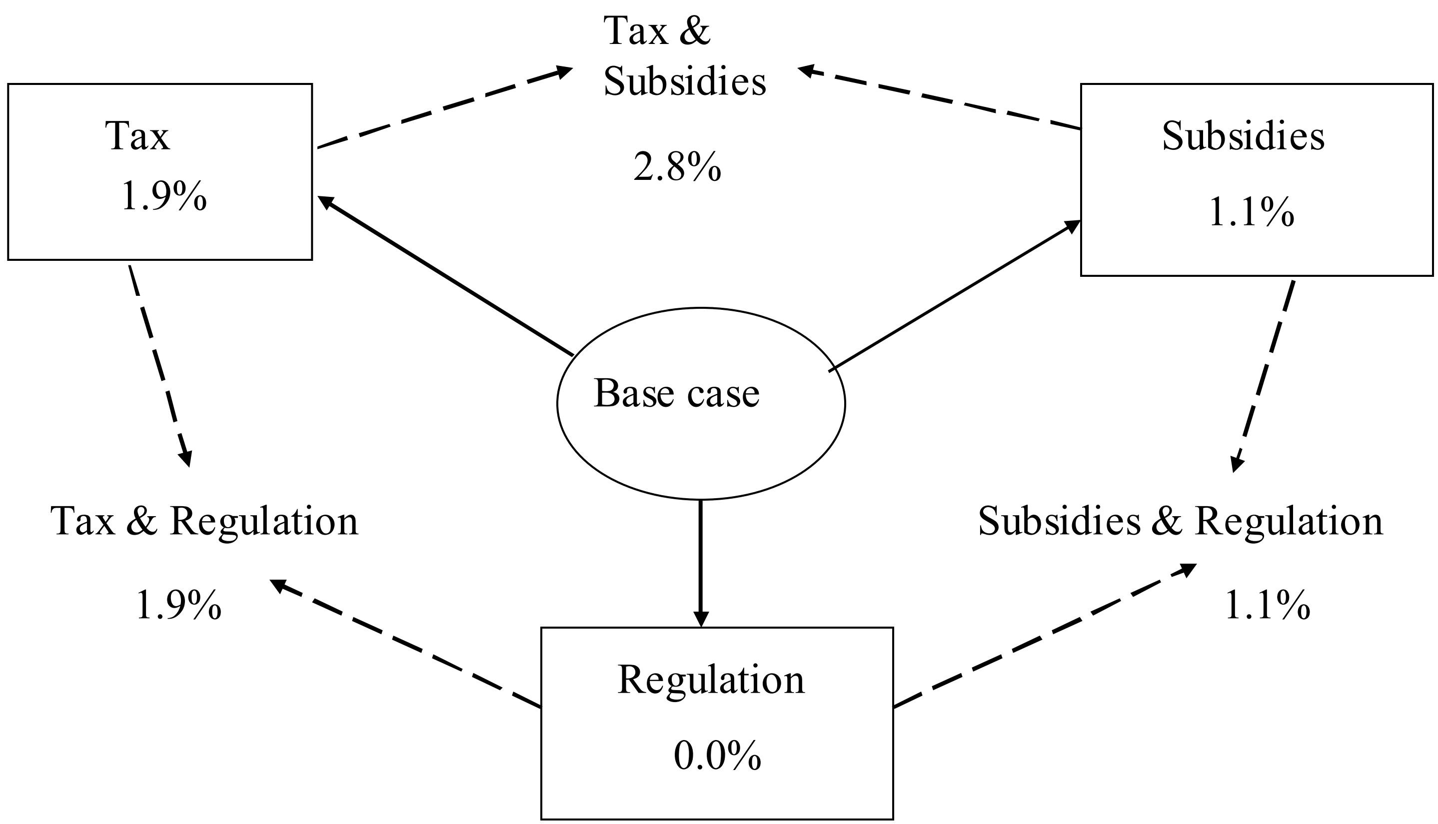
1998	*1999*	*2000*
44.95	**36.92**	**37.44**
54.21	**52.11**	**56.74**
19.64	**18.96**	**18.54**
22.51	**23.67**	**26.14**
9.26	**15.20**	**19.30**
2.87	**4.71**	**7.60**
1998	*1999*	*2000*
20.40	16.75	16.99
24.60	23.65	25.75
8.91	8.60	8.41
10.22	10.74	11.86



Figure(s)


Tax &
Subsidies
3.8%
Tax
2.0%
Subsidies
1.8%
Base case
Tax & Regulation
4.5%
Subsidies & Regulation
4.5%
Regulation
3.1%

1e = gas en 2e = elektr



Tax &
Subsidies
2.8%
Tax
1.9%
Subsidies
1.1%
Base case
Tax & Regulation
1.9%
Subsidies & Regulation
1.1%
Regulation
0.0%

Table(s)

Table 1: Contribution of measure types with respect to the conditions for implementation and proper utilization of saving options

	Implementation				Proper utilization
	Available for application	Known to appliers	Restrictions lifted	Motivation to invest	
Measure type:					
Legislation					
- implementation	X	X	X	X	
- utilization					X
- labels		X		X	
Taxes				X	X
Support					
- financial		X		X	
- audits		X			
Information					
- options		X		X	
- utilization					X
Agreements		X	X	X	
Procurement	X	X		X	
R&D-facilities	X		X	X	
Emission-trading				X	

Table 2: Overview of policy measures for household energy efficiency in the Netherlands 1990-2003

	Policy measure	Application	Target group
1	Building Code insulation 1991	New dwelling	Builders
2	Energy Performance New dwelling (EPN)	“ “	Builders
3	Sustainable Building options (DuBo)	“ “	Builders
4	Optimal Energy Infrastructure (EPL/OEI)	“ “	Builders
5	Novem demonstration programmes	“ “	Builders
6	Building Code insulation 2002	“ “	Builders
7	Renovation/saving subsidies	Old dwelling	Housing associations
8	Retrofitting program rented houses	“ “	Housing associations
9	Advice energy savings (EPA)	“ “	Owner/Associations
10	Energy efficiency labels	Appliances	Consumers
11	Action Plan distribution sector (MAP)	Various	All parties
12	Regulatory Energy Tax (REB)	General	Consumer/Owner
13	Climate Campaign ‘21	General	Consumers/Municipality
14	Agreement housing associations (LTA)	Dwellings	Housing associations
15	Energy Premium Scheme (EPR)	General	Consumer/Owner

Table 3: Strong interaction effects between important policy measures in Dutch households

	First measure	Second measure	Type of interaction
A	Building codes	Performance standard	Mitigating
B	Performance standard	Energy tax	Mitigating
C	MAP-subsidies	Energy tax	Reinforcing
D	Energy tax	Energy premiums	Mitigating
E	Advice energy savings	Energy premiums	Reinforcing
F	Labels appliances	Energy premiums	Reinforcing

Table 4 Development of main input variables for simulation of household energy consumption

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

Table 5: Overview of household energy consumption developments 1990-2000 (*)

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

(*) Corrected for yearly variations in temperature during the heating season

Table 6: Energy savings owing to a regulatory tax, investment subsidies, regulation, and the combination for 1995 and 2000

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

Table(s)

Table A.1: Contribution of policy measures with respect to meeting the conditions for implementation and proper utilization of saving options for households in the Netherlands

	Measure type	Implementation				Proper utilization
		Available for application	Known to appliers	Res-trictions lifted	Motivation to invest	
1	Building code-1991	X	X	X	X	
2	Performance standard	X	X	X	X	
3	Sustainable options	X	X			
4	Optimal infrastructure		X	X	X	
5	Demonstration programs	X	X		X	
6	Building code-2002	X	X	X	X	
7	Renovation subsidies				X	
8	Retrofit-program		X	X		
9	Advice energy savings		X			
10	Labels appliances		X			
11a	MAP-new dwellings		X	X	X	
11b	MAP-old dwellings		X	X	X	X
11c	MAP-appliances		X		X	
12	Energy tax				X	X
13	Climate campaign		X		X	X
14	Agreement housing		X	X	X	
15	Energy premiums		X		X	

Table(s)

Table A.2: Rating of the interaction between policy measures to stimulate energy savings in Dutch households in the period 1990-2003

No	First measure	Second measure	Common saving options	Effect on conditions overlap	complement	Time overlap	Total rating	Comments	Indirect
1	EPN	BD1991	insulation	A/K/R/M	x	61%	- - -		
2	DuBO	BD1991	insulation	A/K	x	66%	- -		
3	DuBo	EPN	insulation, boiler, heat-recovery	A/K	x	89%	- - -		
4	EPL	BD1991	X				0	Different options	
5	EPL	EPN	epc-measures	K/R/M	x	94%	- -		Post-mitigating
6	EPL	DuBo	large heat distr.projects	K	R/M-A	89%	0		
7	Demonstr	BD1991	insulation	A/K/M	x	79%	0	Time lag	Pre-reinforcing
8	Demonstr	EPN	insulation, boiler, heat-recovery	A/K/M	x	57%	0	Time lag	Pre-reinforcing
9	Demonstr	DuBo	insulation, boiler, heat pump/rec.	A/K	x	64%	0	Time lag	Pre-reinforcing
10	Demonstr	EPL	heat pump, etc.	K/M	A-R	50%	0	Time lag	
11	BD2002	EPN	insulation	A/K/R/M	x	63%	- - -		
12	BD2002	DuBo	insulation	A/K	x	61%	- - -		
13	BD2002	EPL	X				0	Different options	
14	BD2002	Demonstr	insulation	A/K/M	x	57%	0	Time lag	Pre-reinforcing
15	MAP-new	BD1991	X				0	Different options	
16	MAP-new	EPN	options for lower epc	K/R/M	x	44%	- -		Pre-reinforcing
17	MAP-new	DuBO	heat pump/recovery/distribution	K	R/M-A	53%	+		
18	MAP-new	EPL	large heat distrib.projects	K/R/M	x	35%	0	MAP-new >1997 = 0	
19	MAP-new	Demonstr	heat pump, etc.	K/M	R-A	86%	+	Overlap M needed	
20	Retrofit	Renovate	insulation, boiler social rented	x	K/R-M	40%	+++		
21	EPA	Retrofit	insulation, boiler	K	x	18%	-		
22	MAP-old	Renovate	insulation, boiler rented	(M)	K/R-M	40%	0	Mutual excl.subsidies	
23	MAP-old	Retrofit	insulation, boiler social rented	(K/R)	M - K	70%	++	No overlap K/R	
24	MAP-old	EPA	insulation, boiler	(K)	R/M-K	9%	+	No overlap K in time	
25	Labels	MAP-appl.	white appliances	x	K-M	50%	+	Few subsidies	
26	REB	BD1991	insulation	M	x	61%	-	BD-overlap << EPN (27)	
27	REB	EPN	insulation, boiler, heat-recovery	M	x	100%	- - -		
28	REB	DuBO	all DuBo-options	x	M - A/K	94%	+		
29	REB	EPL	heat pump/distribution	M	M-K/R	88%	+	Overlap M needed	
30	REB	Demonstr	advanced options	M	M-A/K	79%	+	Overlap M needed	
31	REB	BD2002	insulation	M	x	25%	0	BD-overlap << EPN (27)	
32	REB	MAP-new	heat pump/recovery/distribution	M	M-K/R	50%	+++	Overlap M needed	
33	REB	Renovate	insulation, boiler	M	x	11%	0		

34	REB	Retrofit	insulation, boiler	x	M-K/R	56%	+	
35	REB	EPA	insulation, boiler	x	M-K	50%	+	
36	REB	MAP-old	insulation, boiler	M/P	M-K/R	50%	- -	Overlap stronger
37	REB	MAP-appl.	appliances	M	M-K	50%	- -	Overlap stronger
38	REB	Labels	appliances	x	M-K	100%	++	
39	Campaign	BD1991	insulation	K/M	x	55%	0	Focus on different actors
40	Campaign	EPN	insulation, boiler, heat-recovery	K/M	x	94%	0	Focus on different actors
41	Campaign	DuBO	all DuBo-options	K	M - A	89%	+	
42	Campaign	EPL	heat pump/distribution	K/M	x	100%	0	Focus on different actors
43	Campaign	Demonstr	heat pump/distribution	K/M	M - A	75%	0	Different M
44	Campaign	BD2002	insulation	K/M	x	29%	0	Focus on different actors
45	Campaign	MAP-new	heat pump/distribution	K/M	x	44%	0	Focus on different actors
46	Campaign	Renovate	insulation, boiler rented	M	x	31%	0	Focus on different actors
47	Campaign	Retrofit	insulation, boiler rented	K	M - R	49%	0	Focus on different actors
48	Campaign	EPA	insulation, boiler	K	x	57%	- -	
49	Campaign	MAP-old	insulation, boiler	K/M/P	M-R	44%	+	Different M
50	Campaign	MAP-appl.	appliances	K/M	M-K	44%	+	Different M
51	Campaign	Labels	appliances	K	M-K	94%	+	
52	LTA	BD1991	X				0	Overlap LTA-new = 0
53	LTA	EPN	X				0	LTA-options new = EPN+
54	LTA	DuBO	advanced options rented new	K	R/M-A	67%	0	Few same applications
55	LTA	EPL	heat distribution new rented	K/R/M	x	71%	0	Few same applications
56	LTA	Demonstr	new options rented	K/M	R-A	61%	0	Few same applications
57	LTA	MAP-new	advanced options new rented	(M)/K/R	x	65%	0	No overlap M for LTA-new
58	LTA	Retrofit	insulation, boiler rented (old)	K/R	x	71%	- - -	Overriding M-LTA
59	LTA	EPA	insulation, boiler rented (old)	K	x	25%	- - -	Overriding M-LTA
60	LTA	MAP-old	insulation, boiler rented (old)	K/R	x	65%	- -	Overriding M-LTA
61	EPR	BD1991	X				0	Different options
62	EPR	EPN	heat pump new dwellings	K/M	x	75%	-	EPR-new very few
63	EPR	DuBO	heat pump new dwellings	K	M-A	72%	0	
64	EPR	EPL	heat pump new dwellings	K/M	x	79%	0	Different actors
65	EPR	Demonstr	various options new dwellings	K/M	M-A	64%	++	Complement stronger
66	EPR	BD2002	X				0	Different options
67	EPR	MAP-new	X				0	EPR from 2002 > 2000
68	EPR	Retrofit	insulation, boiler old dwellings	K	M-R	18%	0	
69	EPR	EPA	insulation, boiler old dwellings	K	M-K	100%	+++	Complement stronger
70	EPR	MAP-old	options old dwellings	K/M	x	16%	0	

71	EPR	MAP-appl.	some appliances	K/M	x	16%	0	
72	EPR	Labels	most efficient appliances	K	M-K	75%	+++	Complement stronger
73	EPR	REB	appliances, insulation old	M	x	75%	- - -	
74	EPR	Campaign	appliances, insulation	K/M	M-K	79%	+	Different M
75	EPR	LTA	insulation rented old	K/M	x	21%	-	
76	Campaign	REB	all Campaign issues	M/P	K-M	94%	++	Complem.much stronger
77	LTA	REB	options rented dwellings	M	x	69%	- -	
78	LTA	Campaign	options rented dwellings	K/M	x	71%	0	Focus on different actors

EGY-D-05-00035 **October 2005**

Actual interaction effects between policy measures for energy efficiency - A qualitative matrix method and quantitative simulation results for households

P.G.M. Boonekamp, Energy research Centre of the Netherlands (ECN), Unit Policy Studies

Reply to comments of the first referee

(Actions in **bold).**

a. *Generic interaction matrix not useful*:

Partly the reviewer is right. Under the subsection "Optimal combinations of policy measure types" it is already remarked that "that the optimal set of policy measures to be applied is dependent on the type of saving option". However, this does not mean that the method cannot be use d as a general tool to map interaction. It means that it should be applied to actual sets of policy measures in the past. Then there is no uncertainty about the specific content of each measure. Also the results on penetration of saving measures are known (at least in the Netherlands for this case). In that case it is possible to state that a double financial incentive is needed to implement advanced saving options, while the same double incentive is rated as "overlap" in case of state-of-the-art saving options. Of course this demands that the composer of the matrix has a thorough knowledge of the set of measures and the energy developments in the sector of analysis. On the other side, it must be stressed that in many cases the character of interaction are quite obvious, e.g. between energy taxes and obligatory saving measures.

The matrix of general policy measures (figure 3) was meant to introduce the matrix-method to the reader. However, in the light of the earlier discussion, this figure and matching text have been omitted. Now only interaction is specified and analyzed for the actual case. Moreover, to stress that this method is meant to select the interesting interaction-cases for further in-depth analysis, the term "possible interaction" is used in the article, where appropriate. To increase the transparency of the matrix-composition, two tables are presented in a new appendix. The first table specifies the influence of the actual policy measures on meeting the conditions (as done in table 1 earlier). From this table it is clear how two actual measures overlap and/or complement each other as to meeting the conditions. In the second table all 77 interaction combinations are presented, with the information that has led to the final rating. For each combination it is specified which common saving options both measures aim at. This facilitates the specific rating as discussed earlier (this information highlights some zero ratings because the specific content of the two measures shows no common saving options). Further the overlap and/or complement cases as to conditions are shown. If there is only overlap or only complement the rating is often quite clear. If both are present, this often results in a marginal or zero rating. However, further analysis reveals that in some cases the complement and overlap are not of the same strength (e.g. for EPR-subsidy and EPA-advice the overlapping information-role of EPR and EPA is far less important then the

complementing motivation/subsidy and information/advice mix). The overlap in time of two measures has been calculated from the starting and end-year (or 2003 as last year). This is the mean of the overlap related to the period for each of the two measures. This information has only been used to adapt the rating in case of very short overlapping in time. In six cases indirect interaction is detected, which has not been decisive for the rating. Finally the comments contain some specific knowledge on the working of combinations (on specific saving options) that has led to fine-tuning of some ratings.
As with all methods presented in literature my matrix-method demands knowledge of the field of analysis and a careful application. I hope that the adaptations make it clear that it is a general approach (line of analysis and the factors to look at) as well as a tailored analysis based on experience.

b. Broad definition of restriction
Restriction is indeed broadly defined in chapter 2, as this analysis is meant to sketch the general framework. However, in the application, described in chapter 4, the content of both policy measures and the saving options are known. Then it becomes clear what the restriction are, and how the policy measures meet this condition. E.g. the landlord-tenant restriction is a important reason to introduce the policy measure "agreement (LTA) with housing corporations".

c. Interaction between conditions
This is often true. If a measure provides much motivation, the applier will better search for the information. However, this information must be available in some form. So, it is the combination of information and motivation that will decide the implementation success. **As it is already trying to estimate the direct influence of policy measures on meeting the conditions for implementation, this kind of interaction has been left aside**.

d. Column headings in table 1:
The headings have been extended in table 1 and table A.1. Figure 1 has been adapted in the same way.

e. First, second and third order effects.
First order effects represent the interaction between the two policy measures themselves. As this effect is already described the text has been shortened. **Only the examples of earlier policy measures and second order effects are presented. The third order effect has been omitted, being of no practical meaning in the further analysis. The example for the second order effect is more clearly described as an actual development for the Netherlands**.

f. Ybema-example
The combination of labels and subsidies made it attractive for Dutch consumers to buy very efficient appliances. Therefore it became attractive for retailers to offer (almost) only these appliances. However, for Europe as a whole this was an isolated effect that did not really change the total package of appliances produced in Europe. Therefore I do not agree that the combination did not work. **Because another reference, an evaluation of the "Belastingdienst" shows this**

transformation of the appliance market more clearly, reference Ybema has been replaced by the reference "Belastingdienst".

g. REB-tax (p.20)

This was meant in the context of implementation of extra saving options, and not in the more general sense (rebound and behavior). **The sentence has been adapted "Given the strong EPN demands the REB does not lead to implementation of extra energy efficiency measures in new dwellings"**

h. *Discount rates and steepness in formula*

The discount-rate has been set at 8% and the steepness has three values that effect the form of the S-curve (however it is difficult to explain the effect very shortly as it effects mainly the penetration for a CBR that differs substantially from the acceptable CBR). Moreover, for each saving options the parameters are adapted to the observed penetration patterns. In principle, with another discount-rate (and a new validation of the model) about the same results should be found.

i. Showerheads and double glazing

According to the yearly surveys the penetration of water saving shower heads is only 30% while they are already profitable because of the avoided cost of less water consumption. Actually, (in economic terms) all energy savings are for free! This penetration-CBR relation can only be modeled by introducing a low acceptable CBR. Double glazing has reached more than 80% penetration, despite the fact that it is often not financially attractive, especially in bedrooms. Therefore a high acceptable CBR must be used to simulate actual penetration trends.

j. Abbreviations, etc.

This has been adapted in the text.

k. *Probably*

The sentence is adapted: "Further analysis reveals that this is due …". The stated cause for the observed difference was already deducted from the detailed results, but presented as if this should be done still.

l. *Policy recommendations*.

Agree with this reasoning. It is already mentioned earlier that other reasons can make interaction acceptable. **The sentence "Sometimes the overlapping combination is still effective in relation to the costs" has been added**.

EGY-D-05-00035 **October 2005**

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P.G.M. Boonekamp, Energy research Centre of the Netherlands (ECN), Unit Policy Studies

Reply to comments of the second referee

Suggestion to highlight factor analysis as an alternative:
This is an interesting suggestion, but given the length of the original article and the extensions, due to the comments of the other referees, I'm afraid that there is no room to handle this issue in sufficient detail.

EGY-D-05-00035 **October 2005**

Actual interaction effects between policy measures for energy efficiency - A qualitative matrix method and quantitative simulation results for households

P.G.M. Boonekamp, Energy research Centre of the Netherlands (ECN), Unit Policy Studies

Reply to comments of the third referee

(Actions in **bold).**

a. *Uncertainty in quantitative results*:

I'm very well aware of uncertainties in the calculation of energy savings for the reason the referee provides. In my article "Evaluation of methods used to determine realised energy savings" to be published in Energy Policy, I present a 30% s uncertainty margin in total energy savings for the Netherlands for a decomposition method that is often used to calculate savings. See for background the report "Onzekerheid in energiebesparingscijfers- Achtergrondrapport bij"Gerealiseerde energiebesparing 1995-2002' (Uncertainty in energy saving figures –Background report to "Realised energy savings 1995-2002"), written by A. Gijsen (RIVM) and myself.
However, the foregoing regards top-down methods, where an uncertain reference trend and an uncertain actual trend are compared, and the relative small difference represents energy savings. The simulation presented here regards a bottom-up method where total energy savings result from the increased penetration of a great number of saving options. The savings per saving measure are fairly well known from research executed as part of new subsidy schemes; the increase in penetration rates is known very well from yearly surveys. As described in the article, these observed penetration rates has been used to adapt the penetration algorithms per saving option in such a way that observed and calculated penetration trends match. Therefore the simulation model is able to provide realized total energy savings by comparing the actual energy trend with that of a simulation, using penetration rates at base year level. Even if there would be some uncertainties in the calculated savings per saving options, the law of great numbers will diminish the deviation in total calculated savings to a large extent. So, it is believed that the calculated total energy savings are reasonably accurate, and much more accurate than that of generally used top-down methods.

With respect to the saving effects in the simulation variants, with and without different types of policy measures, the following can be said. The saving due to one or more policy measures is the difference between the results of two simulations. Uncertainty about driving factors or actual energy consumption do not play a role, as the model provides exact figures based on the same riving factors. The question is: does the simulation model present the real savings do to a change in policy measures. Given the penetration-algorithms for each saving option (that have been fitted to actual detailed developments in the period 1990-2000), it is supposed that these algorithms also describe the saving developments for changes in deployed policy measures. Again, the total change in savings is the result of a number of changes for the penetration of various saving options. It cannot be proved directly that the calculated total change in savings is right; this believe is based on the good simulation of past developments at a detailed level. This reasoning is valid for most models that predict future trends and that have been validated by fitting the parameters to historic trends (e.g economic models with price- and income-elasticities). **See extra paragraph on "Uncertainty in the results of the analysis" in chapter 7.**

b. *Interactions, indirect effects and behavioral savings*

The analysis has focused on the direct effect of (combinations of) three policy measures on the penetration of saving options. Not regarded are the direct effect of these measures on behavioral savings and indirect effects. The policy measures regulation and subsidies do not have a direct effect on behavioral savings, but energy taxes could have. However, as discussed in my article on price elasticities in Energy policy this effect is estimated to be quite small due to the low elasticity values in the Netherlands. Moreover, it is claimed that short term price reactions are not the result of daily behavior but of choosing more efficient systems and appliances (which are covered in the simulation). The indirect effects of implementing saving options are second order effects and the rebound effect. Second order effects, such as less profitable high-efficiency boilers due to subsidized insulation measures are taken into account quite well in the simulation model. The rebound-effect can take three forms: more intense use of the efficient system, buying extra energy using systems or spending the money saved on things that demand energy to be produced. The main example of the first form is higher thermostat setting after insulation/boiler measures. As energy poverty is hardly a problem in the Netherlands, thermostat settings were already such high that this did not increase much after the saving measures. Examples of the second form are extra CFL's and appliances. According to literature the introduction of very efficient CFL's has probably contributed to increased use of light in gardens and against burglary. This effect has not been accounted for when changing the policy measure "subsidies" and "energy taxes". The spending of money on other products or services (that cause extra energy use) falls outside the scope of this analysis. **See extra paragraph "Other effects left aside" in chapter 7.** Given the extra text on behavioral savings in chapter 7 the text on this subject on page 4 has been omitted.

c. *Page 10: too rigid conclusion*

Effectiveness in a broader context can lead to other "optimal" combinations of policy measures than the combinations only based on the "optimality" criterium used here. Therefore an extra disclaimer has been added to the paragraph: **As touched upon in the preceding paragraph and in chapter 4, in practice the overall optimality of a combination of policy measures will depend on other factors too.**

d. *Consistent terms:*

In table 1 the MURE-terms for policy measure types have been copied, among which legislation. This term should be used in the first part of the article. In the second part of the article the term "regulation" has been used to take together three policy measures on gas use for space heating However, in some case this difference was not followed. **Where appropriate the wrong terms have been**

replaced. The term “standard” is used for specific policy measures. **“Standard” is deleted as an example of a policy measure type in the rules to construct the matrix** (as well as the other example). With regard to an earlier description of the performance standards the following sentence has been inserted at the beginning of chapter 4: **Some policy measures (energy tax, various subsidy schemes, building codes, performance standards and agreement) are described more extensively in chapter 6.**

e. Percentages in table 6:
One of the reasons to present total energy consumption figures in table 5 was the possibility to put the PJ-effects in table 6 into perspective. To avoid too many figures in table 6 it has been decided to present the percentages in the text.

f. Explanation of table 1 (10 sentences at start of page 7).
It is not quite clear to me what is the problem. But the sentence “**The measures of an obligatory nature, such as (performance) standards, often focus on the investment decision. But some of these measures focus at the later utilization phase (obligatory maintenance) or the preceding phase when information is needed (mandatory labels)”** has been removed as this already touches upon the influence of policy measures on conditions that is dealt with later.

g. Rebound-effect (p.14)
The matrix for the general set of measures (figure 3) has been omitted in reaction to comments of the first referee. Therefore the remark on the rebound effect is no longer made here. See extra paragraph in chapter 7 (answer b).

h. Local climate campaigns (p.17)
Next to mass media campaigns also activities at municipal level were set up. **The sentence has been adapted: “Some measures also regard local activities (climate campaign) ….”**

i. *Overall energy consumption trends*
Structural change in the economy towards more service and information technology regards developments at the national level. However, it is not clear to me what this means for household energy consumption, being the subject of this article. At the end of the paragraph some factors behind the growth of energy consumption are already mentioned shortly. To avoid confusion the title has been changed to: “Overall results **for household** energy consumption’.

j. Base case (section 6)
To clarify the introduction of the base case the text at the start of chapter 6 has been adapted. The results for the base case are also calculated values and not realizations. Therefore the sentence has been adapted somewhat: “In this base case the ***calculated*** level of fuel and electricity consumption is higher than the actual consumption, ***indicating*** that …”

k. Splitting of MAP in table 2.
Table 2 gives an overview of policy measures as such. The split of the MAP-measure should be presented as part of the matrix-method. **To avoid confusion between table 2 and matching text, the sentence on splitting the MAP-**

measure has been shift to the next paragraph. The extended list of policy measures, used in the analysis, is presented in the new A.1 table (that was introduced in reaction to the comment of the other referee).

l. *Explaining regulation*

In chapter 6 the content of regulation is described rather extensive in the paragraph "Saving effect of regulation". However, at the start of chapter 5 regulation is described probably too shortly. **The text has been adapted here as follows: "- regulation of gas use for space heating (building code and performance standards for new dwellings and agreement with housing associations on existing dwellings)."**

m. *Abbreviations and country in literature.*

The references have been updated according to the rules of the editor, including the abbreviations of institutes (although I think that this should not be a problem, as all these institutes or organizations can be found with full name on the internet.

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Actual interaction effects between policy measures for energy efficiency -
A qualitative matrix method and quantitative simulation results for households

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Abstract

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

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Key words: policy measures; energy savings; interaction; households.

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1. Introduction

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

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Remarks on (possible) policy measure interaction are dutifully made in ex-post evaluations, e.g. Vermeulen [37], or discussed for individual cases in Gunningham and Grabosky [15] or Jacobsen [18]. In ex-ante evaluations the interaction between specific combinations of policy measures is analysed too. Recently this subject has attracted new interest because of the set up of an European emission trading system. The interaction mechanism with national policy is extensively analysed in Sorell [33]. However, a general and quantitative method to investigate possible interaction effects is missing so far. The methodological problem of unravelling the effects of various policy measures, which simultaneously affect energy consumption, has not been solved yet. According to Sorrell [33] the analysis of interaction still asks for a systematic approach. In contrast with ex-post evaluations many scenario studies use energy models that can cope with a combination of policy measures, e.g. PRIMES of Capros [9] and the model of Verbruggen and Goetghebuer [36]. But here too the interaction effects between various policy measures are scarcely treated explicitly.

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From a policy viewpoint there is a pressing need to look at interaction effects. In most developed countries a great number of policy measures for energy savings was introduced in

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the nineties. In Europe not only national governments, but the EU as well have become more and more active in this field, as can be seen in the policy measures database MURE [25]. With more measures deployed, interaction between measures can very well become stronger too. If interaction effects become more and more negative, i.e. the total effect is less than the sum of the separate effects, one could say that energy policy as a whole is becoming less effective. New methods to investigate possible interaction effects in sets of policy measures are needed, both in a qualitative and a quantitative manner.

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

In section 2 the mechanisms underlying interaction effects of policy measures for energy savings are analysed. This information is used in section 3 to develop a method to map possible interaction effects qualitatively for combinations policy measures. In section 4 the method is applied to the set of actual policy measures for households in the Netherlands, regarding the period 1990-2003. The next sections are devoted to the quantification of interaction effects. The focus lies on the three most important ones: a regulatory tax on energy consumption, investment subsidies on saving options and regulation of energy use for space heating. In section 5 the key features of the applied bottom-up household simulation model are described. The quantitative interaction results are presented in section 6 for the period 1990-2000. After discussion of the results in section 7 conclusions and policy observations follow.

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2. Application of saving options using policy measures

In the following analysis it is assumed that the various policy measures try to realise energy savings by stimulating the application of so-called saving options, which either reduce energy demand or increase the conversion efficiency. Most measures focus on the implementation of these saving options, but some measures (e.g. mandatory maintenance) regard a proper utilization of the energy system. The general framework developed here is applicable to the end-use sectors households, industry, transport and services.

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Conditions for a successful implementation of saving options

In literature, e.g. Blok [4], Greene [13], Hennicke and Ramesohl [16], Jochem [19] or Velthuijsen [35], many factors on the implementation of saving options are mentioned. Here the realization is assumed to be dependent on the following set of conditions:

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1. The saving option must be available for application.

2. The option must be sufficiently known to the appliers.

3. Restrictions that prevent a choice for the saving option must be lifted.

4. The decision maker must become motivated to take a positive investment decision.

As illustrated in figure 1, all four conditions have to be met before the saving option will actually be implemented.

Figure 1

For proven saving options **availability** is hardly an issue; however, when demand is growing very fast the supply of the efficient systems can pose a (temporally) problem. For new options 'availability' can have different meanings. The first one, the proof of the concept after

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fundamental research, is not what is meant here. The saving option should be technically grown up and provide the energy-function in (almost) the same manner as the reference system it replaces. However, it need not serve all applications from the start. Often it suffices to supply a niche market; for instance, in case of an electrical heat pump, only new dwellings which have no connection to the gas grid. Thus availability of new saving options regards market ready saving options, at least for some applications.

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

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An important **restriction** for current energy applications is the remaining lifetime of the existing energy using systems. Normally decisions on implementing a more energy efficient system are taken at the 'natural moment' only, when old equipment must be replaced. In Velthuijsen [35] this is one of often mentioned barriers for energy saving, as the earlier investment is not yet depreciated. However, retrofit-options can be installed at any time. Another restriction can be the split between ownership/investment and utilization/benefits. In the case with rented office buildings or shop malls this hinders costly investments in energy savings. Finally a number of specific restrictions can be present, such as lack of space for the system, scarcity of investment money or lack of personnel resources (see Velthuijsen [35]).

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Unless legal pressure forces the implementation of saving options, the decision maker should **become motivated** to choose the more efficient system. The most cited motivation is the financial benefit resulting from the implementation of the saving option. This motivation can be enhanced by introducing a tax on energy consumption; the higher financial value of energy saved shortens the pay back time. Another possibility is lowering the investment costs by providing investment subsidies. However, enhancing non-economic motivation to invest is possible too, for instance by increasing the general awareness of the greenhouse problem and its relation with energy use. Another way is the creation of social pressure by public campaigns. Hennicke and Ramesohl [16] mention the role of regional networks and the behaviour of the peer group. Sometimes a saving option creates its own investment motive, as is the case with the extra living comfort that is achieved by installing double-glazing.

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

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Influence of policy measures on the conditions

Various policy measure types are used to stimulate the application of saving options. Overviews are given in Braathen and Serret [8], Gunningham and Grabosky [15], Oosterhuis [29], Vermeulen [37] and WRR [40]. In table 1 a list of policy measure types according to

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MURE [24] is presented; this set represents common measures in European countries. These policy measures can be split into different types, from very pressing (legislation on implementation) to no engagement whatsoever (public campaigns on behaviour). Financial measures consist of energy taxes, investment subsidies or other types of financial support, such as tax deductions or low interest rates. Information measures range from client-specific advice and education of fitters to TV-campaigns to raise awareness on the subject of energy savings. Agreements between government and energy users or other parties generally do not focus at specific saving options but at total energy use in a sector. The obligatory character depends on the formulation of the agreement and country specific habits. Procurement focuses on co-ordinated action of the various parties involved with respect to a specific saving option. Both agreements and procurement are often used in combination with other measures. Stimulation of research and development (R&D) was added to the list of MURE-measures; it must be stressed that this regards not fundamental research but demonstration projects or additional development to provide a market ready product. Finally the policy measure 'emission trading', which was recently introduced in the EU, was added to the list of policy measures (see Sijm and Sorell [32]).

Table 1

The columns in table 1 represent the conditions; the contribution of each policy measure in meeting the conditions is indicated with crosses. A general observation, which can be drawn from the table, is that most common policy measures are designed to influence investment decisions, especially motivation. It is clear too that there are few measures that affect both implementation (first four conditions) and utilization (fifth condition). Only energy taxes will by nature affect both. The effect of policy measures on each condition will now be highlighted into more detail.

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The **availability** of new market ready saving options is often dependent on additional R&D to deliver a marketable option. In the latter stages of development legislation (e.g. standards) could also speed up the development process according to Newell [25]. Financial measures could stimulate the creation of marketable options too, provided that they are considered to last over a long period. With the exception of high taxes on transport fuels, sustained for decades in various countries, this has not been the case for energy taxes in general. As Newell [25] shows, even the very high energy prices due to the oil crises were only partly responsible for increased energy efficiency. Finally procurement could speed up actual availability. The **knowledge** of saving options, not only about the concept but also about the actual performance, is most effectively increased by dedicated information, such as mandatory labels. Other possibilities are free information on specific saving options. Audits, agreements and procurement combine the search for saving opportunities with the provision of information on saving options. Vermeulen [35] and Blok [3] state that subsidies often focus attention of energy users to saving options and thus serve as an information source too. Regional and branch networks of ... [1]

The **availability** of new market ready saving options often is dependent on additional R&D to deliver a marketable option. In the latter stages of development, legislation (e.g. standards) can speed up the development process too according to Newell [27]. Financial measures can stimulate the creation of marketable options too, provided that they are considered to last over a long period. With the exception of high taxes on transport fuels, sustained for decades in various countries, this has not been the case for energy taxes in general. As Newell [27] shows, even the very high energy prices due to the oil crises were only partly responsible for increased energy efficiency. Finally procurement can speed up actual availability. The **knowledge** as to saving options, not only about the concept but also about the actual performance, is most effectively increased by dedicated information, such as mandatory labels. Other possibilities are free information on specific saving options. Audits, agreements and procurement combine the search for saving opportunities with the provision of information on saving options. Vermeulen [37] and Blok [4] state that subsidies often focus attention of energy users to saving options and thus serve as an information source too. Regional and branch networks of entrepreneurs are a means to provide knowledge as well, as parties often imitate each other's decisions (see Hennicke and Ramesohl [16]). The level of implementation already achieved contributes to knowledge of other users too. Actually all measures that stimulate the take-off of a new saving option contribute to it becoming more widely known. Finally, as stated earlier, legislation on the implementation of the saving option is an alternative because it cancels the need for information. **Restrictions** that hamper the implementation of saving options often are of a non-economic nature; therefore they cannot be lifted easily by financial measures according to Vermeulen [37]. Restrictions on performance can be overcome partly by adaptations to the saving option with additional R&D. For instance the development of a high-efficiency boiler with 'closed air circulation' has diminished the problems of placement to a great extent. Restrictions with respect to the decision making process sometimes can be circumvented with tailored policy measures. For rented dwellings this can be an agreement between housing associations, representatives of occupants and the government on the division of costs and benefits. But hardly any measure is able to influence the replacement moment when there is an opportunity to realise energy savings. Even legislation on more efficient systems does not influence directly the actual lifetime of the old systems (see policy measure descriptions in MURE [25]). Almost all measures can contribute to the **motivation** to invest in new saving options. Some provide an economic motivation, such as subsidies or taxes. Other measures, such as information campaigns and voluntary agreements, can create a social motivation. Legislation creates by definition the strongest "motivation". In the longer run this can be accomplished too in an indirect way, by some other measures mentioned that lead to the disappearance of less efficient options altogether. Influencing the **proper utilization** of energy systems asks for continuous action, as opposed to the one-time investment decision. Moreover, the users of the systems are more difficult to reach. In practice relatively few measures are available to ensure a proper utilization, for instance legislation on maintenance and monitoring of performance. Regular feedback can lead to avoiding unnecessary energy use for space heating according to Jensen [21], but for practical applications feedback costs have to be low. Groot [14] states that energy taxes lead to limited energy savings on daily energy use given the rather low short term price elasticities

As Sorrell [33] shows, it must be pointed out that the influence of policy measures does not only regard government and the energy users, but other actors in an implementation network as well. Shop owners that are pressed to sell more efficient appliances to their customers form an example of these other actors. The network of researchers, suppliers of technologies, energy advisers, user associations, public interest groups and subsidizing agencies, each with their own interests, defines the relationship between policy measures and implementation too. This means that the different conditions for realising saving options are not tied to the same actor. For instance the condition 'availability' often will be associated with the manufacturing of new appliances or systems, while the condition 'motivation' mostly regards the energy user. In this analysis the role of these other parties is taken into account when analysing possible interaction between policy measures.

Optimal combinations of policy measure types

Looking to the rows in table 1 it is clear that most policy measures do not cover all conditions. The influence of taxes is limited to one of the implementation conditions only; information and subsidies cover two implementation conditions. Legislation can affect all conditions for implementation but is not always acceptable or applicable. Therefore a combination of policy measures appears necessary to comply with all conditions. However, the importance of each condition differs per saving option. For instance, when a saving option is readily available and restrictions are minor, financial and information measures alone can do the job. Therefore the optimal set of policy measures to be applied is dependent on the type of saving option. With respect to the application of saving options one can formulate general rules to reach an optimal set of policy measures. From the preceding analysis the following general criteria for an optimal set follow:

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

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

As touched upon later in chapter 4, in practice the overall optimality of a combination of policy measures will depend on other factors too. Not all types of policy measures present are applicable to every saving option. In energy policy formulation many other factors play a role when choosing a policy measure type. For instance, legislation demands extensive ex-ante knowledge about the appropriateness of the regulated saving option; this knowledge is not always easy to provide. Subsidies often affect actors not belonging to the target group; too much free riders diminish the effectiveness of the measure (see Blok [4] and Vermeulen [37]).

3. Rating of possible interaction between two policy measures

The theoretical approach from section 2 is translated into a method that estimates, for any set of policy measures, the interaction effect between two measures. To this end the concept of optimal combinations is used to formulate a qualitative rating of the possible interaction effect between two measures.

Qualitative rating of the possible interaction effect between two measures

In this analysis the interaction effect regards the direct influence of one policy measure on the saving effect of another measure. Measures from an earlier period, such as R&D-programmes, can influence the effect of present policy measures but are not taken into account. Second order effects, such as the past agreement on industrial energy efficiency in the Netherlands which has provided for a structure that was beneficial to the new measure benchmarking, are not taken into account either.

The qualitative rating of the possible interaction effect proceeds as follows. The more two measures exert influence at the same condition(s) for implementation, the more they mitigate each other's effect. Depending on the specific situation this results in a relative rating:

marginal-, modest- or strong mitigating ('-', '- -' or '- - - '). The last rating can be characterised as 'too much of the same kind'. An example is the combination 'standards and subsidies' which provides more motivation to invest into a saving option than is actually needed. Their combined effect is less than the sum of the separate effects of both measures apart. These cases are also called 'overlapping' or, as in Braathen and Serret [8], 'counterproductive'. In the extreme opposite case two measures complement each other in such a way that the combined effect is much greater than the total effect of both measures apart. This synergetic combination is rated as strong reinforcing ('+++'). A Dutch example is the label system for appliances and the energy premium scheme. The evaluation in Belastingdienst [1] shows that this combination has led, in a few years only, to people purchasing efficient or very efficient appliances only. If the mutual reinforcement of two measures is less optimal the rating is modest or marginally reinforcing ('++'or '+'). In cases where it can be reasoned that one measure does not affect the saving effect of the other the rating '0' is given.

It must be stressed that the interaction analysis regards the common scope of two measures, e.g. in case of appliance standards and subsidies only the part of the subsidy scheme that is devoted to appliances. Because the quantification of interaction effects in literature often gives rise to confusion, the outcomes of interaction analysis for two measures A and B are illustrated in figure 2. For the mitigating combination the total saving effect is less than the sum of both effects; for the reinforcing combination this is the other way around. A neutral combination provides (almost) the same total savings as the sum of both measures. In Braathen and Serret [8] the combination of performance standards and labels for appliances is called 'complementary, as both measures contribute to more efficient appliances in their own way. Gunningham and Grabosky [15] present the fact that the saving effect of a measure is enhanced by another measure as positive. However figure 2 shows that an increase in total savings due to a second measure is valid for all combinations, even the mitigating one. The point is: how relates the combined effect to the sum of the effects of both measures on their own?

Figure 2

Non-existing interactions

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

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

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

Indirect interaction effects

In a few cases measures interact at another point than the implementation of saving options or the stimulation of a proper utilization. Post-implementation effects regard interaction between the resulting saving effects of two measures. E.g. insulation decreases heat demand; this lowers the benefits of installing a more efficient boiler, which is detrimental to the success of a policy measure directed at efficient boilers (see Sezgen [31]). Pre-implementation interaction regards a measure that affects another measure's potential to realise energy efficiency. For instance, Johannsen [22] finds that voluntary agreements have the (implicit) goal to forestall other policy measures, such as a CO_2 tax. Therefore the combination with a tax measure will touch the content of the agreement. The combination will deliver less effect than can be determined from the original content of both measures. In the few relevant cases the rating in the matrix is corrected as to these effects.

Summary of the rating method

The ratings of possible interaction effects in a set of policy measures can be:

- Mitigating: (-), (- -) or (- - -)
- Reinforcing: (+), (++) or (+++)
- Neutral: (0)
- Not possible (x).

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The rules to construct an interaction matrix can be summarised as follows:

1. Define the different measure-types,
2. Define (mutually excluding) applications in the sector that is analysed,
3. Attach to every policy measure the type, the application and year-in/year-out,
4. If necessary split measures with a broad scope into different applications,
5. If necessary split broadly defined measures into different types,
6. Determine the matrix-cells which show no overlap in time for the measures,
7. Determine the matrix-cells where the two measures focus on different applications or different actors,
8. For other cells, rate the possible interaction effect, taking into account the relevant conditions for successful implementation or proper utilization, the influence of both measures on these conditions and the overlap or synergy,
9. Correct for a relatively short overlap in time as to the period for both measures,
10. Correct for indirect interaction, such as the overlap in the resulting savings.

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

The method has been applied to the set of policy measures to promote energy efficiency in households in the Netherlands. In table 2 all measures in the period from 1990 on, and with a non-trivial saving effect, are presented. Some measures regard local activities as well (e.g. climate campaign) and others regard EU-wide legislation (mandatory appliance labels), but most measures are part of national energy policy. A description of these measures is given in MURE [25] and, into more detail for some measures, in Oosterhuis [29]. Some policy measures (energy tax, various subsidy schemes, building codes, performance standards and agreement) are described more extensively in chapter 6. The first ten measures aim at three specific applications: new dwellings (measures 1-6), existing dwellings (7-9) and appliances (10). The other measures (12-15) relate to various or all applications; this category 'General' encompasses taxes, agreements and general subsidy schemes.

Table 2

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

The influence of the policy measures on the various conditions is shown in the Appendix in table A.1. These results have been based on an extensive analysis of the content of the policy measures, the available evaluation reports and general literature mentioned earlier. The Environmental Action Plan (MAP) of energy distributors forms a special case because of its very broad scope. To facilitate the interaction analysis, this measure was split into three segments, directed at new dwellings (11a), existing dwellings (11b) and appliances (11c).

In figure 3 the matrix of possible interaction effects is shown, with the measures grouped according to application. The total number of combinations of two measures is (15+2)*(14+2)/2 = 136. The two extra measures in the formula originate from splitting the MAP-measure. The division by two is because only one half of the matrix should be specified. First attention is paid to the cells of the matrix where interaction is not possible because of different applications (dark shaded, with x). These cells encompass all combinations of measures aimed at respectively new versus old dwellings (columns {1-6,11a} & rows {7-9,11b}), new dwellings versus appliances ({columns 1-6,11a} & rows {10,11c}) or old dwellings versus appliances (columns {7-9,11b} & rows {10,11c}). Combinations regarding all dwellings versus appliances (columns {10,11c} & row {14}) cannot show interaction either. Secondly there are cells where interaction is not possible because measures do not overlap in time (light shaded, with x). For instance all measures starting after 1996 cannot interact with measure 7 ending in 1996. It shows that 58 cells (43%) of the matrix are not relevant with regard to interaction between policy measures. For the remaining cells the detailed results of the interaction analysis are presented in table A.2 in the Appendix.

Figure 3

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

- old or new building code and performance standard (column 1 & row 2 and column 2 & row 6);
- new building code and sustainable building options (column 3 & row 6);

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- energy performance standard and sustainable building options (column 2 & row 3).

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

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

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

The last and greatest part of the matrix concerns the interaction effects between general measures and the measures focused on specific applications. The broadly defined general measures interact easily with dedicated measures. A strong mitigating effect exists between the performance standard and energy tax (column 2 & row 12); the tax is not needed to stimulate decisions on saving options when standards already force to save energy. A second example is the retrofit-programme that overlaps with the agreement with the housing

Deleted: <#>the EPN and the sustainable building code (2 & 3). ¶
In these cases two measures are of the same type, aim at the same actors, or focus on the same conditions for implementation of saving options. Therefore these interaction effects are rated as mitigating. There is also a mitigating interaction effect between MAP-activities for advanced options in new dwellings and the EPN; due to the limited period of overlap this effect is rated as modest. This is also true for the old building code and the DUBO code.¶
¶
For **existing dwellings** only four specific measures are present and subsequently the number of possible interaction effects is limited. A strong reinforcing effect exists between the retrofitting programme, providing the organisational structure, and the subsidies for renovation, that provide the motivation (8 & 7). For **appliances** there is only one possible interaction effect. Because there were no substantial MAP-subsidies on appliances and most labels only started at the end of the MAP-period the interaction effect is rated small anyhow. ¶
¶
The lower far right part of the matrix contains the interaction effects for combinations of two general measures. The most important mitigating effect exists between the EPR-subsidies and the REB-tax (15 & 12) that together provide (too much) motivation. The REB modestly reinforces the effect of the Climate campaign as motivation and information are combined. ¶
¶
The last and greatest part of the matrix concerns the interaction effects between general measures and the measures for specific applications. The broadly defined general measures interact easily with dedicated measures. A strong mitigating effect exists between the REB-tax and the EPN (12 & 2); the tax is not needed as motivation when building standards already force to save energy. A second example is the agreement with the housing association on existing dwellings that overlaps with the earlier started retrofit-programme (14 & 8). The subsidized energy advices (EPA) are also devoted to dwellings of housing associations that have already agreed to take action; again this creates a strong mitigating effect (14 & 9). Strong reinforcing interaction effects are present between subsidies and EPA (15 & 9), or subsidies and labels (15 & 10), because of the combination of motivation and information.¶
¶
Top six interacting combinations¶
The preceding analysis shows 12 strong interacting combinations (9% of all combinations). However, a strong interaction effect between two measures is not always of the same importance. If both measures only have a very limited saving effect, the combination will not be decisive for the effectiveness of saving policy. From table 2 the most imp ... [2]

associations on energy savings in existing dwellings (column 8 & row 14). Further, subsidized energy advices are devoted to dwellings of housing associations, which have already agreed to take action; again this creates a strong mitigating effect (column 9 & row 14). Strong reinforcing interaction effects are present between advice and subsidies (column 9 & row 15), or labels and subsidies (column 10 & row15), because of the combination of motivation and information. Other mitigating interactions, such as between MAP-subsidies and energy tax (columns 11b/11c and row 12) are not rated strongly mitigating because consumer are generally not knowledgeable about energy prices and taxes when deciding on saving options. For the same reason the combination labels and energy tax (column 10 & row 12) is rated less mitigating than labels and subsidies.

The interaction for the remaining combinations is rated to be small or even zero. Small effects are found because the influence of the two measures on conditions shows overlap for some conditions, but complementary effects on other conditions as well. The zero effect cases comprise eight combinations where further investigation has shown that both measures do no focus on common saving options (see table A.2 in the Appendix).

Top six interacting combinations

The preceding analysis shows 12 strong interacting combinations (9% of all combinations). However, a strong interaction effect between two measures is not always of the same importance. When both measures have a very limited saving effect only, the combination will not be decisive for the effectiveness of savings-policy. The most important measures were selected based on various evaluation studies, such as Berenschot [2], IBO [17], Jeeninga [20], Berkhout [3], Das [11] and Oudshof [30]. These measures are:

- Building codes (version 1991 and 2002) regarding insulation,
- Energy performance standard (EPN), started in 1995,
- MAP-subsidies (period 1992 -1999),
- Regulatory energy tax (REB), started in 1996,

- Labels for various appliances, introduced between 1996 and 2002,

- Energy premium scheme (EPR), started in 2000,

- Energy advice (EPA), started in 2000.

The strong interaction effects between these measures are given in table 3; three combinations are rated as mitigating and three combinations as reinforcing.

Table 3

In case A the performance standard (EPN) comes on top of the building codes that define minimum specifications for the different technical measures. The overlap is a deliberate choice of policy makers; the performance standard assures that energy efficiency can be realised at the lowest costs. But the building codes restrict the EPN-choices with respect to insulation because the consequences stretch very long into the future. This deliberate choice is not true in case B with performance standard and energy tax. Given the strong demands of the performance standard the energy tax does not lead to implementation of extra energy efficiency measures in new dwellings; however it is practically impossible to exclude occupiers of new dwellings from paying the energy tax. In case C the combination of MAP-subsidies and energy tax reinforces the total effect for saving options (in new dwellings) that are not yet proved and rather expensive. Subsidies focus the attention of users at specific saving options as well; this task cannot be accomplished by the energy tax alone according to Daamen [10]. In case D, again with subsidies and energy tax, the interaction effect was rated as mitigating. This differs from case C because energy premiums were submitted from the start to proven saving options, especially appliances. Moreover, the level of the tax was much higher than at the time of the MAP-subsidies. The ineffective spending of energy premiums has been justified with the argument that the subsidies facilitated the acceptance of the ever-higher energy tax. People were given the opportunity to avoid part of the high tax by investing in (subsidized) saving options. In Menkveld [23] an analysis was made of energy premiums restricted to options saving the most and being relatively expensive. With regard to the reinforcing cases E and F one would expect lasting support of energy policy; especially the reinforcing combination of labels and energy premiums was found to be very successful. This combination led to such a rapid transformation of the appliance market that, in a few years, a great part of appliances for sale consisted of high-efficiency appliances. However, due to budget constraints the energy premium was cancelled in 2004 for most saving options. According to Boonekamp [6] this will diminish the saving effect of labels and (still subsidized) energy advice to a great extent.

5. Quantitative analysis of interaction effects with a simulation model

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

- regulatory energy tax,
- all subsidies (energy premiums, MAP and renovation)
- regulation of gas use for space heating (building code and performance standards for new dwellings and agreement with housing associations on existing dwellings).

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As mentioned in the first section, the models used in policy scenario studies often are designed to cope with interaction between policy measures. Therefore it seems beneficial to use such a model to investigate interaction effects between policy measures in the past. To this end an adapted version of such a model, described in Boonekamp [5] and used earlier in national scenario studies such as NEO [26], was applied to quantify the interaction effects. For practical reasons this analysis was not done for the period until 2003 but for 1990-2000 only. First the key properties of the model, which are important for interaction analysis, are presented. Then the model adaptations are summarised and some background results are given for the analysis which is described in section 6.

Main structure of the simulation model

In figure 4 the broad design of the household energy model is presented. Demographic, social, economic and life style trends are the driving factors that determine the demand for so-called energy-functions, for instance the heating and lighting of dwellings, cleaning, cooking, etc.. This demand is met with a number of appliances and other energy using systems (boilers, etc.). Energy prices, technological developments and policy measures affect energy use of these systems and appliances.

Determination of energy consumption developments

The model contains a detailed description of energy consumption in the base year. Total energy consumption from statistics is first disaggregated to the level of energy functions (e.g. space heating or lighting) and than to the energy input of all adjoining systems or appliances. When appropriate, a distinction between type of dwelling and type of household is made as well. Most details are based on extensive information on electricity and natural gas consumption, from surveys by EnergieNed [12]. Energy consumption over time of each of the systems or appliances is determined by three factors:

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

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Figure 4

The **total number of systems or appliances** is equal to number of households/dwellings times the ownership rate, i.e. the fraction of households which uses the system or appliance.

For ‘standard’ appliances such as washing machines the number is dependent on the number of households only. For dishwashers and dryers the number is dependent on socio-demographic-economic trends as well. The second factor, **intensity of use**, is mainly dependent on socio-demographic trends (see Weber [38]). For instance a higher fraction of households with two jobs, an important trend in the Netherlands in the nineties, has decreased the occupation rate of dwellings and thus space heating demand. But it has increased the demand for cooled food storage. The third factor, **change in energy efficiency**, is dependent on quite different factors. It is supposed that energy efficiency is realised by purchasing systems or appliances having higher conversion efficiencies, or by application of demand reducing technologies such as wall insulation. This decision is restricted by the fixed gradual replacement of the existing stock of appliances or energy using systems.

Calculation of change in energy efficiency

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

$$CBR = [(Inv - Subs) * Ann + O\&M] / [Saving * (Price + Tax)] \quad (1)$$

Inv = Investment in saving option (€)

Subs = Subsidy on saving option (€)

Ann = Fixed annuity factor to calculate yearly investment costs

O&M = Yearly operation & maintenance costs (if present)

Saving = Annual energy savings realized with option (GJ)

Price = Price of energy excluding tax (€/GJ)

Tax = Tax on energy (€/GJ)

The relation between the penetration of saving options and the cost/benefit ratio is modelled in the form of an S-shaped curve (see Figure 5). The S-curve prohibits an "all-or-nothing' decision for a CBR-value near 1. It allows for different investment decisions at the same CBR because actual circumstances differ per household: greatly varying intensities of use, varying costs of saving options, etcetera.

Figure 5

The relationship is defined such that in 50% of the decision cases the saving option will be chosen, provided that the cost/benefit-ratio is equal to the "acceptable" ratio" (see equation 2).

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

P = Penetration level of saving option (fraction of replaced systems)

Stp = Steepness of S-curve

CBR50 = acceptable cost/benefit ratio

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

Model adaptations to simulate past energy use

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

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- Replacement of all scenario inputs by historical values for 1990-2000
- Fitting calculated penetration levels of saving options to known historical levels by adjusting the parameters of the S-curve equations. Most of this work regarded the determination of the acceptable cost/benefit ratio CBR50 for every saving option. Values found are shown in table A.2 in Boonekamp [7].
- Correcting the resulting energy consumption per energy function by adjusting the activity levels (time devoted to cooking, number of showers per day, etc.) to the observed levels from surveys.
- Correcting total energy consumption for space heating by adjusting the parameter ‘average indoor temperature’ to estimated patterns in past years.

Inputs used

Inputs used in the simulation of past energy use can be split into:

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- socio-demographic and life style trends,
- penetration rates of energy systems or appliances,
- energy prices,
- policy measures.

The economic inputs for the past have been incorporated in the other inputs and are therefore not presented here (see discussion in Boonekamp [7]). The development of main socio-demographic trends and penetration of important energy using systems or appliances are given in table 4.

Table 4

Figure 6 presents gas- and electricity prices for households in the period 1990-2000. Total gas and electricity prices increase; however without the regulatory tax after 1996 the prices would have been substantially lower in 2000 than in 1990. The policy measures are described in section 6.

Figure 6

Overall results for household energy consumption

Table 5 shows the actual energy consumption of households in 1990 (first row) and in 2000 (last row). Total electricity consumption increases by one-third but total gas consumption, being 97% of total fuel use, proves to be quite stable. The 'consumption-excluding-savings' in 2000, or 'frozen technology consumption', was determined by stalling, from 1990 on, all improvement of conversion efficiencies or insulation levels in the model (see for methodology Boonekamp [5]). The difference with observed consumption in 2000 is equal to total savings in the period 1990-2000. These total savings are the result of either policy measures or other developments such as price-induced savings or autonomous efficiency improvements. The difference with the 1990-level, called the "Growth 1990-2000" effect, is the result of more households, higher ownership rates for appliances, more consumption of hot water and many other factors.

Table 5

6. Energy savings from combinations of policy measures

The simulation model described reproduces past energy developments, using the relationship between various policy measures and the penetration of saving options. This approach enables the analysis of alternative developments for deviating policy inputs. These variants describe a (theoretical) past trend without one or more of the three policy measures of interest: regulatory tax, investment subsidies and regulation of gas use for space heating. When these variants are compared with the actual development case (with the three policy measures), negative saving effects will be found. For presentation reasons it was decided to compare the results of all variants with that of the simulation without the three measures, the so-called 'base case'. In this base case the calculated level of fuel and electricity consumption is higher than the observed consumption, indicating that the policy measures save energy. However, the base case consumption is lower than the 'consumption-excluding-savings' level from table 5. Only 50% of all fuel savings and 15% of all electricity savings can be attributed to these three measures. Starting from this base case the efficiency gains were determined for each of three policy measures, followed by all combinations of these measures.

Saving effect of the energy tax

The regulatory tax increases the benefits of energy saved, and thus lowers the cost/benefit-ratio for investments in saving options (see equation 1 in section 5); this in turn leads to lower energy consumption. The regulatory tax on fuels and electricity was gradually introduced from 1996 on. In 2000 the energy tax amounted to 36% of the total gas price and 32% of the total electricity price (see figure 6). Because of the five year interval an average value for 1996-2000 was used to determine the total saving effect in 2000 (16-18% of the total energy price). In table 6 the difference with base case energy use is shown as the saving effect for "tax only". The energy tax decreases the base case consumption in 2000 by 2.0% for gas and

1.9% for electricity. Because the energy tax was introduced after 1995 there is no effect in 1995.

Table 6

Saving effect of investment subsidies

Subsidies decrease the additional investment into the saving options, and therefore the cost/benefit-ratio, which results in lower energy consumption. Investment subsidies (MAP-subsidy, renovation subsidies and energy premium, see section 4) were available in the entire period 1990-2000 for all important saving options, such as various insulation measures, high-efficiency boilers and heat pumps. Subsidies often amounted to 20-25% of the extra investments in more energy efficient options. The simulation run with subsidies shows that gas and electricity consumption decrease compared to the base case (see table 6, "subsidies only"). In 2000 gas use is 4.3% lower and electricity consumption decreases with 3.2%

Saving effect of regulation

In the period 1990-2000 regulation has mainly focused on fuel use in new dwellings. Until 1995 the building code defined minimum insulation levels for wall, roof, floor and windows. From 1996 on the energy performance standard (EPN) limited total energy consumption of new dwellings. The choice of saving measures, additional to the building codes, was left to the builder. However, the builder had to prove beforehand, by means of a prescribed calculation method, that the performance standard was met. The yearly surveys by EnergieNed [12] provided information on the saving options actually applied. The total number of new dwellings with regulation of gas use amounted to 13% of the total housing stock in 2000. In the model runs with regulation the actually chosen options because of the performance standard were forced into the simulation by replacing the calculated cost/benefit-ratio with a very low fixed ratio.

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

For the case without regulation the usual cost/benefit formula (see section 5) was used to calculate penetration rates of the saving options concerned. For new dwellings the regulated saving options often were not economically attractive. But for the existing dwellings of housing associations the simulations without regulation showed almost the same amount of saving options in most cases. After introducing regulation in the base case the gas consumption decreased with 4.6% in 2000; the electricity consumption was not affected (see table 6).

Combined effect of three policy measures

In the previous analysis only one policy measure at a time was introduced in the simulation of past energy use. With all three measures present one can expect the sum of the three effects given earlier. However, from table 6 it follows that the combined effect often is lower than the sum of the three effects, and only in one case equal. This means that there is an overlap in the effects of the three measures, up to a maximum of 10% for gas in the period 1990-2000. However, before drawing conclusions, an analysis is made of the interaction effects between each combination of two measures.

Combined effect of two policy measures

With three different measures at hand there exist three combinations of two measures only. For each of these combinations a simulation run with the model was made. In figure 7a results are presented for gas and in figure 7b for electricity.

Figure 7a

Figure 7b

Results are given for the period 1995-2000 because all three measures were active in this period only. All changes are given as a percentage of total gas or electricity consumption in the base case. The results for a single policy measure are shown in the rectangles. These values correspond to the "tax-only', etc. cases in table 6; the increase in savings from 1995 to 2000 translates into the percentages given. Combined saving effects for two measures are shown between the rectangles in figure 7. These saving effects are larger than that of each of the corresponding single measures. This is because two policy measures will have more influence than one. However, in case of electricity the saving of 'tax & regulation" is equal to that of "tax" because the electricity savings owing to regulation are practically zero. The same is valid for "subsidies & regulation" and "subsidies".

The qualitative results presented in section 4 show mainly mitigating combinations of the three policy measures. Therefore one may expect that the combined saving effect of two measures often is lower than the sum of the separate savings; the two policy measures will overlap with regard to their influence on saving options. For instance, in the case of both regulation and tax, the extra effect of the tax on top of regulation will be negligible. This is confirmed in figure 7a: the combined effect of "tax & regulation" is -4.5% against -5.1% for the sum of the two effects. Thus the amount of overlap between these measures is almost 13%. For the combination "subsidies & regulation" the amount of overlap is less profound (8%). From figure 7b it follows that for electricity the overlap for "tax & subsidies" is 4%.

However, in the case of gas and "tax & subsidies" the combined effect is **not** lower than the sum of the two separate effects. This combination proves to be of a reinforcing nature. Further analysis reveals that this is due to the fact that in the period 1995-2000 part of the subsidies is given to advanced, and expensive, saving options. In these cases the combined financial stimulation of the two measures was needed to force the start of the implementation process (see also analysis in Boonekamp [7]). The other part of the subsidies was spent on proven options, leading to a mitigating combined effect. This case resembles the reinforcing and mitigating combinations C and D described in section 4.

The overlap for the three measures together is more than 13% for gas and 4% for electricity. The 4%-figure is equal to that found earlier for the combination "tax & subsidies". Because the other combinations of two measures show no overlap, the three-measure overlap is equal to the only existing two-measure overlap. For gas the three-measure overlap is slightly greater than the overlap for the two measure combination "tax & regulation". The other overlap for "subsidies & regulation" does scarcely provide an extra contribution to the total overlap for three measures. One of the rare cases to compare these results with is provided by Vaisanen [34] for energy savings in the Finnish industry. The overlap of approximately 20% for the combination of audits, subsidies and voluntary agreements has the same order of magnitude as was found here.

7. Discussion on interaction results

The new approach in analysing interaction between policy measures raises a number of questions that will be addressed in the following paragraphs.

Effect of measures not regarded

Besides the measures used in the preceding analysis, the following policy measures were present in the period 1990-2000 as well (see table 2) : OEI (optimal energy infrastructure), DUBO (sustainable building options), EPA advice and energy efficiency labels for appliances. The infrastructural measures (OEI) have contributed to a 50% increase for the number of dwellings connected to a town-heating system. However, this type of dwellings still regards only 3% of the total number in 2000. Sustainable building options related to energy use can be ignored too, as they overlap to a very great extent with the insulation standards already dealt with in the preceding analysis. In section 4 the energy advice was mentioned as an important measure in the qualitative analysis of possible interaction for 1990-2003. However, it was introduced in the last year of the simulation period only. The effect of labelling was substantial in the Netherlands according to Winward [39]. Moreover, the combination of labels and subsidies was mentioned earlier as an important combination. However, most MAP-subsidies did not coincide with labels, and the consecutive energy premium was introduced in the last year of the simulation period. This is not true for labelling and the energy tax, which both were introduced step by step after 1996. Although this combination is rated less reinforcing than that of labelling and subsidies (see figure 3) a synergetic effect cannot be excluded. However, it regards electricity consumption only. Given these notes it is concluded that the measures, which were not selected in the quantitative analysis for 1990-2000, are of limited importance with respect to the overall results.

Contribution of substitution between gas and electricity

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

Interaction effects in the longer term

As the three policy measures analysed have been continued after 2000 it can be expected that the interaction effect have increased further. More and more new dwellings will have an energetic design according to regulation that mitigates the potential saving effect of the energy tax on new dwellings. The same is true for the combination "tax & subsidies" or "subsidies & regulation", at least when lowered subsidies in 2004 rise again in the future. However, an analysis with simulation runs for the period 2000-2005 is not possible, as realisations for 2005 are not available yet. To provide some raw estimate about the further increase in the size of interaction effects, past household energy use was simulated with artificially enforced measures. The tax level for 1995-2000 was doubled, bringing the average value at 30-35% of the total energy price. Investment subsidies were doubled as well, and the scope of regulation of gas use in new dwellings was expanded according to current policy. The effects on total energy use were calculated for the three enhanced measures and for the combination. The results for intensified policy show 25-30% lower energy savings for the combination of three measures compared to the sum of effects for each measure apart. The overlap is more than two times higher than that found earlier for three measures (see table 6).

Interaction effects between subsets of more than two measures

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

Uncertainty in the results of the analysis

In the so-called top-down calculation of realised savings an uncertain reference trend is compared with an uncertain actual trend. The relative small difference representing energy savings could have a quite substantial uncertainty margin. However, the simulation method presented here regards a bottom-up method where total energy savings are the result of increased penetration of a great number of saving options. The energy savings per saving option are fairly well known from research (e.g. executed as part of new subsidy schemes). The increase in penetration rates is known very well from yearly surveys. The simulation model calculates total energy use with actual penetration rates and penetration rates of the base year. The difference, being total energy savings, takes account of interaction between the saving effects of various options as well (see chapter 3). Further, the (limited) uncertainties in the amount of savings per option have a small effect on the uncertainty in total savings, due to the law of large numbers for the numerous saving options. So, it is believed that the calculated total energy savings are considerably accurate. However, the more important issue is the quality of calculated savings in the simulation variants with and without policy measures. The energy savings owing to one or more policy measures are equal to the difference between the results of two simulations. Uncertainty in observed quantities does not play a role here, as both results regard calculated figures based on the same inputs. The only deciding factor is how the simulation model accounts for changes in deployed policy measures. Given the penetration-algorithms for every saving option (that were fitted to actual detailed developments in the period 1990-2000), it is supposed that these algorithms also describe saving developments in case one or more of these policy measures are absent. Again, the total change in savings is the result of a number of changes for the penetration of various saving options. This approach is used as well in most models that predict future trends, and which are validated by fitting the parameters to historical trends (e.g. economic models with price- and income-elasticities).

Other effects left aside

The analysis focused on the direct effect of (combinations of) three policy measures on the penetration of saving options. Not regarded are the **direct effect on use** of the energy systems or appliances of these policy measures, and the **indirect effects** of implementing saving options. The policy measures “regulation” and “subsidies” do not have a direct effect on the use of systems or appliances, but energy taxes can. However, according to Groot [14] this effect is quite small due to the low price elasticity values in the Netherlands. The first indirect effect constitutes interaction between the saving effects of different saving options. However, these specific interactions, such as less profitable high-efficiency boilers due to subsidized insulation measures, are taken into account in the simulation model. Another indirect effect is the rebound-effect which can show up in three forms: more intense use of the efficient system, purchasing extra energy using equipment or spending the money saved on products that demand energy when produced. The most important example of the first form is a higher thermostat setting after implementing saving measures. As energy poverty is hardly a policy problem in the Netherlands, thermostat settings have always been such high that this rebound-effect will be small. An example of the second form of rebound effect are new lighting applications. According to literature the introduction of very efficient bulbs (CFL’s) has probably contributed to increased use of light in gardens and against burglary. This effect was not accounted for in the simulations with the policy measures “subsidies” and “energy taxes”. The spending of money on other products or services (that cause extra energy use) falls outside the scope of this analysis.

8. Conclusions and observations

New framework for investigating possible interaction effects between measures

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

Qualitative interaction results for actual policy measures in households

The method has been applied to the actual set of 15 policy measures on energy efficiency for households in the Netherlands, in the period 1990-2003. The matrix of possible interaction effects shows that interaction is non-existing for 43% of all measure combinations. Only 9% can be rated as strongly interacting, of which the greater part mitigating. Taking into account measures with a substantial saving effect only, the important interaction effects are between:

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

Quantitative interaction results for the most important policy measures

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

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

Observations for optimal policy

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

The matrix-method has been applied to sets of policy measures for EU-15 countries. From Odyssee [28] it can be concluded that the method offers a quick overview of possible interaction effects in actual sets of policy measures. In case of a structural and extensive use of many types of policy measures the matrix-method can be useful to avoid overlapping effects for policy measures. Moreover, the analysis can show opportunities for reinforcing combinations of measures. However, some interaction effects have to be accepted for practical reasons, e.g. the part of energy use which is affected by standards cannot be exempted from taxation. Sometimes the overlapping combination is effective yet in relation to the government efforts demanded. Finally, other criteria influence the choice of policy measures, for instance policy expenditures or public acceptance.

Acknowledgement:

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Appendix 1 Rating of interaction between policy measures for households

In table A.1 the contribution of the various policy measures in meeting the conditions for implementation of saving options in Dutch households are shown. The Action Plan of the distribution companies, mentioned in table 2, was split into three different measures. For the policy measures building codes (1991 and 2002) and the performance standard, the mandatory character forces that all conditions for implementation are met. As to motivation, it must be mentioned that it can follow from legal measures (obligations), financial measures (subsidies and taxes) or social pressure. This last type of motivation is valid for 'Optimal Infrastructure' and 'Climate campaign'.

Table A.1.

In table A.2 the factors that contribute to the rating of the interaction between combinations of policy measures are given:

- the common saving options affected by the two measures,
- overlapping/complementary effects as to the conditions for implementation (A = availability, K = known, R = restrictions, M = motivation and P = proper utilization),
- the overlap in time (average fraction as both periods).

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Under the heading "comments" individual factors are given for some combinations; these have contributed to the overall rating of the interaction too. In case of absence of common saving options the interaction was rated zero.

Table A.2

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Figure 1: Conditions for a successful implementation of a saving option

Figure 2: Cases for the saving effect of two measures with interaction (example)

Figure 3: Relative ratings possible interaction effects between 15 policy measures for energy savings in households in the Netherlands 1990-2003

Figure 4: Set up of the simulation model of household energy consumption

Figure 5: Relationship between cost/benefit ratio and penetration level for saving options (example)

Figure 6: Gas- and electricity prices and regulatory tax for households 1990-2000 (€-ct1990 per m^3 or kWh)

Figure 7a: Savings on gas 1995-2000 for combinations of policy measures (% of base case consumption)

Figure 7b: Savings on electricity 1995-2000 for combinations of policy measures (% of base case consumption)

Figure 1: Conditions for a successful implementation of a saving option

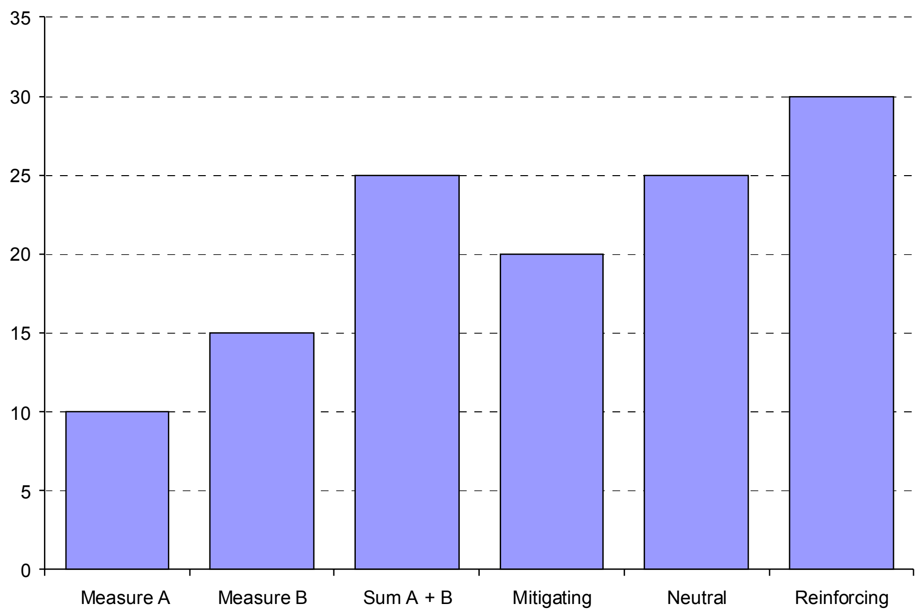

Figure 2: Cases for the saving effect of two measures with interaction (example)

	Active period Start	End	1 BD1991 new	2 EPN new	3 DuBo new	4 EPL new	5 Demon. new	6 BD2002 new	11a MAP new	7 Renov. old	8 Retrofit old	9 EPA old	11b MAP old	11c MAP appl.	10 Labels appl.	12 REB	13 Camp.	14 LTA	15 EPR
1	1992	2001																	
2	1996		- - -																
3	1995		- -	- - -															
4	1997		0	- -	0														
5	1985		0	0	0	0													
6	2002		x	- - -	- - -	0	0												
11a	1991	2000	0	- -	+	0	+	x											
7	1993	1996	x	x	x	x	x	x	x										
8	1994	2000	x	x	x	x	x	x	x	+++									
9	2000		x	x	x	x	x	x	x	x	-								
11b	1991	2000	x	x	x	x	x	x	x	0	++	+							
11c	1991	2000	x	x	x	x	x	x	x	x	x	x	x						
10	1996		x	x	x	x	x	x	x	x	x	x	x	+					
12	1996		-	- - -	+	+	+	0	+++	0	+	+	- -	- -	+ +				
13	1991		0	0	+	0	0	0	0	0	0	- -	+	+	+	++			
14	1998	2000	0	0	0	0	0	x	0	x	- - -	- - -	- -	x	x	- -	0		
15	2000	2003	0	-	0	0	+ +	0	0	x	0	+++	0	0	+++	- - -	+	-	

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

Figure 3: Relative ratings of possible interaction effect between 15 policy measures for energy savings in households in the Netherlands 1990-2003

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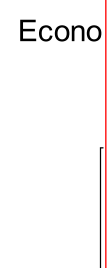

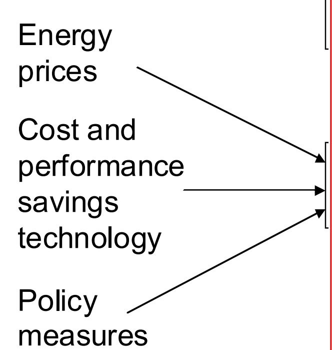

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Figure 5: Set up of the simulation model of household energy consumption¶
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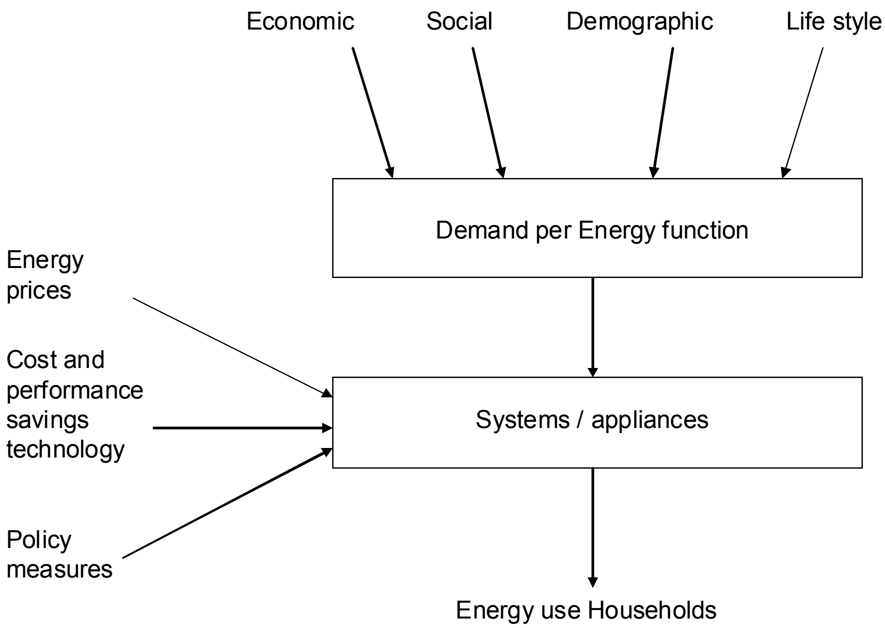

Figure 4: Set up of the simulation model of household energy consumption

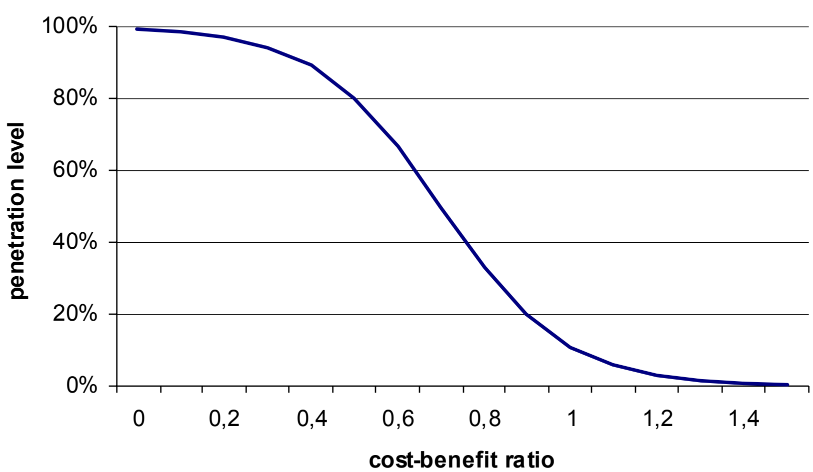

Figure 5: Relationship between cost/benefit ratio and penetration level for saving options (example)

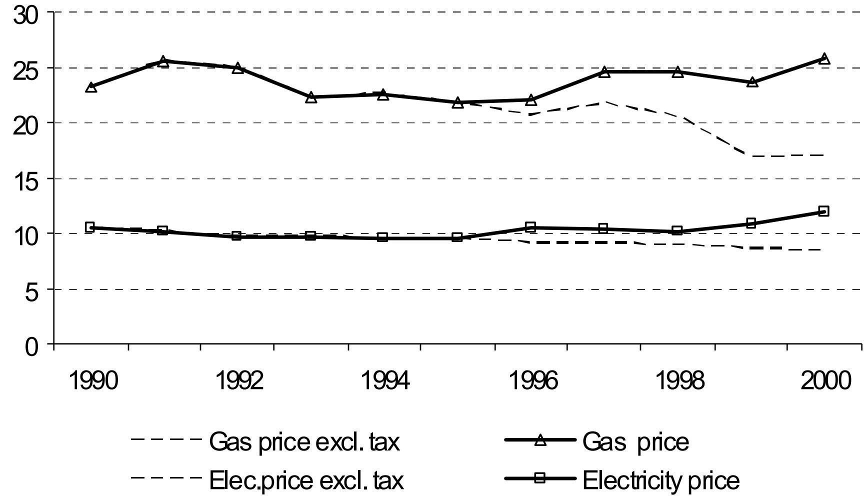

Figure 6: Gas- and electricity prices and regulatory tax for households 1990-2000 (€-ct1990 per m^3 or kWh)

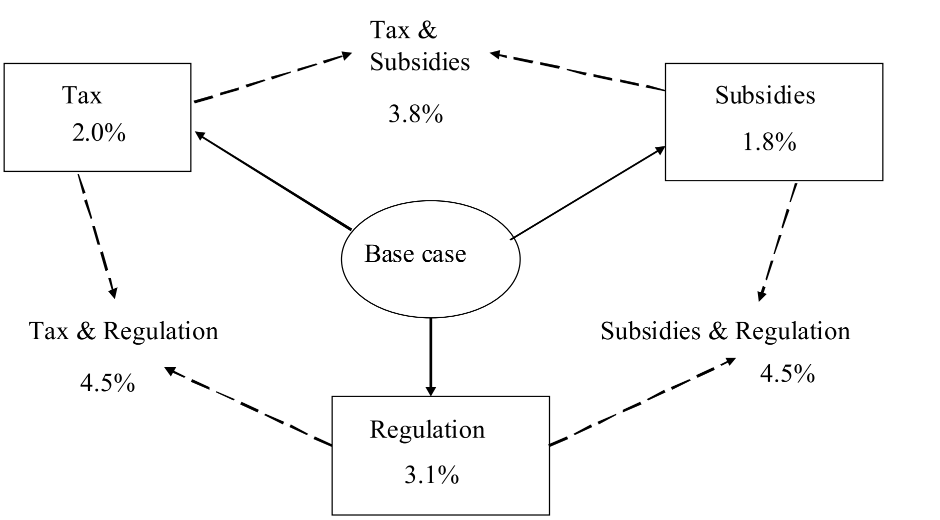

Figure 7a: Savings on gas 1995-2000 for combinations of policy measures (% of base case consumption)

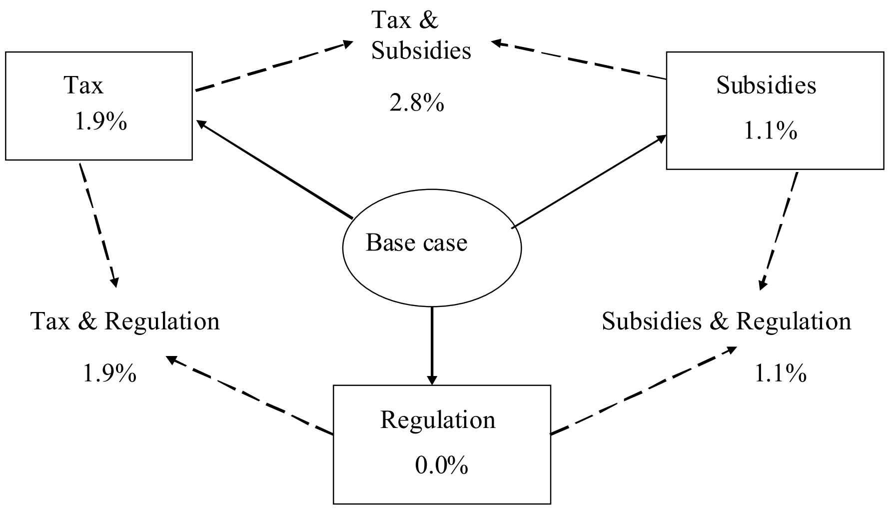

Figure 7b: Savings on electricity 1995-2000 for combinations of policy measures (% of base case consumption)

Table 1: Contribution of measure types with respect to the conditions for implementation and proper utilization of saving options

	Implementation				Proper utilization
	Available for application	Known to appliers	Restrictions lifted	Motivation to invest	
Measure type:					
Legislation					
- implementation	X	X	X	X	
- utilization					X
- labels		X		X	
Taxes				X	X
Support					
- financial		X		X	
- audits		X			
Information					
- options		X		X	
- utilization					X
Agreements		X	X	X	
Procurement	X	X		X	
R&D-facilities	X		X	X	
Emission-trading				X	

Table 2: Overview of policy measures for household energy efficiency in the Netherlands 1990-2003

	Policy measure	Application	Target group
1	Building Code insulation 1991	New dwelling	Builders
2	Energy Performance New dwelling (EPN)	“ “	Builders
3	Sustainable Building options (DuBo)	“ “	Builders
4	Optimal Energy Infrastructure (EPL/OEI)	“ “	Builders
5	Novem demonstration programmes	“ “	Builders
6	Building Code insulation 2002	“ “	Builders
7	Renovation/saving subsidies	Old dwelling	Housing associations
8	Retrofitting program rented houses	“ “	Housing associations
9	Advice energy savings (EPA)	“ “	Owner/Associations
10	Energy efficiency labels	Appliances	Consumers
11	Action Plan distribution sector (MAP)	Various	All parties
12	Regulatory Energy Tax (REB)	General	Consumer/Owner
13	Climate Campaign ‘21	General	Consumers/Municipality
14	Agreement housing associations (LTA)	Dwellings	Housing associations
15	Energy Premium Scheme (EPR)	General	Consumer/Owner

Table 3: Strong interaction effects between important policy measures in Dutch households

	First measure	Second measure	Type of interaction
A	Building codes	Performance standard	Mitigating
B	Performance standard	Energy tax	Mitigating
C	MAP-subsidies	Energy tax	Reinforcing
D	Energy tax	Energy premiums	Mitigating
E	Advice energy savings	Energy premiums	Reinforcing
F	Labels appliances	Energy premiums	Reinforcing

Table 4 Development of main input variables for simulation of household energy consumption

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

Table 5: Overview of household energy consumption developments 1990-2000 (*)

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

(*) Corrected for yearly variations in temperature during the heating season

Table 6: Energy savings owing to a regulatory tax, investment subsidies, regulation, and the combination for 1995 and 2000

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

Table A.1: Contribution of policy measures with respect to meeting the conditions for implementation and proper utilization of saving options for households in the Netherlands

	Measure type	Implementation				Proper utilization
		Available for application	Known to appliers	Res-trictions lifted	Motivation to invest	
1	Building code-1991	X	X	X	X	
2	Performance standard	X	X	X	X	
3	Sustainable options	X	X			
4	Optimal infrastructure		X	X	X	
5	Demonstration programs	X	X		X	
6	Building code-2002	X	X	X	X	
7	Renovation subsidies				X	
8	Retrofit-program		X	X		
9	Advice energy savings		X			
10	Labels appliances		X			
11a	MAP-new dwellings		X	X	X	
11b	MAP-old dwellings		X	X	X	X
11c	MAP-appliances		X		X	
12	Energy tax				X	X
13	Climate campaign		X		X	X
14	Agreement housing		X	X	X	
15	Energy premiums		X		X	

Table A.2: Rating of the interaction between policy measures to stimulate energy savings in Dutch households in the period 1990-2003

No	First measure	Second measure	Common saving options	Effect on conditions overlap	Effect on conditions complement	Time overlap	Total rating	Comments	Indirect
1	EPN	BD1991	insulation	A/K/R/M	x	61%	- - -		
2	DuBO	BD1991	insulation	A/K	x	66%	- -		
3	DuBo	EPN	insulation, boiler, heat-recovery	A/K	x	89%	- - -		
4	EPL	BD1991	X				0	Different options	
5	EPL	EPN	epc-measures	K/R/M	x	94%	- -		Post-mitigating
6	EPL	DuBo	large heat distr.projects	K	R/M-A	89%	0		
7	Demonstr	BD1991	insulation	A/K/M	x	79%	0	Time lag	Pre-reinforcing
8	Demonstr	EPN	insulation, boiler, heat-recovery	A/K/M	x	57%	0	Time lag	Pre-reinforcing
9	Demonstr	DuBo	insulation, boiler, heat pump/rec.	A/K	x	64%	0	Time lag	Pre-reinforcing
10	Demonstr	EPL	heat pump, etc.	K/M	A-R	50%	0	Time lag	
11	BD2002	EPN	insulation	A/K/R/M	x	63%	- - -		
12	BD2002	DuBo	insulation	A/K	x	61%	- - -		
13	BD2002	EPL	X				0	Different options	
14	BD2002	Demonstr	insulation	A/K/M	x	57%	0	Time lag	Pre-reinforcing
15	MAP-new	BD1991	X				0	Different options	
16	MAP-new	EPN	options for lower epc	K/R/M	x	44%	- -		Pre-reinforcing
17	MAP-new	DuBO	heat pump/recovery/distribution	K	R/M-A	53%	+		
18	MAP-new	EPL	large heat distrib.projects	K/R/M	x	35%	0	MAP-new >1997 = 0	
19	MAP-new	Demonstr	heat pump, etc.	K/M	R-A	86%	+	Overlap M needed	_
20	Retrofit	Renovate	insulation, boiler social rented	x	K/R-M	40%	+++		
21	EPA	Retrofit	insulation, boiler	K	x	18%	-		
22	MAP-old	Renovate	insulation, boiler rented	(M)	K/R-M	40%	0	Mutual excl.subsidies	
23	MAP-old	Retrofit	insulation, boiler social rented	(K/R)	M - K	70%	++	No overlap K/R	
24	MAP-old	EPA	insulation, boiler	(K)	R/M-K	9%	+	No overlap K in time	_
25	Labels	MAP-appl.	white appliances	x	K-M	50%	+	Few subsidies	_
26	REB	BD1991	insulation	M	x	61%	-	BD-overlap << EPN (27)	
27	REB	EPN	insulation, boiler, heat-recovery	M	x	100%	- - -		
28	REB	DuBO	all DuBo-options	x	M - A/K	94%	+		
29	REB	EPL	heat pump/distribution	M	M-K/R	88%	+	Overlap M needed	
30	REB	Demonstr	advanced options	M	M-A/K	79%	+	Overlap M needed	
31	REB	BD2002	insulation	M	x	25%	0	BD-overlap << EPN (27)	
32	REB	MAP-new	heat pump/recovery/distribution	M	M-K/R	50%	+++	Overlap M needed	
33	REB	Renovate	insulation, boiler	M	x	11%	0		

34	REB	Retrofit	insulation, boiler	x	M-K/R	56%	+	
35	REB	EPA	insulation, boiler	x	M-K	50%	+	
36	REB	MAP-old	insulation, boiler	M/P	M-K/R	50%	- -	Overlap stronger
37	REB	MAP-appl.	appliances	M	M-K	50%	- -	Overlap stronger
38	REB	Labels	appliances	x	M-K	100%	++	
39	Campaign	BD1991	insulation	K/M	x	55%	0	Focus on different actors
40	Campaign	EPN	insulation, boiler, heat-recovery	K/M	x	94%	0	Focus on different actors
41	Campaign	DuBO	all DuBo-options	K	M - A	89%	+	
42	Campaign	EPL	heat pump/distribution	K/M	x	100%	0	Focus on different actors
43	Campaign	Demonstr	heat pump/distribution	K/M	M - A	75%	0	Different M
44	Campaign	BD2002	insulation	K/M	x	29%	0	Focus on different actors
45	Campaign	MAP-new	heat pump/distribution	K/M	x	44%	0	Focus on different actors
46	Campaign	Renovate	insulation, boiler rented	M	x	31%	0	Focus on different actors
47	Campaign	Retrofit	insulation, boiler rented	K	M - R	49%	0	Focus on different actors
48	Campaign	EPA	insulation, boiler	K	x	57%	- -	
49	Campaign	MAP-old	insulation, boiler	K/M/P	M-R	44%	+	Different M
50	Campaign	MAP-appl.	appliances	K/M	M-K	44%	+	Different M
51	Campaign	Labels	appliances	K	M-K	94%	+	
52	LTA	BD1991	X				0	Overlap LTA-new = 0
53	LTA	EPN	X				0	LTA-options new = EPN+
54	LTA	DuBO	advanced options rented new	K	R/M-A	67%	0	Few same applications
55	LTA	EPL	heat distribution new rented	K/R/M	x	71%	0	Few same applications
56	LTA	Demonstr	new options rented	K/M	R-A	61%	0	Few same applications
57	LTA	MAP-new	advanced options new rented	(M)/K/R	x	65%	0	No overlap M for LTA-new
58	LTA	Retrofit	insulation, boiler rented (old)	K/R	x	71%	- - -	Overriding M-LTA
59	LTA	EPA	insulation, boiler rented (old)	K	x	25%	- - -	Overriding M-LTA
60	LTA	MAP-old	insulation, boiler rented (old)	K/R	x	65%	- -	Overriding M-LTA
61	EPR	BD1991	X				0	Different options
62	EPR	EPN	heat pump new dwellings	K/M	x	75%	-	EPR-new very few
63	EPR	DuBO	heat pump new dwellings	K	M-A	72%	0	
64	EPR	EPL	heat pump new dwellings	K/M	x	79%	0	Different actors
65	EPR	Demonstr	various options new dwellings	K/M	M-A	64%	++	Complement stronger
66	EPR	BD2002	X				0	Different options
67	EPR	MAP-new	X				0	EPR from 2002 > 2000
68	EPR	Retrofit	insulation, boiler old dwellings	K	M-R	18%	0	
69	EPR	EPA	insulation, boiler old dwellings	K	M-K	100%	+++	Complement stronger
70	EPR	MAP-old	options old dwellings	K/M	x	16%	0	

71	EPR	MAP-appl.	some appliances	K/M	x	16%	0	
72	EPR	Labels	most efficient appliances	K	M-K	75%	+++	Complement stronger
73	EPR	REB	appliances, insulation old	M	x	75%	- - -	
74	EPR	Campaign	appliances, insulation	K/M	M-K	79%	+	Different M
75	EPR	LTA	insulation rented old	K/M	x	21%	-	
76	Campaign	REB	all Campaign issues	M/P	K-M	94%	++	Complem.much stronger
77	LTA	REB	options rented dwellings	M	x	69%	- -	
78	LTA	Campaign	options rented dwellings	K/M	x	71%	0	Focus on different actors

added to the list of policy measures.

Table 1

The columns in table 1 represent the conditions; the contribution of each measure to comply with the conditions is indicated with crosses. A general observation, which can be drawn from the table, is that most common policy measures are designed to influence investment decisions, especially motivation. Also it is clearthat there are few measures that influence both implementation (first four conditions) and utilization (fifth condition). Only energy taxes will by nature influence both. The effect ofmeasures on each condition will now be highlighted into more detail.

The **availability** of new market ready saving options is oftendependent on additional R&D to deliver a marketable option. In the latter stages of development legislation (e.g. standards) could also speed up the development processaccording to Newell [25]. Financial measures could stimulate the creation of marketable options too, provided that they are considered to last over a long period. With the exception of high taxes on transport fuels, sustained for decades in various countries, this has not been the case for energy taxes in general. As Newell [25] shows, even the very high energy prices due to the oil crises were only partly responsible for increased energy efficiency. Finally procurement could speed up actual availability. The **knowledge** of saving options, not only about the concept but also about the actual performance, is most effectively increased by dedicated information, such as mandatory labels. Other possibilities are free information on specific saving options. Audits, agreements and procurement combine the search for saving opportunities with the provision of information on saving options. Vermeulen [35] and Blok [3] state that subsidies often focus attention of energy users to saving options and thus serve as an information source too. Regional and branch networks of entrepreneurs are also a means to provide knowledge, as partiesimitate often each other's decisions (see Hennicke and Ramesohl [14]). The level of implementation already achieved also contributes to knowledge of other users. Actually all measures that stimulate the take-off of a newoption contribute to it becoming more widely known. Finally, as stated earlier, legislation on the implementation of the saving option is an alternative as it cancels the need for information. **Restrictions** that hamper the implementation of saving options are oftenof a non-economic nature; therefore they cannot be lifted easily by financial measures according to Vermeulen [35]. Restrictions on performance can be overcome partly by adaptations to the saving option with additional R&D. For instance the development of a high efficiency boiler with 'closed air circulation' has diminished the problems of placement to a great extent. Restrictions with respect to the decision making process sometimes can be circumvented with tailored policy measures. For rented dwellings this could be an agreement between housing associations, representatives of occupants and the government on the division of costs and benefits. But hardly any measure is able to influence the replacement moment that provides the opportunity to realise energy savings. Most regulation on more efficient systems does not influence directly the actual lifetime of the old systems (see policydescriptions in MURE [23]). Almost all measures can contribute to the **motivation** to invest in new saving options. Some provide an economic motivation, such as subsidies or taxes; other measures, such as information campaigns and voluntary agreements, could create a social motivation. Legislation creates by definition the strongest "motivation". But in the longer run this could also be accomplished indirectly by some other measures mentioned, as they lead to the disappearance of less efficient options altogether. Influencing the daily **utilization** of energy systems asks for continuous action, as opposed to the one time investment decision. Also the daily users of the systems are more difficult to reach. In practice relatively few measures are available to ensure a proper daily utilization, for instance legislation on maintenance and monitoring of performance. Regular feedback can lead to savings for space heating according to Jensen [19], but for practical applications feedback costs have to be low. Groot [12] states that energy taxes lead to limited energy savings on daily energy use given the rather low short term price elasticities.

As Sorrell [31] shows too, it must be pointed out that the influence of policy measures does not just regard government and the energy users but also other actors in an implementation network. Shop owners that are pressed to sell more efficient appliances to their customers form an example of these other actors. The network of researchers, suppliers of technologies, energy advisers, user associations, public interest groups and subsidizing agencies, each with their own interests, defines also the relationship between policy measures and implementation. This means that the different conditions for realising saving options are not tied to the same actor. For instance the condition 'availability' will oftenbe associated with the manufacturing of new appliances or systems, while the condition 'motivation' mostly regards the energy user. In this analysis the role of these other parties is taken into account when analysinginteraction between policy measures.

Optimal combinations of policy measure types

Looking to the rows in table 1 it is clear that most policy measures do not cover all conditions. The influence of taxes is limited to only one of the implementation conditions; information and subsidies cover two implementation conditions. Regulation can influence all conditions for implementation but is not always acceptable or applicable. Therefore a combination of policy measures seems necessary to comply with all conditions. However, the importance of each condition differs per saving option. For instance, if a saving option is readily available and restrictions are minor, financial and information measures alone could do the job. On the other hand, not all types of policy measures present are applicable to each saving option. In energy policy formulation many other factors play a role when choosing a policy measure type. For instance, regulation demands extensive ex-ante knowledge about the appropriateness of the regulated saving option; this knowledge is not always easy to provide. Subsidies often affect actors not belonging to the target group; too much free riders diminish the effectiveness of the measure (see Blok [3] and Vermeulen [35]). From the foregoing it follows that the optimal set of policy measures to be applied is dependent on the type of saving option.

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

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

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

3. Interaction-matrices for a set of policy measures

The theoretical approach from section 2 is translated into a method that specifies, for any set of policy measures, the interaction effect between two measures. To this end the concept of optimal combinations is used to formulate a qualitative rating of theinteraction effect between two measures.

Qualitative rating of theinteraction effect between two measures

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

The qualitative rating of theinteraction effect proceeds as follows. The more two measures exert influence at the same condition(s) for implementation, the more they mitigate each other's effect. Depending on the specific situation this results in a relative rating: marginal-, modest- or strong mitigating ('-', '- -' or '- - -'). The last rating can be characterised as 'too much of the same kind'. An example is the combination 'standards and subsidies' that provides more motivation to invest into a saving option than is actually needed. Their combined effect is less than the sum of the separate effects of both measures apart.In the extreme opposite case two measures complement each other in such a way that the combined effect is much greater than the total effect of both measures apart. This synergetic combination is rated as strong reinforcing ('+++'). A Dutch example is the label system for appliances and the energy premium scheme.Ybema [39] shows that this combination has led, in a few years only, to shops offering efficient or very efficient appliances only. If the mutual reinforcement of two measures is less optimal the rating is modest or marginally reinforcing ('++'or '+'). In cases where it can be reasoned that one measure does not influence the saving effect of the other the rating '0' is given.

The possible interaction cases for two measures A and B are illustrated in figure 2. For the mitigating combination the total saving effect is less than the sum of both effects and for the reinforcing combinationthe other way around. A neutral combination provides (almost) the same total savings as the sum of both measures. In literature the interaction effect is not always described in this way. Gunningham and Grabosky [13] presents the fact that the saving effect of a measure is enhanced by another measure as positive. Howeverthis increase in savings is the case for all three combinations described; even mitigating combinations will deliver more savings than measure A or measure B alone. The real question is: how relates the combined effect to the sum of the effects of both measures on their own?

Figure 2

Interaction matrix for a general set of measures

For the set of measures from section 2 the matrix of interaction effects has been constructed (see figure 3). Strong reinforcing combinations (value '+++') are 'support application & legislation information' and 'information on use & regulatory tax'. These combinations provide for the knowledge of the saving possibilities and the motivation to realise them. A practical example of the first case is the combination of subsidies and mandatory labels for electric appliances that was mentioned earlier. An example of the second case regards regular feedback on daily energy use; according to Jensen [19] it enhances the effect of higher energy prices due to a tax substantially. In case the market readiness of saving options could pose a problem the combination 'R&D-

promotion & support application' could create a strong reinforcing combination. Temporary subsidies could create a firm position for the market ready option. However concrete examples have not emerged in recent years in the Netherlands. Strongly overlapping (value '- - - ') combinations are legislation on investment decisions and other measure types: (financial) support, information, negotiated agreements or procurement. In these cases actors are already forced to choose an option, so other policy measures are not needed. Subsidies for saving options that are also used in new dwellings with an energy performance standard are an example of such an overlap. Labels that promote appliances that are hardly more efficient than the prescribed minimum level form another example. Combinations of mandatory information and free information measures are more of the same and therefore also mitigating. Substantial prices to be paid for emission rights in an emission trading system provide a financial motivation for energy efficiency. Therefore the interaction effect with a CO_2-tax, that has the same influence, will show a strong overlap, as Sijm [30] also concludes.

Figure 3

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

The remaining combinations are rated as marginally mitigating (-), reinforcing (+) or even neutral (0) because the two policy measures neither lead to much overlap nor full coverage of the conditions for implementation. With respect to emission trading the interaction ratings resemble that of a regulatory tax (see figure 3). However, in some cases there are slight differences because the price signal from a regulatory tax, that seldom decreases, is thought to be more robust.

Non-existing interactions

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

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

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

Post- and pre-implementation interaction effects

In a few cases measures interact at another point than the implementation of saving options or the stimulation of a proper utilization. Post-implementation effects regard interaction between the resulting saving effects of two measures. E.g. insulation decreases heat demand; this lowers the benefits of installing a more efficient boiler, which is detrimental to the success of a policy measure directed at efficient boilers (see also Sezgen [29]). Pre-implementation interaction regards a measure that influences another measure's potential to realise energy efficiency. For instance, Johannsen [20] finds that voluntary agreements have the (implicit) goal to forestall other policy measures, such as a CO_2-tax. Therefore the combination with a tax measure will touch the content of the agreement. The combination will deliver less effect than could be determined from the original content of both measures. In the few relevant cases the rating in the matrix is corrected for these effects.

Summary of the rating method

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

Mitigating: (-) to (- - -)

Reinforcing: (+) to (+++)

Neutral: (0)

Not possible (x).

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

Define the different measure-types (standards, financial, etc.)

Define (mutually excluding) applications for each sector

Attach to each policy measuretype,application and year-in/year-out,

If necessary split measures with a broad scope into different applications

If necessary split broadly defined measures into different types

Determine the matrix-cells with no overlap in time for the measures

Determine cells with different applications for the two measures

Rate the interaction effect, taking into account the relevant conditions for successful implementation or proper utilization, the influence of both measures on these conditions and the overlap or synergy.

Correct for the fraction of the period when one of the measures is not present

Correct for post-implementation interaction: the overlap in the resulting savings.

Take account of pre-implementation interaction: one measure changes the content of another measure partly or wholly.

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

The method has been applied to a set of policy measures to promote energy efficiency in households in the Netherlands. In table 2 all measures in the period from 1990 on, and with a non-trivial saving effect, are presented. Some measures originate from local initiatives (climate campaign) or EU-legislation (appliance labels), but most measures are part of nationalpolicy. A description of these measures is given in MURE [23] and, into more detail for some measures, in Oosterhuis [27]. The MURE-measure types ‘legislation on use’ and ‘procurement’ (see table 1) are not used for households in the Netherlands. The first ten measures aim at three specific applications: new dwellings (measures 1-6), existing dwellings (7-9) and appliances (10). The other measures (12-15) relate to various or all applications; this category ‘General’ encompasses taxes, agreements and general subsidy schemes. The Environmental Action Plan (MAP) of energy distributors forms a special case because of its very broad scope. This measure has been split into three segments, directed at new dwellings (11a), existing dwellings (11b) and appliances (11c), to provide for a much easier analysis of interaction effects.

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

Table 2

In figure 4 the matrix ofinteraction effects is shown, with the measures grouped according to application. Thenumber of possible combinations of two measures is (15+2)*(14+2)/2 = 136. The two extra measures in the formula originate from splitting the MAP-measure into three sub-measures. The total number is divided by two because only one half of the matrix has to be specified. First attention is paid to the cells of the matrix where interaction is not possible because of different applications (dark shaded, with x). These cells encompass all combinations of measures for new and old dwellings ({1-6,11a} & {7-9,11b}), for new dwellings and appliances ({1-6,11a} & {10,11c}) or for old dwellings and appliances ({7-9,11b} & {10,11c}). Secondly there are cells where interaction is not possible because measures do not overlap in time (light shaded, with x). For instance all measures starting after 1996 cannot interact with measure 7 ending in 1996. It shows that 57 cells (42%) of the matrix are not relevant with regard to interaction between policy measures.

Figure 4

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

old or new building code andenergy performance standard (1 & 2, 6 & 2);

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the EPN and the sustainable building code (2 & 3).

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

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

The lower far right part of the matrix contains the interaction effects for combinations of two general measures. The most important mitigating effect exists between the EPR-subsidies and the

REB-tax (15 & 12) that together provide (too much) motivation. The REB modestly reinforces the effect of the Climate campaign as motivation and information are combined.

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

Top six interacting combinations

The preceding analysis shows 12 strong interacting combinations (9% of all combinations). However, a strong interaction effect between two measures is not always of the same importance. If both measures only have a very limited saving effect, the combination will not be decisive for the effectiveness of saving policy. From table 2 the most important measures have been selected based on various evaluation studies, such as Berenschot [1], IBO [15], Jeeninga [18], Berkhout [2], Das [9] and Oudshof [28]. These measures are:

- Building codes (version 1991 and 2002) for insulation,
- EPN (energy performance standard), started in 1995,
- MAP-subsidies (period 1992 -1999),
- REB (regulatory energy tax), started in 1996,
- Labels for various appliances, introduced between 1996 and 2002,

- EPR-subsidies (energy premium scheme), started in 2000,
- EPA-energy advice, started in 2000.

The strong interaction effects between these measures are given in table 3; three combinations are rated as mitigating and three combinations as reinforcing.

Table 3

In case A the EPN comes on top of the building codes that define minimum specifications for the different technical measures. The overlap is a deliberate choice of policy makers; the EPN assures that energy efficiency can be realised at the lowest costs. But the building codes restrict the EPN-choices with respect to insulation because the consequences stretch very long into the future. This deliberate choice is not true for case B with EPN and REB. Given the strong EPN-demands the REB does not provide any extra energy efficiency for new dwellings; however it is practically impossible to exclude occupiers of new dwellings from paying the REB-tax. In case C the combination of MAP-subsidies and REB-tax reinforces the total effect for subsidies that are given to saving options in new dwellings that are not yet proved and rather expensive. Subsidies also focus the attention of the users at specific saving options; this task cannot be accomplished by the REB-tax alone according to Daamen [8]. For case D, also with subsidies andtax, the interaction effect was rated as mitigating. This differs from case C because the EPR was submitted from the start to very well known saving options, especially appliances; moreover the level of the tax was much higher than at the time of the MAP-subsidies. The ineffective spending of EPR-money could be justified with the argument that the subsidies facilitated the acceptance of the ever-higher REB-tax. People were given the opportunity to avoid part of the high tax by investing in (subsidized) saving options. In Menkveld [21] an analysis was made of an EPR restricted to the options that save the most and being relatively expensive. With regard to the reinforcing cases E and F one would expect lasting support of energy policy; especially the reinforcing combination of labels and EPR was found to be very successful. This combination led to such a rapid transformation of the appliance market that, in a few years, a great part of appliances for sale consisted of high efficiency appliances. However, due to budget constraints the EPR has been cancelled in 2004 for most saving options. According to Boonekamp [5] this will diminish the saving effect of labels and (still subsidized) EPA-advice to a great extent.

5. Quantitative analysis of interaction effects with a simulation model

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

energy tax (REB),

all subsidies (EPR, MAP, renovation)

regulation (building code, EPN and agreement with housing associations).

As mentioned in the first section, the models used in policy scenario studies often are designed to cope with interaction between policy measures. Therefore it seems beneficial to use such a model to investigate interaction effects between historic policy measures. To this end an adapted version of such a model, described in Boonekamp [4] and used earlier for national scenario studies such as NEO [24], has been applied to quantify the interaction effects. For practical reasons this analysis was not done for the period until 2003 but for 1990-2000 only. First the key properties of the model, that are important for interaction analysis, are presented. Then the model adaptations are summarised and some background results are given for the analysis that is described in section 6.

Main structure of the simulation model

In figure 5 the broad design of the household energy model is presented. Demographic, social, economic and life style trends are the driving factors that determine the demand for so-called energy-functions, for instance the heating and lighting of dwellings, cleaning, cooking, etc.. This demand is met with a number of appliances and other energy using systems (boilers, etc.). Energy prices, technological developments and policy measures could influence energy use of these systems and appliances.

Determination of energy consumption trends

First a detailed description of energy consumption in the base year is made. Total energy consumption from statistics is first disaggregated to the level of energy functions (e.g. space heating or lighting) and than to the energy input of all adjoining systems or appliances. When appropriate, also a distinction between type of dwelling and type of household is made. Most details are based on extensive information on electricity and gas consumption from surveys by EnergieNed [10]. Energy consumption over time for each of the systems or appliances is determined by three factors:

the (change in) total number of a specific system/appliance,

the (change in) intensity of use,

the (change in) efficiency of energy consumption.

Figure 5

The **total number of systems or appliances** is equal to number of households/dwellings times the ownership rate, i.e. the fraction of households that use the system or appliance. For 'standard' appliances such as washing machines the number is dependent on the number of households only. For dishwashers and dryers the number is also dependent on socio-demographic-economic trends. The second factor, **intensity of use**, is mainly dependent on socio-demographic trends (see Weber [36]). For instance a higher fraction of households with two jobs, an important trend in the Netherlands in the nineties, has decreased the occupation rate of dwellings and thus space heating demand. But it has increased the demand for cooled food storage. The third factor, **change in energy efficiency**, is dependent on quite different factors. It is supposed that energy efficiency is realised by purchasing systems or appliances having higher conversion efficiencies, or by application of demand reducing technologies such as wall insulation (see also discussion). This decision is restricted by the fixed gradual replacement of the existing stock of appliances or energy using systems.

Calculation of change in energy efficiency

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

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

Inv = Investment in saving option (Euro)

Subs = Subsidy on saving option (Euro)

Ann = Fixed annuity factor to calculate yearly investment costs

O&M = Yearly operation & maintenance costs (if present)

Saving = Annualsavings realized with option (GJ)

Price = Price of energy excluding tax (Euro/GJ)

Tax = Tax on energy (Euro/GJ)

The relation between the penetration of saving options and the cost/benefit ratio is modelled in the form of an S-shaped curve (see Figure 6). The S-curve prohibits an "all-or-nothing' decision for a CBR-value near 1. It allows for differentdecisions at the same CBR because actual circumstances differ per household: greatly varying intensities of use, varying costs of saving options, etcetera.

Figure 6

The relationship is defined such that in 50% of the decision cases the saving option will be chosen, provided that the cost/benefit-ratio is equal to the "acceptable" ratio" (see equation 2).

$$P = 1 - 1 / \{1 + \text{Exp}\,[-Stp * (CBR - CBR50)]\} \qquad (2)$$

P = Penetration levelsaving option (fraction of replaced systems)

Stp = Steepness of S-curve

CBR50 = acceptable cost/benefit ratio

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

Model adaptations to simulate past energy use

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

Replacement of all scenario inputs by historical values for 1990-2000

Fitting calculated penetration levels of saving options to known historical levels by adjusting the parameters of the S-curve equations. Most of this work regarded the determination of the acceptable cost/benefit ratio CBR50 for each saving option. Values found are shown in table A.2 in Boonekamp [6].

Correcting the resulting energy consumption per energy function by adjusting the activity levels (time devoted to cooking, number of showers per day, etc.) to the actual levels from surveys.

Correcting total energy consumptionby adjusting the general parameter ‘mean temperature for space heating’ to estimated historic patterns.

Inputs used

Inputs used in the historic simulationcan be split into:

socio-demographic and life style trends

penetration rates for energy systems or appliances

energy prices

policy measures.

The historical economic inputs are incorporated into the other inputs and are therefore not presented here (see discussion in section 7). The development of main socio-demographic trends and penetration of important energy using systems or appliances are given in table 4.

Table 4

In figure 7 gas- and electricity prices for households are given for the period 1990-2000. The total gas and electricity prices increase; however without the regulatory tax after 1996 the prices would have been substantially lower in 2000 than in 1990. The policy measures are described in section 6.

Figure 7

Overall energy consumption trends

Table 5 shows the actual energy consumption of households in 1990 (first row) and in 2000 (last row). Electricity consumption increasesone-third butgas consumption, 97% of total fuel use, proves to be quite stable. The ‘consumption-excluding-savings’ in 2000, or ‘frozen technology consumption’, has been determined by stalling, from 1990 on, all improvement of conversion efficiencies or insulation levels in the model (see for methodology Boonekamp [4]). The difference with actual consumption in 2000 is equal to total savings in the period 1990-2000.

These total savings are the result of either policy measures or other developments such as price-induced savings or autonomous efficiency improvements. The difference with the 1990-level, called the "Growth 1990-2000" effect, is the result of more households, higher ownership rates for appliances, more consumption of hot water, etc.

Table 5

6. Energy savings from combinations of policy measures

The simulation model described reproduces past energy trends using the relationship between different policy measures and the penetration of saving options. This approach enables the analysis of alternative developments for deviating policy inputs. These alternatives describe a (theoretical) past trend that could have been realised with another set of policy measures. First a so-called 'base case' trend has been simulated, without the three policy measures of interest: regulatory tax, investment subsidies and regulation ofsavingoptions. In this base case thelevel of fuel and electricity consumption is higher than the actual consumption, meaning that the policy measures save energy. However, the base case consumption is lower than the 'consumption-excluding-savings' level from table 5. Only 50% of all fuel savings and 15% of all electricity savings can be attributed to these three measures. Starting from this base case the efficiency gains have been determined for each of three policy measures, followed by all combinations of the measures.

Saving effect of the energy tax

The regulatory tax increases the benefits of energy saved and thus lowers the cost/benefit-ratio for investments in saving options (see equation 1 in section 5); this in turn leads to lower energy consumption. The regulatory tax on fuels and electricity (REB) has been gradually introduced from 1996 on. In 2000 the REB amounted to 36% of the total gas price and 32% of the total electricity price (see also figure 7). Because of the five year interval a mean value for 1996-2000 has been used to determine the total saving effect in 2000 (16-18% of the total energy price). In table 6 the difference with base case energy use is shown as the saving effect for “tax only”. The REB decreases the base case consumption in 2000 by 2.0% for gas and 1.9% for electricity. Because the energy tax has been introduced after 1995 there is no effect in 1995.

Table 6

Saving effect of investment subsidies

Subsidies decrease the additional investment for the saving options, and therefore the cost/benefit-ratio, which results in lower energy consumption. Investment subsidies (MAP, renovation subsidies and EPR, see section 4) have been available in the entire period 1990-2000 for all important saving options: various insulation measures, high efficiency boilers, heat pumps, etc. Subsidies often amounted to 20-25% of the extra investments in more energy efficient options. The simulation run with subsidies shows that gas and electricity consumption decrease compared to the base case (see table 6, “subsidies only”). In 2000 gas use is 4.3% lower and electricity consumption decreases with 3.2%

Saving effect of regulation

In the period 1990-2000 regulation has mainly focused on fuel use in new dwellings. Until 1995 the building code defined minimum insulation levels for wall, roof, floor and windows. From 1996 on the energy performance standard (EPN) limited total energy consumption of new dwellings. The choice of saving measures, additional to the building codes, was left to the builder. However, the builder had to prove beforehand, by means of a prescribed calculation method, that the EPN-standard was met. The yearly surveys by EnergieNed [10] provided information on the saving options actually applied. The total number of new dwellings with regulationamounted to 13% of the total housing stock in 2000. In the model runs with regulation the actually chosen EPN-options have been forced into the simulation by replacing the calculated cost/benefit-ratio with a very low fixed ratio.

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

For the case without regulation the usual cost/benefit formula (see section 5) has been used to calculate penetration rates of the saving options concerned. For new dwellings the regulated saving options were oftennot economically attractive. But for the existing dwellings of housing associations the simulations without regulation showed almost the same amount of saving options in most cases. After introducing regulation in the base case the gas consumption decreased with 4.6% in 2000; the electricity consumption was not influenced (see table 6).

Combined effect of three policy measures

In the previous analysis only one policy measure at a time was introduced in the historic simulation. With all three measures present one could expect the sum of the three effects given earlier. However, from table 6 it follows that the combined effect is oftenlower than the sum of the three effects and only in one case equal. This means that there is an overlap in the effects of the three measures, up to a maximum of 10% for gas in the period 1990-2000. However, before drawing conclusions, an analysis is made of the interaction effects between each combination of two measures.

Combined effect of two policy measures

With three different measures at hand there are three possible combinations of two measures. For each of these combinations a simulation run with the model has been made. In figure 8a results are presented for gas and in figure 8b for electricity.

Figure 8a

Figure 8b

Results are given for the period 1995-2000 only because all three measures have been active in this period only. All changes are given as a percentage of total gas or electricity consumption in the base case. The results for a single policy measure are shown in the rectangles. These values correspond to the “tax-only’, etc. cases in table 6; the increase in savings from 1995 to 2000 translates into the percentages given. Combined saving effects for two measures are shown between the rectangles in figure 8. These saving effects are greater than that of each of the corresponding single measures. This is because two policy measures will have more influence than one. However, in case of electricity the saving of ‘tax & regulation” is equal to that of "tax" because the electricity savings due to regulation are practically zero. The same is valid for “subsidies & regulation” and “subsidies”.

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

However, in the case of gas and “tax & subsidies” the combined effect is **not** lower than the sum of the two separate effects. This combination proves to be of a reinforcing nature. Probably this due to the fact that in the period 1995-2000 part of the subsidies is given to new, still expensive, saving options. In these cases the combined financial stimulation of the two measures was needed to force the start of the implementation process. The other part of the subsidies has been spent on proven options, leading to a mitigating combined effect. This case resembles the reinforcing and mitigating combinations C and D described in section 4.

The overlap for the three measures together is more than 13% for gas and 4% for electricity. The 4% figure is equal to that found earlier for the combination “tax & subsidies”. Because the other combinations of two measures show no overlap the three-measure overlap is equal to the only existing two-measure overlap. For gas the three-measure overlap is slightly greater than the overlap for the two measure combination “tax & regulation”. The other overlap for “subsidies & regulation” does hardly provide an extra contribution to the total overlap for three measures. One of the rare cases for comparison is provided by Vaisanen [32] for energy savings in the Finnish industry. The overlap of about 20% for the combination of audits, subsidies and voluntary agreements has the same order of magnitude asfound here.

7. Discussion on interaction results

Effect of measures not regarded

Besides the measures used in the preceding analysis a number of other policy measures were also present in the period 1990-2000(see table 2). :

OEI (optimal energy infrastructure)

DUBO (sustainable building standards);

EPA advice,

energy efficiency labels for appliances.

The infrastructural measures (OEI) have contributed to a 50% increase for the number of dwellings connected to a town-heating system. However, this type of dwellings still regards only 3% of the total number in 2000. DUBO-standards related to energy use can be ignored too as they overlap to a very great extent with the insulation standards that have been taken care of already in the preceding analysis. In section 4 the EPA has been mentioned as an important measure in the qualitative analysis ofinteraction for 1990-2003. However, it was introduced in the last year of the simulation period only. The effect of labelling has been substantial in the Netherlands according to Winward [37]; moreover the combination of labels and subsidies (EPR) has been mentionedas an important combination. However, most MAP-subsidies did not coincide with labels, and the consecutive EPR-subsidy has been introduced in the last year of the simulation period. This is not true for labelling and the REB-tax that both have been introduced step by step after 1996. Although this combination is rated less reinforcing than that of labelling and subsidies (see figure 4) a synergetic effect cannot be excluded. However, possible effects regard electricity consumption only. Given these notes it is concluded that the measures that were not selected in the quantitative analysis for 1990-2000 are of limited importance with respect to the overall results.

Contribution of substitution between gas and electricity

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

Interaction effects in the longer term

As the three policy measures analysed have been continued after 2000 it can be expected that the interaction effect have increased further. More and more new dwellings will have been constructed according to regulation that mitigates the potential saving effect of the REB-tax on new dwellings. The same is true for the combination "tax & subsidies" or "subsidies & regulation", at least if lowered subsidies in 2004 rise again in the future. However, an analysis with simulation runs for the period 2000-2005 is not possible as realisations for 2005 are not available yet. To provide some raw estimate about the further increase in the size of interaction effects, past household energy use has been simulated with artificially enforced measures. The tax level for 1995-2000 has been doubled, bringing the average value at 30-35% of the total energy price. Investment subsidies have also been doubled and the scope of regulation for new dwellings has been expanded according to current policy. The effects on total energy use have been calculated for the three enhanced measures and for the combination. The results for intensified policy show 25-30% lowersavings for the combination of three measures compared to the sum of effects for each measure apart. The overlap is more than two times higher than that found earlier for three measures (see table 6).

Interaction effects between subsets of more than two measures

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

8. Conclusions and observations

New framework for investigatinginteraction effects between measures

The interaction effect between two policy measures can be rated by investigating how these policy measures influence a number of conditions for a successful implementation of saving options.

For a set of policy measures this approach results in a matrix with ratings of theinteraction effect for all combinations of two measures. If two measures complement each other with respect to the conditions for implementation the interaction effect is reinforcing. The combined effect is greater than the sum of both effects apart. In the opposite case the interaction effect is mitigating. The rating ‘neutral’ holds if the measures do not interact. For a set of actual policy measures the matrix willalso show non-existing interactionsbecause policy measures aim at different energy applications or do not overlap in time.

Qualitative interaction results for actual saving measures in households

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

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

Quantitative interaction results for the most important policy measures

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

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

Observations for optimal policy

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

The matrix-method has been applied to sets of policy measures for EU-15 countries. From Odyssee [27] it can be concluded that the method offers a quick overview of the interaction effects in actual sets of policy measures. In case of a structural and extensive use of many types of policy measures the matrix-method could be useful to avoid the overlapping effects of different policy measures. Moreover, the analysis could show opportunities for reinforcing combinations of measures. However, some interaction effects have to be accepted for practical reasons, e.g. the part of energy use that is influenced by standards cannot be exempted from taxation.Moreover other criteria influence the choice of policy measures, for instance the policy outlay or the public acceptance of standards.

Acknowledgement:

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Figure 1: Conditions for a successful implementation of a saving option

Figure 2: Cases for the saving effect of two measures with interaction (example)

Figure 3: Relative ratings of the interaction effect between general policy measures for implementation of saving options

Figure 4: Relative ratings of interaction effect between 15 policy measures forsavings in households in the Netherlands 1990-2003

Figure 5: Set up of the simulation model of household energy consumption

Figure 6: Relationship between cost/benefit ratio and penetration level for saving options (example)

Figure 7: Gas- and electricity prices and regulatory tax for households 1990-2000 (E-ct1990 per m^3 or kWh)

Figure 8a: Savings on gas 1995-2000 for combinations of policy measures (% of base case consumption)

Figure 8b: Savings on electricity 1995-2000 for combinations of policy measures (% of base case consumption)

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Figure 1: Conditions for a successful implementation of a saving option

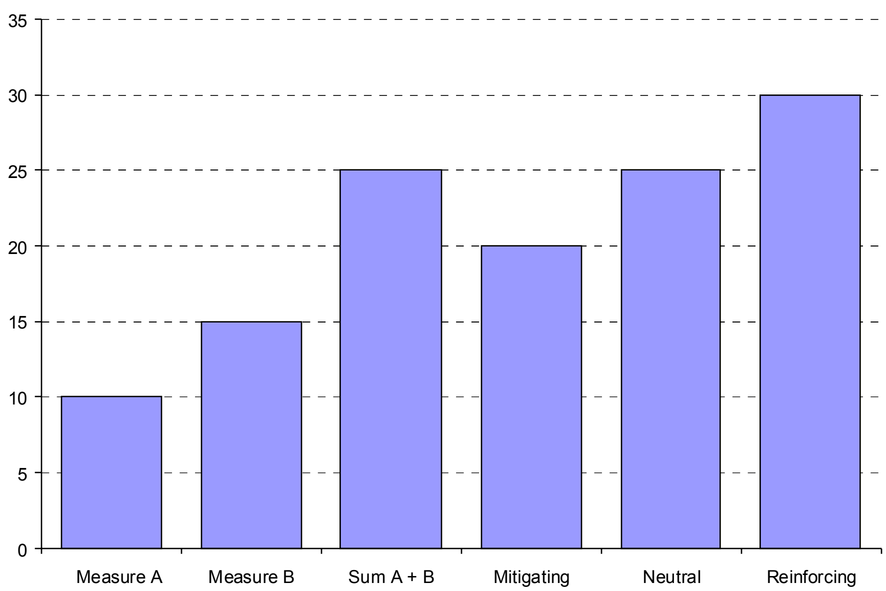

Figure 2: Cases for the saving effect of two measures with interaction (example)

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

Mitigating: - - - = strong / - - = modest / - = marginally, 0 = no interaction, reinforcing: + = marginally / ++ = modest / +++ = strong)

Figure 3: Relative ratings of the interaction effect between general policy measures for implementation of saving options

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Figure 4: Relative ratings of interaction effect between 15 policy measures forsavings in households in the Netherlands 1990-2003

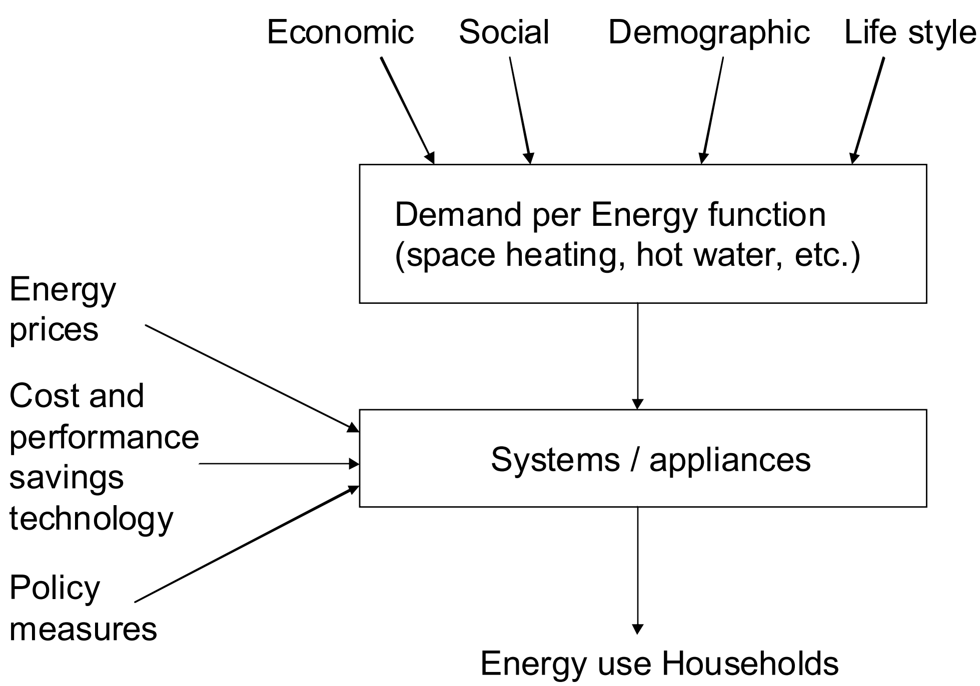

Figure 5: Set up of the simulation model of household energy consumption

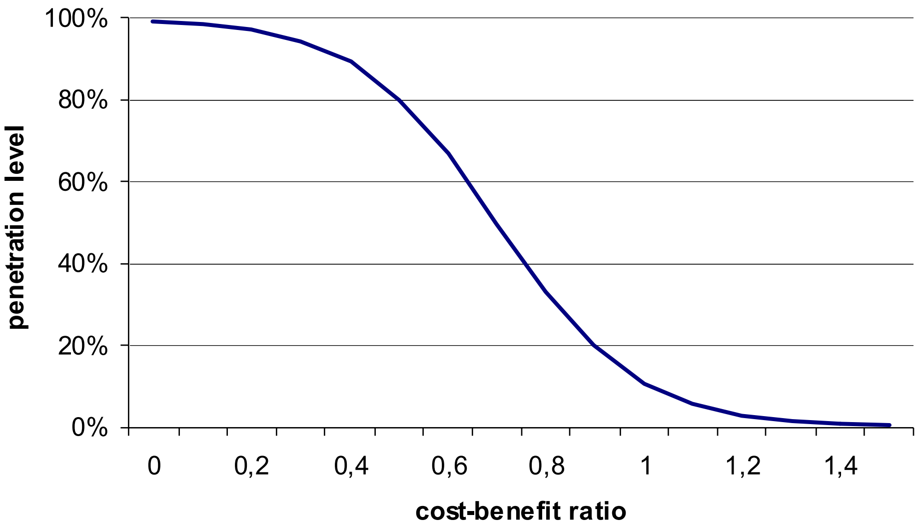

Figure 6: Relationship between cost/benefit ratio and penetration level for saving options (example)

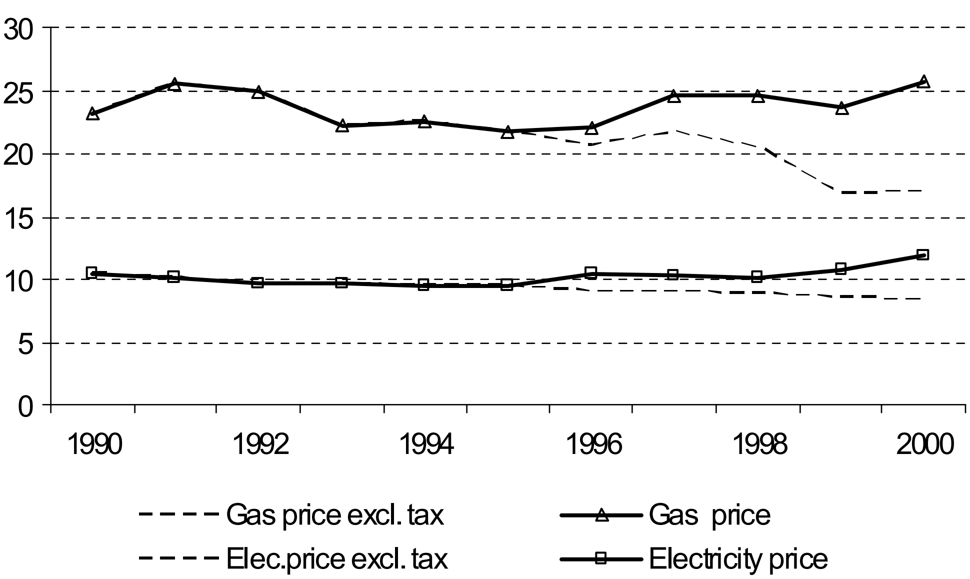

Figure 7: Gas- and electricity prices and regulatory tax for households 1990-2000 (E-ct1990 per m^3 or kWh)

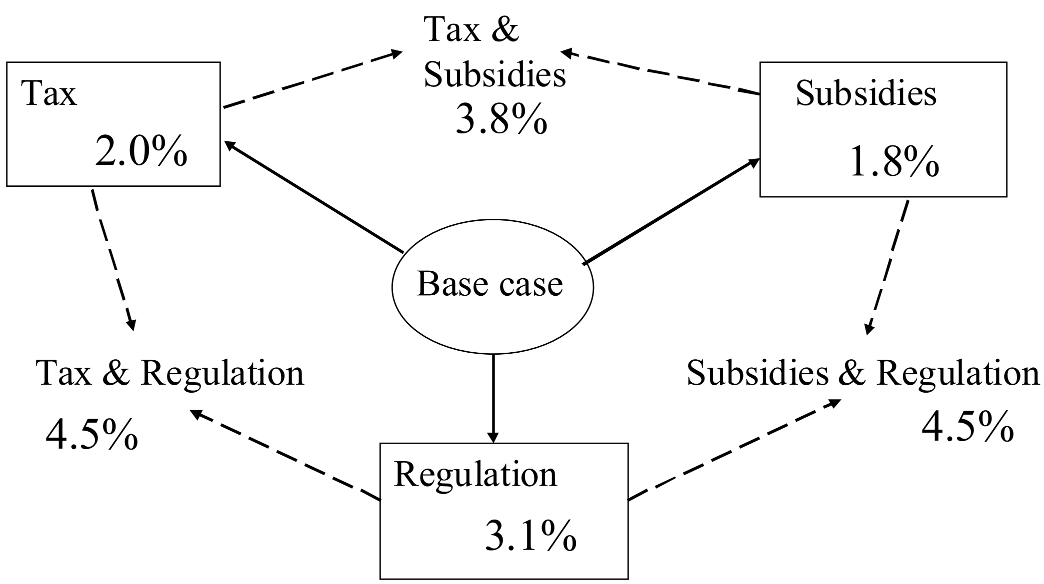

Figure 8a: Savings on gas 1995-2000 for combinations of policy measures (% of base case consumption)

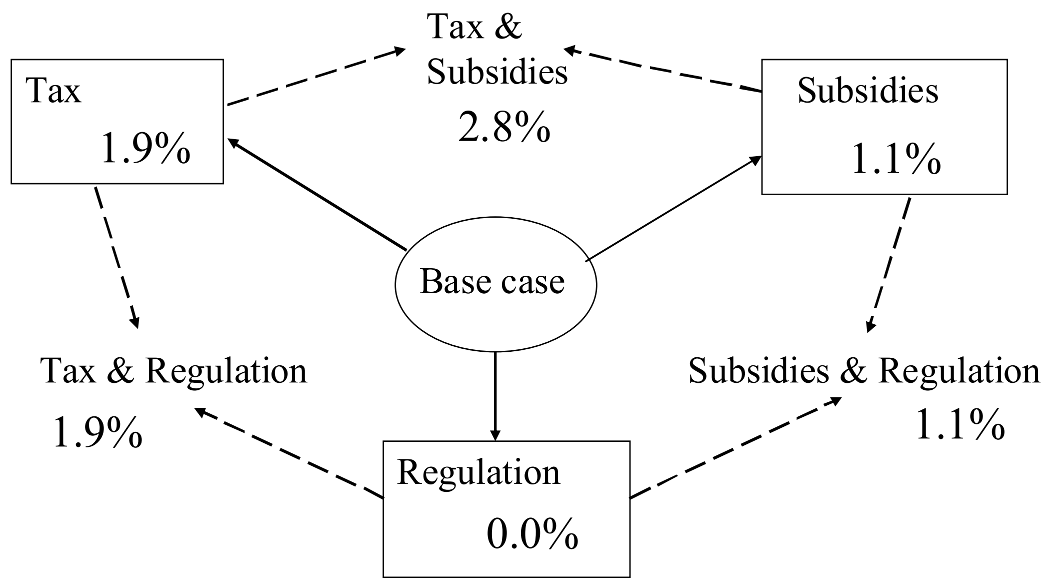

Figure 8b: Savings on electricity 1995-2000 for combinations of policy measures (% of base case consumption)

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Table 1: Contribution of measure types with respect to the conditions for implementation andutilization of saving options

	Implementation				Proper utilization
	Available	Known	No restrictions	Motivation	
Measure type:					
Legislation					
- implementation	X	X	X	X	
- utilization					X
- labels		X		X	
Taxes				X	X
Support					
- financial		X		X	
- audits		X			
Information					
- options		X		X	
- utilization					X
Agreements		X	X	X	
Procurement	X	X		X	
R&D-facilities	X		X	X	
Emission-trading				X	

Table 2: Overview of policy measures for household energy efficiency in the Netherlands 1990-2003

	Application	Target group

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

Table 3: Strong interaction effects between important policy measures in Dutch households

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

Table 4 Development of main input variables for simulation of households energy trends

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

Table 5: Overview of household energy consumption developments 1990-2000 (*)

	Fuel	Electricity
	PJ	PJe
Actual energy consumption 1990	394	60.3
Growth effect 1990-2000	+77	+44.4

Consumption-excluding-savings 2000	471	104.7
Total savings effect	-78	-25.2
Actual energy consumption 2000	393	79.5

(*) Corrected for yearly variations in temperature during the heating season

Table 6: Energy savings due to a regulatory tax, investment subsidies, regulation, and the combination for 1995 and 2000 (PJ)

	1995		2000	
	Gas	Electricity	Gas	Electricity
Policy measures:				
- tax only	0.0	0.0	8.5	1.6
- subsidies only	10.1	1.5	18.1	2.7
- regulation only	6.1	0.0	19.3	0.0
(sum)	(16.2)	(1.5)	(45.9)	(4.3)
- tax & subsidies & regulation	15.3	1.5	41.5	4.2