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Investment behavior for the adaptation of energy efficient technology: looking for key barriers

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1. Introduction

The existence of proven technology for environmental improvement is no warrant for widespread application. For energy efficiency, many technologies and practices apparently have net revenues, but even then, many investors disregard or reject them. Although there is a large literature on investment theory, the question remains to what extent this theory applies to actual behavior and simple decision making on energy efficient technologies and practices. In this chapter, an overview is presented of arguments why decisions on energy efficiency may deviate from simple investment theory. Moreover, for each of these considerations is shown how they are dealt with in the National Energy Outlook Modeling System (NEOMS) developed by ECN. Practical suggestions are formulated to extend regular modeling of behavior regarding energy efficiency in several ways.

Overview

Section 2 poses the conceptual framework for the analysis in this chapter. In the following sections 3 and 4, many of the deviations and exceptions are described including how they are dealt with in the NEOMS. Suggestions are made how these phenomena can be empirically founded. In section 5, a selection is made of the most relevant of these phenomena and demonstrated with the current model for industry. Section 6 concludes with suggestions for further improvement of the NEOMS.

2. Conceptual framework

In this chapter the concepts for the analysis are presented. First, the assumption of unused efficiency potential, the so-called efficiency gap is defined on a micro level. Then the concept

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of rational investment decisions in energy efficiency is presented. Finally, typical energy consumption categories are defined to offer clear examples for the analysis.

Unused energy efficiency potential

The existence of possibilities to save energy with a positive pay-off is the subject of many policy papers², implying that actions to improve energy efficiency are justified and beneficial for both private and public interests. Why these options are not cashed in autonomously has been studied by many scholars and has become known as the energy efficiency gap. A recent comprehensive overview on this subject has been made by [Masselink, 2007].

How should studies on the potentials for energy efficiency be valued and used in energy demand models? A typical way of estimating the savings potential is to determine best practice of energy efficiency and compare with an observed average. Best practice can be a discrete observation, which is regarded as a realistic alternative for the total population³. To avoid anomalies and assure representativity, the best 5% or 10% could define best practice with more confidence⁴. In figure 1 this is represented by assuming cases distributed around an average.

Assuming some kind of distribution for individual energy efficiency scores of current practice, the potential improvements would depend on the distance to the current average and the shape of the distribution. The distance to the current average is supposed to be caused by outdated or inferior technology or suboptimal operation, which can be improved by new investments.

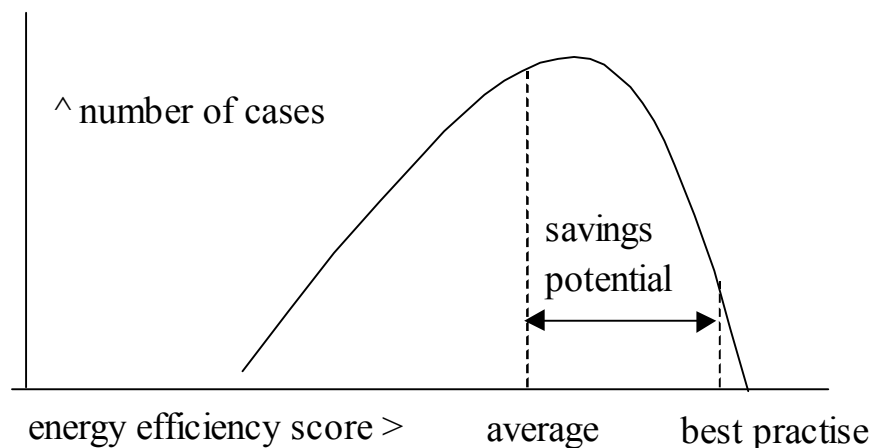


Figure 1: *Energy savings potential distribution*

However, the distance to the current average does not originate entirely from considerations of energy technology, energy costs and energy saving investments. It may also stem from the different designs of installations with different properties. Moreover, specific conditions for individual energy users like the intensity of use and the limitations in existing facilities may account for differences in savings potential. These differences can be of major interest for the

² Recently, the European Commission has presented a green paper stating that 20% energy can be saved in Europe cost efficiently.

³ See for instance ICARUS 4 [Alsema, 2001] and its sources.

⁴ See for instance the Energy Efficiency Benchmarking Covenant, Netherlands Ministry of Economic Affairs, 1999

user, but of minor interest for energy and therefore not observed when determining the savings potential.

Observations about incomplete penetration of cost effective energy saving measures may simply reflect that the business case does not apply for all situations. When business cases are aggregated to a sector level, the observable fact remains that similar actors choose different options. Even if there appears to be no good reason to make these differences in actor situations, often a wide variety of technologies can be observed, ranging from sophisticated energy saving technologies to none at all. No systematic research is done on estimating these variations and identifying their causes for different technologies and actors.

Techno-economic decision rules

In the NEOMS, developments in energy consumption are mostly modeled by simulating investor and consumer behavior. These include decisions on the purchase and use of equipment, buildings, vehicles and industrial installations. Like any investment decision, regular adaptation of energy efficient technology is modeled by offering a set of technology alternatives to a decision-maker. Of each technology, performance is standardized in a suitable unit of output to make them comparable. Energy consumption and cost per unit are known inputs. A behavioral rule is introduced to model an adaptation decision, based on payback time, least costs, highest net present value or internal rate of return. This approach assumes full availability for the actor of this technological potential. A purely rational economic decision is implied, possibly resulting in an overestimation of actual behavior. In the sections 3 and 4, several exceptions to this simple approach are considered. [Gillissen, Sorrell, Koetse]. Many of these however can be modeled as adjustments to the powerful and appealing concept of the rational economic decision.

Hidden costs and market failures

In line with the assumption of rational economic behavior, deviations from the simple concept can be categorized either as hidden costs or benefits and market failures [Stavins, Sorrell, EU barriers project]. Hidden costs include a wide range of examples, such as the costs for acquiring information, transactions costs, the costs of time or reduced comfort, the costs of risk and the increased costs in situations of capital scarcity. Market failures include a wide range of other situations, categorized by Sorrell as incomplete markets; imperfect competition, and imperfect or asymmetric information. Moreover, Sorrell distinguishes organizational failures, where organizations do not act like single profit maximizing actors. However, the phenomena here are similar to market failures: imperfect information; moral hazard and principal-agent relationships and split incentives.

Categories of energy consumption

To clarify and simplify the choices made in modeling of investment behavior, four main categories of energy use are distinguished. The schedule below illustrates these categories and the relevant components and properties.

Table 1 Categories of energy consumption

categories of energy use	relevant applications	typical life time years	relevant components	typical life time years	estimated share primary energy consumption
energy using products	electrical appliances, vehicles, equipment	10-15	motors, displays	10-15	33%
buildings	houses, offices, greenhouses	25-100	windows, light bulbs, boilers	10-15	37%
process installations	basic metals, chemicals, food, minerals, refineries	20-50	furnaces, reactors, separators, motors	10-25	30%
energy conversion	power plants	20-50	gas turbines, boilers	15-25	18%

The shares of energy consumption estimated for the Netherlands illustrate that energy using products, buildings and process installations have about equal shares of total primary consumption. Conversion losses in electricity generation constitute around 18% of primary consumption but are included in the primary energy use of the three other categories.

3. Hidden costs

Hidden costs include:

- cost variations due to specific situations,
- loss of comfort and additional efforts,
- premature capital losses,
- avoidance of uncertainties and opportunity costs of waiting,
- transaction costs,
- neglected features and preferences.

All hidden costs and benefits have in common that they can be introduced in the simple rational behavior approach, basically by correcting or elaborating on the input figures.

Cost variations in specific situations inhibit full implementation

Cost differences for specific situations may be the first and obvious reason for different investment decisions. These differences include variations around an average actor situation and around an average technology to be applied. Variations in the actor situation refer to the existing outfit, the way the new outfit will be used and the relevant energy price levels for the actor. For instance, a gas engine (CHP) is an interesting option in textile industry, but variations include factors like: whether or not both heat and electricity can be used on the premises; whether the boiler house is large enough and sound proof; whether the production is round the clock or only dayshift. Variations in the technology like unit capacity, voltage, temperature, NO_x-emission levels, maintenance conditions etc. occur with different products

and suppliers. Interaction between actor and technology is a relevant source of variations: is the right choice made and is the engineering optimized for the situation?

All these variations result in a different valuation of the energy efficiency improvement project by the investor. One straightforward way of dealing with variations in models is to make refinements where they are relevant. Economies of scale can be more explicitly addressed by modeling different levels of capacity, operating differences can be modeled by defining industrial subsectors. However, there is a trade-off between refinement and generalization: splitting up groups of technologies and groups of actors can make variations small but data gathering burdensome. The level of detail depends on the purpose of the exercise and the availability of data. In NEOMS, a higher level of refinement is applied where it matters: in power generation and in combined heat and power generation⁵ (CHP). Nevertheless, variations in the interaction between the actor and his opportunity to improve energy efficiency keep occurring, and consequently have to be dealt with in modeling.

Extra efforts or disadvantages pose additional hidden costs

Improving energy efficiency can also include non- or small investment options, generally based on the collective noun of “good housekeeping”. For many of these options costs are difficult to determine, since they involve little or no material purchases. Moreover, they may require extra labor or lead to costs that reflect reduced convenience or comfort. For instance, adequately ventilating spaces and avoiding excessive ventilation can save energy for space heating. This involves not just advanced hard- and software, but also a conduct strategy, e.g. closing doors and windows in time. Another example is the energy efficient driving programs [evaluatie het nieuwe rijden, SenterNovem]. Adequately gearing up and maintaining tire pressure can save substantial energy without any material investment. This requires however some extra effort that is not adequately valued. The same holds for switching off lights and appliances when they are not used. However, good housekeeping can be modeled as a regular technology when the costs and benefits are determined or estimated in the right way. This is not always simple and requires research on specific behavior. Costs here involve investments in time both for changing behavior and maintaining it in the efficient manner. Typically, good-housekeeping measures can be explicitly modeled using maintenance costs as an important factor in the decision process. In the NEOMS models, good housekeeping and similar behavior options are basically modeled with simple price elasticities.

Energy efficiency potential follows timing of capacity replacement to avoid capital loss

Simple modeling of energy efficiency improvements may disregard the timing of decisions and therefore overestimate efficiency improvements. When a new line of industrial equipment or components with improved energy efficiency is marketed, not all potential clients will consider buying it. First, clients want to choose a convenient decision moment since purchasing new equipment involves information gathering and processing, procedures, and many decisions on related aspects. Second, the existing equipment has to be depreciated and capital losses may be prohibitive. The ratio of annual capital depreciation to energy costs in industry ranges from 2-10, the lower ratio of 2 representing energy intensive industries like basic metals. So even if 20% of the energy costs are saved, the cost of one year earlier replacement is 10 times the savings. Similar, for a transport company the annual depreciation cost of trucks is in the order of magnitude of annual fuel costs. So a truck that is 10% more

⁵ The CHP section in the SAVE model deals explicitly with different technological types, classes of capacity en classes of operating hours.

fuel-efficient repays only 10% of the capital losses if replacement is one year earlier. Therefore, it is obvious that equipment will serve its lifetime and energy efficiency improvements have to follow the pace of replacement.

The major part of the technologies in the NEOMS models is embodied in capital goods and follows an exogenous replacement rate. Even add-on technologies like building insulation follow a ten-year refurbishment cycle. Although this may lead to a slow model response to e.g. rising energy prices, it is unlikely that the real life response would be a quick penetration of thermal insulation in the building stock. Only behavior options like good housekeeping are applied within short cycles in the models.

Uncertainties about the energy efficiency gains

Uncertainty about future cash flows may be a reason to expect different investment behavior than under assumptions of perfect foresight. For investments in energy efficiency, technological, market and policy uncertainties are distinguished. Technological uncertainties include the performance of installed technology and the availability (testing phase, interruptions), but also the possible improvements of the technology if purchase can be postponed. Energy price volatilities are the main element in market uncertainties and therefore the actual savings in terms of money. Also, product demand determines the occupation rate of the installation and may affect energy efficiency. Policy uncertainties have gained attention with the recent experiences in emissions trading in the EU, where the national governments decide on the allocation of CO₂ emission rights and the price of these appears to be volatile⁶.

Investors basically seek to avoid technological uncertainties by covering them thoroughly in contracts with their suppliers and contractors. There is little technological uncertainty involved in investments in the categories of energy using products and buildings since technology is widespread and products are standardized. In process technology, uncertainties in actual performance and availability of customized installations and components can be an issue that makes investors cautious. For modeling behavior under these uncertainties, a worst-case approach or risk premium would be appropriate. In the Save production model⁷, a simple risk premium on the required rate of return is used. This risk premium depends on the technology properties: new and advanced technologies have higher risk premiums than simple and proven technologies. For the power and refineries sector, technology is mature and no risk premium is applied in the models.

Unlike technological uncertainties, energy and CO₂ market uncertainties are more generally exposed to investors. In sectors where energy and CO₂ represent substantial costs, price volatility is an important factor in daily and midterm operational decisions. These uncertainties are mitigated by contracts mostly ranging for 6 months to several years ahead. Therefore, when deciding on the efficiency of new installations, they are likely to incorporate their market expertise in optimizing energy efficiency. In the NEOMS models, for energy intensive sectors rational behavior is assumed based on energy market analysis. In energy extensive sectors, energy market uncertainties are not analyzed in great detail, since knowledge is limited and energy is not vital for the market position of the company. Therefore, investments in energy efficiency are triggered mostly when returns are high and

⁶ See e.g. www.pointcarbon.com

⁷ The Save production model [Daniëls, 2007] is part of the NEOMS, and simulates the development of energy use in the Dutch industry and agriculture, including combined heat and power generation.

gains are obvious. This is reflected in the NEOMS models by relatively high required returns on investment for the energy extensive sectors.

The effect of policy uncertainties on investment in energy efficiency has not been studied thoroughly; public discussion on this subject suggests that the impact is large. Industries univocally claim that unexpected changes in subsidy schemes may freeze investment in renewable power production and CHP. Long-term certainties on energy policies are said to be a precondition for investments in energy efficiency and renewables. In the NEOMS models renewables and CHP subsidies are only effective in case of long-term schemes. Uncertainties about the CO₂ allowance price are still substantial. There are no firm policy perspectives regarding allocation on the long term. Uncertainties about other energy policies, like taxation or building codes are not explicitly dealt with in the NEOMS models. These policies seem to be fairly stable.

Uncertainties may be reason to postpone investment [Pindyck, 1991]. The uncertainty about future cash flows combined with the irreversibility of an investment, make that there is an opportunity cost of waiting. This is no special feature of environmental technology, but a fact of life in industry. However, strategic timing of investments in energy efficient installations is not likely to occur for buildings, energy using products and process industry. The moment of purchase or investment is likely to be determined by many other more obvious reasons⁸ than speculations on saving energy costs by postponement. For this reason, the end user models in NEOMS consider timing of the decision purely exogenous, e.g. not influenced by market conditions or policies. For power generation and refineries, however the timing of investments is clearly influenced by energy prices⁹. Investment behavior in these sectors is simulated in energy supply models in NEOMS, based on portfolio management considerations of international companies and scenario storylines.

High information and contracting costs regarding energy efficiency

Transaction costs include information costs and costs associated with negotiating, reaching and enforcing agreements. Typically this is an area in between hidden costs and market failures. It is recognized that adequate labeling of appliances will help customers to make a decision on energy efficiency, so the absence of labeling or other standardized information may be regarded a market failure. For buildings, a compulsory certificate as required by the European Performance Building Directive would offer information on the potential for improvement. On the other hand, when more customized energy efficiency measures are considered such as building insulation, the process of reaching the right contract may represent unavoidable costs. In a pilot study [Roos and van Dril, 2004] for the retail and restaurants sector these costs may be typically in the range of 10% of investments.

In the NEOMS models, information costs are not explicitly specified. Information costs are expected to be relevant in the categories energy using products and buildings. For process installations and energy conversion, information costs are part of the project engineering and therefore already assumed to be part of the investment.

⁸ In general, an investor in energy efficiency improvement cannot choose the moment to invest freely as if he was buying on the stock market. The purchase of an energy efficient tractor will not wait for specific favorable trends in the oil market. Building a new energy efficient crude furnace in an oil refinery takes five years, and only very long term trends in the oil market determine the choices made here.

⁹ High oil and gas prices make investment in coal-fired instead of gas-fired power plants more attractive despite lower efficiency and higher CO₂ emission costs.

Features other than energy efficiency are relevant for the investor's choice

In focusing on energy efficiency, it is often neglected that the investment decision on many energy saving technologies involves more aspects than energy efficiency. It can be observed when a consumer buys a house, a car or an electric appliance: functional qualities, good looks, reliability and many other features withhold him from optimizing just energy efficiency. An important characteristic of the complicated process of decision-making is its discrete character. Individuals and organizations do not optimize in a continuous universe but preselect discrete alternatives to choose from. The decision for the most optimal level of energy efficiency is not taken separately. It is not a choice from a range of options that differ only in the energy to capital ratio and satisfy the other aspects equally. Not every brand of printing press or truck has "energy efficient", "improved energy efficient" and "super energy efficient" types with other features being equal. Thus, a saving potential observed on the micro level may be substantially smaller than a potential determined across all brands and types by a scientist specifically interested in energy efficiency.

To some extent, the same holds even for customized energy intensive process installations. E.g. in basic chemicals, contractors for new installations build according to proven designs with specific features¹⁰. The most energy efficient design is not likely to deliver also the highest product purity or operational reliability. Actors value other features possibly higher than energy efficiency and make a rational decision even when the energy efficiency is not optimized.

Referring to the categories of energy use, multi criteria decision-making among discrete choices applies for energy using products, buildings and process installations. However, for components of these installations, e.g. for electric motors, light bulbs and boilers, the focus may be on energy efficiency more than other features. When energy efficiency is an important criterion and the design can be optimized accordingly, like in electricity generation, new investments are likely to reflect best practice in energy efficiency. But choosing from current model designs like the way we buy our computer or car, adding to energy efficiency a range of other criteria, is the rule in many cases, instead of the exception.

In the NEOMS models for energy demand, data for savings options are carefully balanced. Dwellings and household appliances have average sizes or size categories with specific energy consumption properties. Within such categories, the best practice is not automatically adopted once it is cost efficient. The models use low price elasticities, considering the fact that other features determine the investor's choice. The best practice information is only used to maximize the longer-term outcome when policies are applied. For instance, when the best practice for average fridges is 200 kWh of electricity consumption annually, product standards for new fridges may be based on this target. With strict enforcement towards the industry, savings may eventually reach this potential.

Access to capital

Not modeled explicitly. See [Daniëls, 2007] on using the internal rate of return vs. net present value as investment criterion, and specific cost of capital per sector.

¹⁰ See e.g. Jeroen de Beer, Potential for industrial energy efficiency in the long term, PhD thesis 1998, chapter 6 on Nitrogen fixation

4. Market failures

From literature, numerous market failures have been mentioned, some of which may have substantial impact on energy efficiency improvements. The borders between hidden costs and market failures are not always clear-cut. For example, the extra costs of lacking information and uncertainties can be reduced by institutional improvements. But when energy costs are of little importance to actors and the benefits of efficiency improvements are tiny, perfection in market conditions is largely irrelevant. However, the following market failures do matter:

- Environmental externalities,
- Public good aspects of information,
- Positive aspects of technology development,
- Non-rational behavior in private situations.

The first three involve public interests that cannot be properly valued and modeled on the micro level of investment decisions in energy efficiency. Therefore, in the NEOMS models these costs are only taken into account as far as they appear on the account of the individual investors. This occurs either by way of increased investment costs for mitigation of environmental effects or by pricing emissions like CO₂.

Environmental externalities

The environmental externalities of energy consumption mainly include:

- Damage to nature due to the extraction of fuels or the building power generation facilities,
- The risk of climate change caused by CO₂ emissions from fossil fuel consumption,
- Damage and health risks from other airborne emissions like nitrogen oxides, sulfur dioxide, volatile organic compounds and particulate matter due to combustion of fuels,
- The risks of nuclear waste.

Valuation of these externalities is difficult. What can be observed, are the regulations and policies that address these externalities and that aim at mitigating their impacts. The NEOMS models simulate only actual policies and the reaction of economic agents thereupon. Building and fuel costs will include incorporated required environmental measures, and e.g. the costs of emission allowances. There is no optimization of total environmental costs and benefits included. As far as total costs exceed actual costs, a barrier remains for an optimal environmental solution.

Public good aspects of information

For the categories of energy using products and buildings, the precondition of well-informed consumers and investors is often not fulfilled. Lacking information includes:

- Awareness of the actor that energy consumption is an issue that is worthwhile to address
- Awareness of decision moments when energy consumption can be influenced
- Information on the energy efficiency of an acquired product and on the alternatives
- Information on how energy consumption can be influenced in using the product
- Information on the costs of energy

As stated in section 3, the costs of acquiring information can be relevant and have to be included in the actor's decision. However, the lacking information can lead to the absence of a decision that could be beneficial to the actor. There may be insufficient incentives for suppliers to raise awareness and provide adequate standardized information. In such a situation, a barrier exists for beneficial energy efficiency improvement.

In the NEOMS models, policies aimed at information to improve energy efficiency are modeled as a precondition for actual decisions. The extent to which information is reaching the target groups determines the actual implementation of cost effective energy efficiency improvements.

Positive aspects of technology development

Similar to information, technology development may have public good aspects. The incentive to invest in research and development of a successful technology may be too low for individual market parties. This can be the case when:

- The intellectual property of the technology cannot be adequately protected by patents,
- The investments are too high, long-term or uncertain to be borne by private parties,
- The technology is addressing environmental externalities for which there is no market.

These cases may be reason for policy intervention, to improve income or welfare. However, policy intervention aimed at RD&D activities to improve energy efficiency technologies may be suboptimal. There is no proof that stimulating other RD&D activities may not be more beneficial for society.

In the NEOMS models, technological improvement is modeled in two ways: by new technologies replacing existing ones and by existing technologies gradually improving performance or lowering costs. Both forms of improvement have autonomous and endogenous components. There is no optimization modeled of RD&D expenditure, neither public nor private. Policies to stimulate technological development are aimed at the first stages of technology implementation, where costs are still high and information barriers exist. Investors take the available state of technology, costs and stimulating policies as input for their decision. The technology is fully embodied in the capital goods and therefore fixed for its predetermined lifetime.

Non-rational behavior in private situations

There is a large literature on non-rational economic behavior. Sorrell distinguishes:

- Imperfect information (see above)
- Bounded rationality: constraints of time, intellect and capacity lead to routines and rules of thumb in organizations, and to satisfying these conditions instead of optimizing.
- Split incentives: landlords may be reluctant to improve energy efficiency when the tenants reap the benefits of lower energy costs; or within organizations, operators may not reap the benefits from their efforts to improve efficiency, e.g. when they are responsible for production and not for energy costs.
- Adverse selection or asymmetric information: inferior energy efficiency properties of houses or used cars may not be communicated when they are sold, buyers may therefore focus on other features.
- Psychological aspects like: the form of information; credibility of information sources; resistance to changes; attitudes towards environmental issues.
- Organizational aspects like the priorities of management, access to information and funding and company culture.

All these phenomena may lead to deviations from rational decision making on energy efficiency. However, in the NEOMS models, non-rational behavior in private situations in general is not modeled. The notion that for many investments the decision making process is complicated and involves many behavioral aspects, poses a problem for modelers. Empirical

information is mostly incidental. Routines within companies can change rapidly, and behavior that is too far apart from rational economics is bound to be corrected by the market. To some extent, deviation from rationality may be random as far as energy efficiency is concerned, even favoring improvements that are not cost effective. An exception is made for the modeling of energy efficiency improvements in rented housing, which is a separate category in the households' model. Separate energy efficiency policies address this category, and actor behavior is fairly well known.

5. Barriers that matter in energy efficiency

The findings from the previous sections are formalized and summarized in table 2. It shows that barriers to energy efficiency improvements deserve serious attention, especially in end use applications.

Table 2: *Overview of the defined barriers in various categories of energy use*

Barrier	Categories of energy use			
	energy using products	building related	process installations	energy conversion
<i>Hidden costs</i>				
cost variations in specific situations inhibit full implementation	+	++	+	+
required extra efforts or disadvantages pose additional hidden costs	++	++	+	o
energy efficiency potential follows timing of capacity replacement to avoid capital loss	++	++	++	+
uncertainties about the energy efficiency gains	o	+	+	+
high information and contracting costs regarding energy efficiency	+	++	+	o
features other than energy efficiency are relevant for the investor's choice	++	++	+	o
(investor is able to influence energy efficiency of the design)	no	partly	yes	yes
<i>Market failures</i>				
full costs of environmental externalities are not incorporated	+	+	++	++
short supply of information due to public good aspects	++	+	o	o
underdevelopment of technology due to public good aspects	+	+	+	+
non-rational behavior in private situations (split incentives e.g. in landlord-tenant situations, moral hazard, asymmetric information, organisational flaws, etc.)	+	+	o	o

++: very relevant barrier; +: relevant barrier; o: no barrier

Although based on this schedule many barriers deserve serious attention, not all barriers need modeling in the NEOMS. For a selection of the barriers in table 2, some simulations are performed with the Save production model of the NEOMS. Model runs with eliminated

barriers are compared to a reference run for the GE-scenario used for national energy projections. The calculations here refer to final energy consumption, expressed on a primary¹¹ basis. Final consumption means that substantial efficiency gains on conversion technologies like cogeneration and chemical conversions in basic industries are excluded. Therefore the energy is used mainly for process installations (third column in table 2).

General approach of the Save production model

The Save production model covers light and heavy industry and horticulture. Base year energy use is subsequently divided in industrial sectors, energy functions and energy technologies. Improved technologies mainly based on Icarus [Alsema, 2001] compete with reference technologies. The basic mechanism for implementing improved technologies is a microeconomic investment decision. The internal rate of return (IRR) of a project is compared with a sector criterion to decide on adoption. However, various model formulations inhibit instantaneous and complete switches to the best options [see Daniëls, 2007]. Hidden costs are integrated in the economic investment decision mechanism and micro economic market failures are added as additional restrictions. The total energy efficiency gap can be estimated by comparing the economic potential for 2020 from Icarus with results of a model reference run. For final energy consumption, savings in the reference run amount to about 200 PJ in 2020 whereas the economic potential is about 300 PJ. See figure 6 for an overview.

Cost variations

In most NEOMS models, this problem is addressed by assuming a distribution of cost/benefit scores over the actors, leading to adaptation by only part of the group. In figure 2 an example is shown of the cumulative distribution used in the model. In Save production this is based on a normal distribution, with typical standard deviations of 2-10 %points for the IRR.

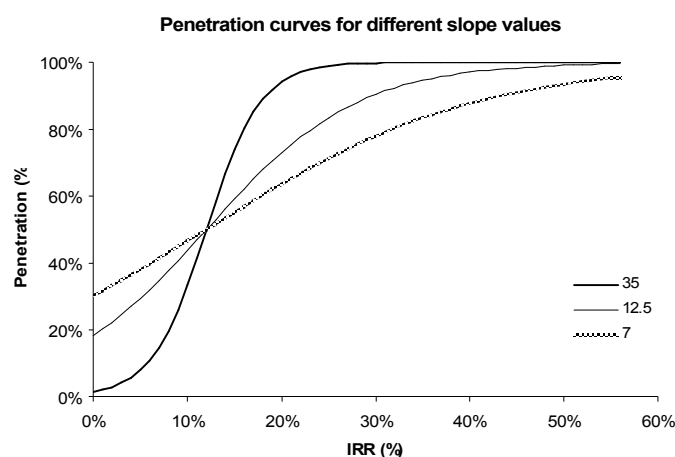


Figure 2: *Penetration in relation to the IRR for different slope values and a required IRR of 12%*

In general, cost variations do not explain an energy efficiency gap, since symmetry levels out penetration in technologies scoring below and above the average. However, at high incentive levels when many technologies have penetrated, relative costly last bits of capacity prevent a 100% score. When at the same time supply of new options is low, the effect of incomplete

¹¹ To obtain primary consumption, steam and heat are multiplied by 1.1 and electricity is multiplied by 2.5.

penetration could prevail. This effect doesn't show in the reference run of the Save production model.

Hidden costs of extra efforts, information, contracting and risk

Costs for these categories are not separately modeled in Save production, but included in the hurdle rate for the adoption of investing projects. These costs are technology dependent and only fragmentary empirical data exist. The model input is based on expert estimates and results are calibrated on sector level. By setting the criterion for acceptance of energy efficiency investment projects at a low risk free rate, some 15 PJ is gained (see figure 3).

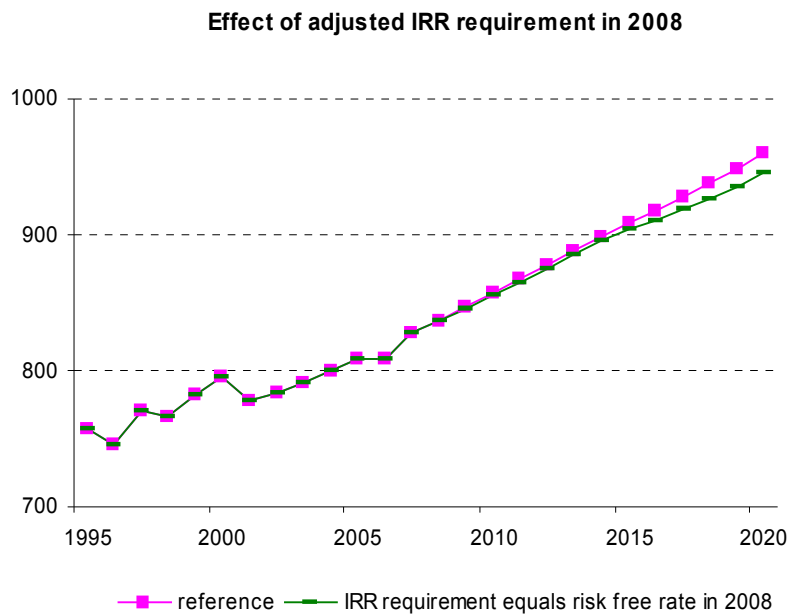


Figure 3: *Final energy consumption in industry, GE scenario, and effect of hidden costs of extra efforts, information, contracting and risk*

Timing of capacity replacement

The Save production model features a vintage approach, where lifetime is exogenous and capacity replacement moments in projections are fixed. These moments are evenly distributed in time, so with a lifetime of twenty years, only 5% of capacity is annually open for replacement by new technology. Some basic industry equipment has an even longer lifetime. In the model, lifetime ranges from zero for add-on technology to 30 years. The effect of this restriction can be found when a reference run is compared to a situation with instantaneous replacement. This is shown in Figure 4. However, with complete instantaneous replacement, what assumptions are made during the lifetime henceforth? Will there be stagnation in efficiency improvement for subsequent years or will every slight improvement of a technology again incur instant replacement? In any case, the effect will decrease in subsequent years. However, in the replacement year, a large part of the energy efficiency gap may be closed. In 2008, the additional cost efficient potential in case of complete replacement of end use technologies amounts to 67 PJ_{prim}.

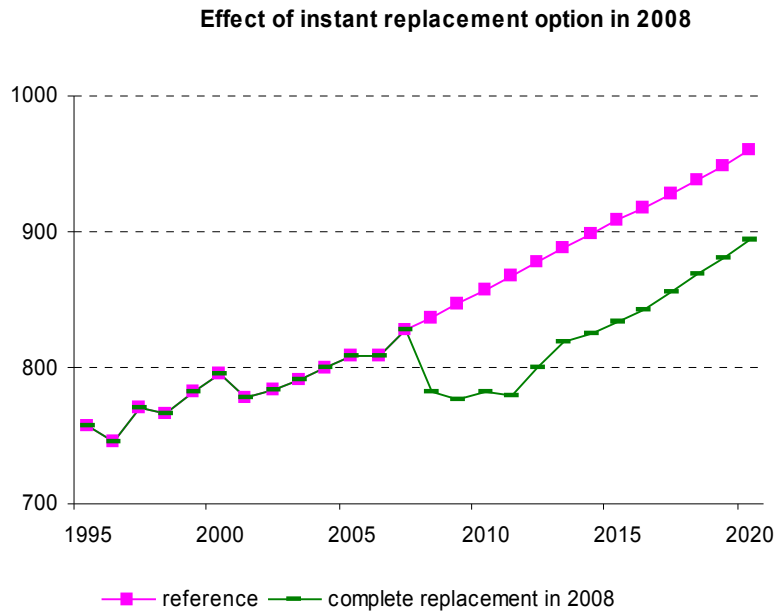


Figure 4: *Final energy consumption in industry, GE scenario, and effect of complete and instant replacement of technologies from 2008 onward*

Relevant features other than energy efficiency

Apart from some known cases of technologies, little general knowledge exists on this subject for industrial processes. It is expected that this phenomenon is smaller in industrial installations than e.g. in the purchase of private cars. The Save production model does not address this issue separately. Case study research is needed to establish the possible loss of this energy efficiency potential for industry.

Market failures on technology development, information supply and institutional flaws

Technical barriers, availability, familiarity, perceived possibilities for implementation, information costs and irrational decision-making all contribute to a dispersion pattern that cannot be explained by rational economic decision-making only. Save production incorporates the non-economic factors in a simplified way, by limiting the introduction speed of the technologies in the initial stages, and letting the technology penetration saturate in the final stages. The currently applied parametrisations of these effects are based on expert judgments, for which information from Icarus-4 and sector representatives has been used.

Both energy prices and policies may influence the role of non-economic factors. High energy prices and stringent policies may lead to more awareness of the possibilities for energy savings and a more active attitude in the search for these possibilities, thus lowering non-economic barriers. To account for these mechanisms, the injection factor and saturation factor partly depend on prices and a policy factor. All relevant formulations are described in [Daniëls, 2007]. A simulation is made with the Save production model, varying values of the policy factor in figure 5. The reference run is based on evaluations of the Dutch long term agreement policies for industry (LTA-1 and the Benchmarking covenant). The effects of intensified information and technology promotion are estimated based on expert judgment.

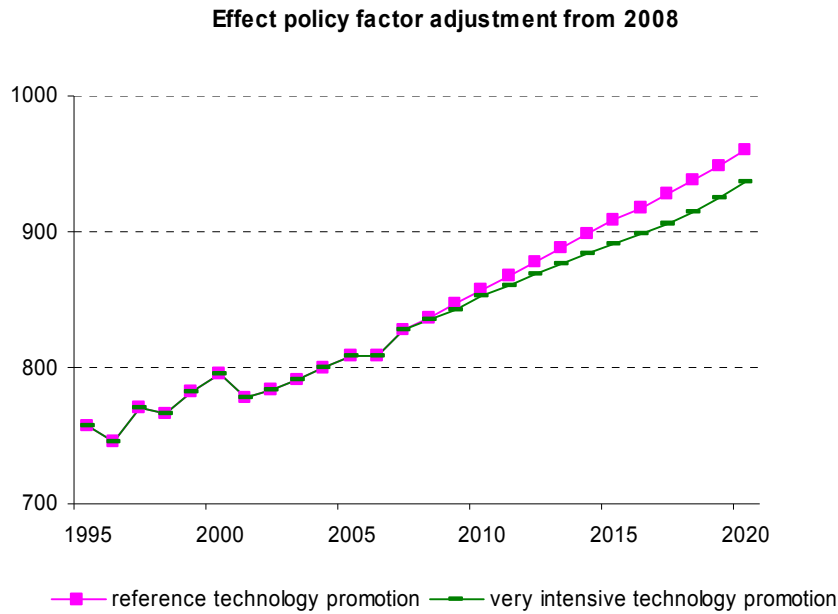


Figure 5: *Final energy consumption in industry, GE scenario, and effect of intensified information policies*

The results show that with intensified policies starting from 2008 an additional effect on final energy consumption of 24 PJ_{prim} may be expected in 2020. In the defined category of energy consumption this effect can be labeled as the actual gap, because the two previous effects are hidden costs. In the overview in Figure 6, therefore parentheses are used for the “gap”.

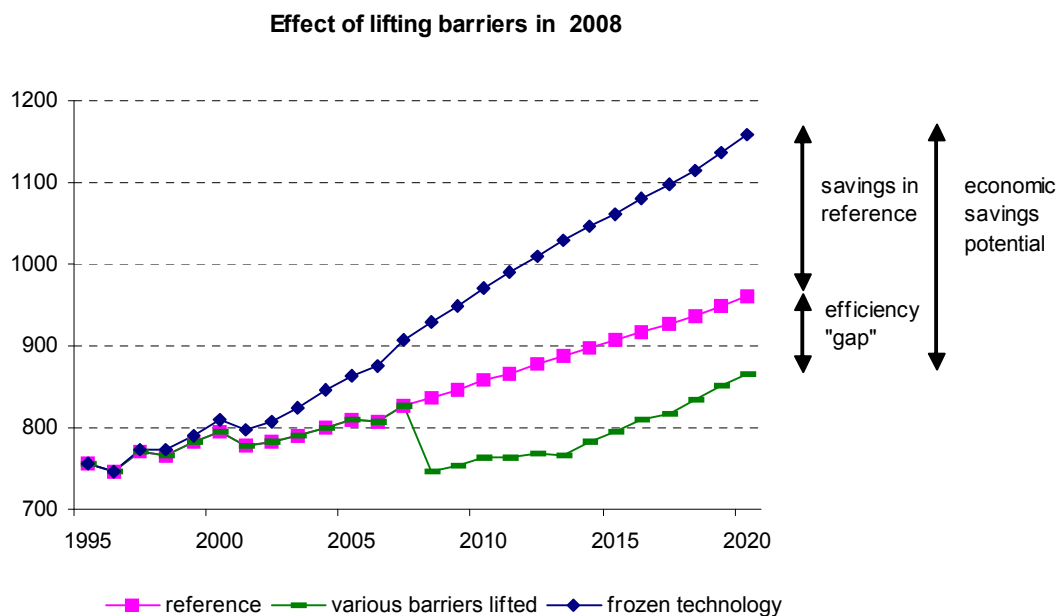


Figure 6: *Final energy consumption in industry, GE scenario, calculated energy savings and remaining potential of the specified barriers*

In the lower line, the combined effects of adjusted IRR; instant replacement and technology promotion policies are combined (Figures 3, 4 and 5). Although this does not include the effect of all conceivable barriers, it's what is modeled in Save production presently.

6. Summary and recommendations

From the model exercises above, it can be concluded that for final energy consumption in industry, the total effect of barriers to energy efficiency for 2020 is about 100 PJ_{prim}. About 75 PJ_{prim} of this are hidden costs, 24 PJ_{prim} refers to market failures. Hidden costs are substantial in all end use sectors, both energy intensive and extensive. By careful modeling, most of the costs are made visible as a normal part of the decision to improve energy efficiency. However, modeling becomes complicated and substantial lacks of knowledge still exist when model parameters have to be derived. These include:

- Variations of costs in specific situations especially buildings and industry
- Estimation of hidden costs in good housekeeping and losses of comfort in households and services sectors
- The relative weight of energy efficiency in multi criteria investment decisions for energy using products and buildings
- Transaction costs in efficiency improvements for buildings and industry

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