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A possible no regrets option for curbing greenhouse gas emissions?

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Energy Efficiency: A Possible No Regrets Option for Curbing Greenhouse Gas Emissions?

by

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SYNOPSIS

The risk of global warming is a problem that is inherently international in its character. A solution may require international cooperation on a wide scale, but binding treaties are difficult to negotiate. Moreover, free rider incentives reduce the chances of successful implementation of these accords. Therefore, governments comitted to reducing the emissions of greenhouse gases should look for areas where unilateral action may be justified. One such proposed area is the domain of energy efficiency, where improvements would lead to reduced emissions of greenhouse gases. In effect, some economists claim that in imperfect economies, possibilities for costless or profitable improvements in energy efficiency may exist. Policies aimed at realizing this potential have been named *no regrets options*; if there is a potential, then realizing it will be desirable even if global warming, or its related costs, should turn out to be negligible.

The purpose of this paper is to examine whether such opportunities occur or if they are just fanciful economic debates. In my study of the topic, I found that very little empirical research has been done to establish whether private companies can simultaneously implement energy conservation measures and save money by doing so. During a summer internship with the Center for International Climate and Energy Research-Oslo (CICERO), I generated data on energy efficiency investments by twenty-six Norwegian companies. These data are presented in section IV. My analyses point to a clear majority of profitable investments, thereby supporting the feasibility of no regrets options. It is not obvious why apparently profitable investments are not undertaken. One possibility could be that investments in energy efficiency are extremely risky; that the profitability of the projects is very sensitive to changes in the input variables. I have tested this hypotheses by a sensitivity analyses, but I did not find a clear evidence supporting this theory. Another possible explanation of the "paradox" of under-investment in energy efficiency, is that there may be barriers in the economy, preventing companies from realizing the potential for savings.

Section I of the paper gives a brief introduction to the problem of global warming, and in section II, possible strategies for curbing greenhouse gas emissions are examined. Section III describes the potential for improved energy efficiency in the Norwegian economy, and section IV examines the profitability of twenty-six Norwegian companies' investments in energy efficiency measures. Section V describes some of the barriers that may prevent realization of the potential for improved energy efficiency. The paper concludes with a brief comment on possible implications for public policy of the analyses.

I. INTRODUCTION

During the 1980s an environmental bandwagon has swept through the world. Public concern over the state of the global commons has brought the issue of environmental degradation to the forefront of political debate. Increasing attention has been given to problems such as ozone depletion, deforestation, acid rain and global warming. The problem of global warming, which will be discussed in this paper, has been of particular interest lately.

Scientific research has found that the combustion of hydrocarbons, such as fossile fuels, releases carbon dioxide (CO_2) into the atmosphere. The consentration of CO_2 and other gases (chloroflurocarbons, methane, nitrous oxide) creates an insulating layer which traps outgoing infrared radiation inside the earth´s atmosphere.[1] This phenomenon is similar to the workings of a greenhouse, only on a global scale, and is expected to lead to an increase in the earth´s temperatures in the future.

1.1 Scientific and economic uncertainty

Widespread attention to environmental degradation is relatively new. There is an important degree of uncertainty in this domaine, both as regards scientific and economic issues. Beyond the fact that greenhouse gases are likely to result in atmospheric warming, other factors held constant, there is very little consensus between researchers in the *scientific domain*. There is no agreement concerning how rapidly greenhouse gases will be emitted over the next century, how quickly they will accumulate in the atmosphere or how extensive the impacts on the earth´s climate would be. Some climatologists have found that the greenhouse effect may alter weather patterns by increasing global temperatures by 1.5 to 4.5 degrees Celsius by the year 2080.[2] The results of this global warming may be increased rainfall in some areas, while in other regions hotter and drier climate may cause drought. Sea levels will rise as a consequence of higher temperatures in polar areas.

Certain researchers believe that the impact on the climate will be extensive if society follows a "business as usual" strategy and does not make any changes in current consumption and investment patterns. Furthermore, it is argued that the effects of global warming on the climate may be considerably greater than what is believed today, due to the complex dynamic working of nature. In effect, our current scientific knowledge may not be sufficiently developed to grasp the complexity of the environmental problems created by industrial society´s intervention with nature. The recent *theory of chaos* supports such thinking. According to this theory, an infinitely small change in a non-linear system may induce a development of which the pattern

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[1] For an introduction, see Cox, L.C. (1991), p. 1-7

[2] An IPCC draft printed in *the Economist*, May 26, 1990, p. 89, gives a high estimate of ca. 6.5 degrees Celsius by 2100, and a low estimate of 3 degrees Celsius.

of development is extremely difficult, if not impossible, to predict in advance. This has been named the butterfly effect,[3] enforcing the vision of a small change which in itself does not seem to make any difference, but that may have vast and unpredictable consequences.

Added to the important scientific uncertainty in the area, is a non negligible degree of *economic uncertainty*. There is no consensus on economic modelling trying to assess the likely future costs of global warming. In effect, all economists don´t even agree as to whether the economic impact of a warmer climate is likely to lead to net aggregate costs or net benefits to the world. More importantly, even between the economists who do agree that net costs are likely to be so large that some sort of response is justified, there is considerable disagreement as regards the costs of such response. I will discuss each of these issues briefly, because they are crucial to the decision of how to respond to global warming. First I will consider the question of net costs or net benefits to society of a warmer climate and second, the cost of possible response strategies.

1.2 Costs or benefits of global warming?

Some economists claim that there are virtually no costs related to global warming, and that certain geographical regions or certain domains of economic activity may actually stand to gain from a warmer climate. In some areas, increased temperatures could have a positive effect by increasing fertility in the agricultural sector. Moreover, it is claimed that "the main factor to recognise (in an attempt to assess the social and economic impact of climate change) is that the climate has little economic impact upon advanced economic societies."[4] To support this statement are estimates showing that only 3% of the United States´ GNP originates in sectors that are described as "sensitive to climate change". Far the largest share, 87%, originates in sectors that are claimed to be only negligibly affected by climate change.[5] Included in the "sensitive sectors" are farming, forestry and fishing. Of course, this same analysis would give different results in countries with a less developed industrial sector than the United States. More importantly, such analyses may lead to a false impression of the economic issues at stake. It is not merely the direct dependence on natural resources and climatic conditions in specific sectors which influence a country´s vulnerability to increased GHG emissions, but also indirect liaisons between environmental degradation, welfare in a broader perspective, and economic output.

There is considerable disagreement between economists on issues concerning economic impacts of a changed climate. Most likely, some of this disagreement is caused by the lack of

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[3] RAMSES (1990)
[4] Nordhaus, W.D. (1990a)
[5] Nordhaus, W.D. (1991a), p.108

quantitative analysis in the domain. Very little quantitative work has been done on the economic costs of global warming.[6] Current work trying to assess these costs has assumed economic damage functions, which relate increase in temperature to economic costs, that are at least linear in the rate of warming. Damage functions are assumed to be continuous.[7] Questions have been posed as to whether these are realistic assumptions.[8] The basis of this criticism is scientific work, suggesting that warming beyond a certain limit may cause "unpredictable and non-linear ecological responses...leading to extensive ecosystem damage."[9] Should this description of ecological consequences turn out to be correct, it means that the ecological damage function may be rise abruptly beyond a certain limit of GHG emissions. If the economic damage function follows the ecological responses, as the figure 1 indicates, it is reasonable to believe that the economic impacts will be discontinuous and non-linear beyond a certain threshold. Consequently, current valuations based on linear and continuous damage functions may seriously underestimate the economic costs of global warming.

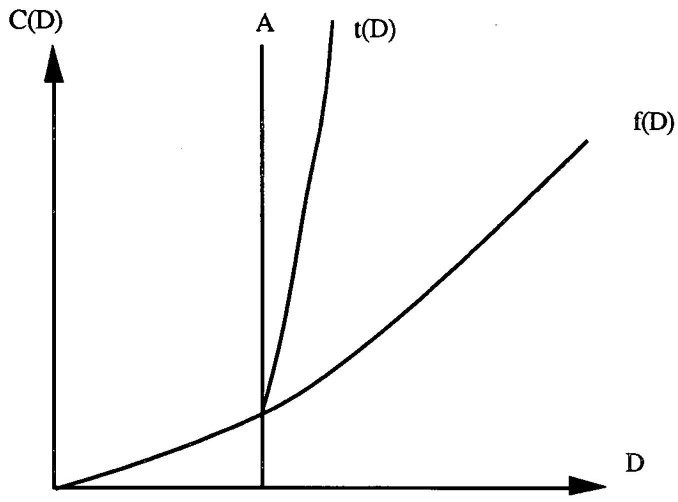

Figure 1. Economic cost of damage under two different assumptions of economic cost functions

A : Threshold
C(D) : Economic cost of damage
t(D) : Economic damage function assuming threshold effects
f(D) : Economic damage function with no threshold effects, assuming damage that is more than linear in the rate of warming
D : Increase in average temperature from one periode to the next

1.3 Preventive or adaptive policies

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[6] As Gary W. Yohe notes in an article in Policy Sciences (Yohe, G.W. (1991)), the problem of global warming is one where society has to make long term decisions under conditions of overwhelming uncertainty. Yohe estimates the cost of various response strategies by valuating the cost of protecting developed property from greenhouse induced sea level rise.

[7] Cline (1991)

[8] Pearce, D. (1991), p.2

[9] Heil and Hootsmans (1990) as cited in Pearce, D. (1991), p.2

The rapid increase in GHG is, to a large extent, due to human activities, among which is the production and consumption of energy. As long as energy prices fail to take into account the adverse effects of energy consumption on the climate, nature's resources will be overused, resulting in environmental degradation. The problem of global warming is a classical example of an external effect, a case where imperfections in the market can be corrected by some sort of government intervention. If the costs of global warming, caused by accumulation of GHG in the atmosphere, should be estimated to be substantial, the primary decision facing society would be what kind of response to give.

Essentially, public policy makers may select between two basic types of responses. One is an attempt to react *ex post* to the changes in the climate with *adaptive policies* characterized by taking a "wait and see" attitude and delaying response until the problem arises. The other approach is to attack the problem *ex ante* with *preventive policies*. Preventive and adaptive policies differ in their time aspect; preventive policies must generally precede global warming, whereas adaptive policies may be implemented when the consequences of climate change are known. Adaptive measures, it is argued, may save unnecessary capital expenditure and institutional restructuring now, by postponing action into the future.[10] Such adaptive measures will essentially be limited to land-use regulations, resettlement of threatened habitations, research on drought-tolerant crops, and building dikes sometime in the future against sea-level rise in low lying regions.[11] Preventive measures, on the other hand, involve taking action now which aim to lessen the probability of future climate change, for instance by reducing emissions of greenhouse gases today, or by implementing massive reforestation programmes.[12] If preventive measures are chosen, the policy equation is one of incurring certain costs today in order to obtain uncertain benefits sometime in the future. With these perspectives, adoption of a reactive stand may seem an alluring policy for two reasons: first, because the time preference means that costs postponed into the future are better than costs today, and second, because delayed action may reduce uncertainty by allowing for more rigourous scientific and socio-economic data to be generated.[13]

Nevertheless, delaying action is not a costless option. In fact, several factors speak in favour of implementing preventive measures today. First, there might exist a threshold beyond which continued emissions of GHG may lead to irreversible damage to the environment. If society takes no preventive measures, but follows a "business as usual" strategy, and the worst-case scenario of climate change turns out to be correct, irreversible damage could be inflicted upon the planet. The longer action is delayed, the greater is the accumulated amount of GHGs in the

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[10] Jackson, T. (1991), p.35

[11] Nordaus, W. D. (1991a), p. 111

[12] Ibid., p.110

[13] This view is discussed, for instance by Pearce, D. , A.Markandya, and E.B. Barbier (1989)

atmosphere, and the greater is the risk of passing the threshold. This risk clearly speaks in favour of some sort of preventive measure. Second, a society which is committed to an environmentally sustainable development, including the concept of equitable distribution between generations, would prefer preventive policies since an adaptive policy would risk shifting the economic burden of environmental degradation to future generations.[14] Moreover, the potential consequences of global warming could be so dramatic in areas where nature already subjects the local inhabitants to severe problems that demand for immediate large scale international endeavors to counter such effects could be justified on moral grounds.

All economic actors that are risk averse are willing to pay a premium for reducing unwanted risk. Some economists conclude that for a society that is risk averse - even if only on a very limited scale - the most prudent choice would be "to favour preventive action at the earliest opportunity."[15] In this terminology, the cost of curbing emissions of greenhouse gases could be regarded as an investment to reduce the risk of future climatic change.

If policy makers decide that some sort of preventive policies should be implemented, they may select between two categories: cooperative measures involving interaction between sovereign states, or unilateral measures on the account of one government. Cooperative measures may be difficult and time consuming to achieve. Permanent prevention of climate change is a public good; no country could be excluded from enjoying the benefits of avoiding global warming once this has been achieved. It follows that participants in an international accord will have an incentive to sign the treaty while implementing no changes on their own account, hoping to free ride on measures taken by other states. The free rider incentive is difficult to hamper due to the lack of a supranational body with reinforcement power. Even if such an organization could be set up, its functioning would be restrained by the existence of potentially substantial control costs.

Policy makers committed to reducing the risk of severe climate change should certainly support endeavors towards negotiating a binding international treaty on reduction of GHG emissions. Acknowledging both that this might take a long time and that such an agreement may not be sufficient, committed policy makers should look for areas where unilateral action may be taken today. Since one small country, acting alone, cannot solve the problem of global warming, unilateral action could be justified by its benefits to the country beyond those of contributing to reduced risk of global warming. The interesting question then, to which I turn next, is to examine whether such possibilities for unilateral action may exist.

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14 This argument in favour of preventive policies is developed, among others, by Pearce, D. , A.Markandya, and E.B. Barbier (1989)
pp.29-49

15 Jackson, T. (1991), p. 36

II. POSSIBLE ABATEMENT STRATEGIES

2.1. Some of the options currently discussed

A wide variety of measures for mitigating climate change by limiting net emissions of greenhouse gases are currently under discussion. In this section, I will give a brief description of some of the possibilities. The aim of these measures is either to increase the capacity of natural *sinks* for sequestering greenhouse gases, or to limit *emissions* from greenhouse gas sources in energy production, distribution and use.

Massive reforestation is examined as a measure to increase the capacity of the earth´s forests to accumulate carbon dioxide and thereby act as a natural sink. This option is widely favoured by environmentalists because it has a positive impact on other problems caused by deforestation, such as soil erosion. Moreover, massive reforestation programmes in developing countries are thought to have favourable side-effects on employment. *Geoengineering* has recently been put forward as another possibility of abating global warming without limiting emissions from greenhouse gas sources. These measures include means of capturing carbon dioxides from large utility boilers and sequester it or use it for instance to repressure oil fields.[16] More innovative, and probably less likely to be realized, is the idea of setting up large *mirrors* in the atmosphere to reflect the sun´s beams so that less heat is able to penetrate.[17]

Measures to limit *emissions* of greenhouse gases include *add-on pollution control technologies* [18]. These technologies reduce emissions by modifying existing capital equipment in companies. *Energy conservation measures or improved energy efficiency* are policies which reduce emissions of greenhouse gases indirectly, by decreasing energy consumption through either supply side or demand side measures. Thus, output per unit of energy consumed is increased. Such measures would include a transition towards *clean technologies* [19], i.e. technologies which combine more energy efficient operations or processes and reduced pollutant production without necessarily entailing a change in the form of energy used. Other possibilities include increased use of *alternative energy sources* [20], which do not emit greenhouse gases, such as solar or wind energy, photovoltaics, geothermal or hydroelectric power.[21] Increased use of *nuclear energy* to replace energy generated from the combustion of fossile fuels has strong proponents.[22] Also, policies are searched in order to promote *fuel substitution* away from energy sources with high greenhouse gas emissions, over to sources

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16 Ayres, R. (1991a)
17 Newsweek, June 17,1991
18 IEA (1989)
19 IEA (1989)
20 Brown,L.et al. (1990)
21 Darkazalli, G. (1991)
22 See Taylor, J. (1991) or Keepin, B. and Kats, G. (1991)

with lower or no emissions.[23] This goal could be obtained for instance by differentiated *carbon dioxide taxes.* [24] Another way of limiting emissions is by *tradable carbon dioxide emission permits*.[25] In order to be cost-effective on a global scale, this option requires successful completion of international negotiations in order to agree on an acceptable global level of emissions. Such emissions would subsequently be parted between nations, and later within each country.

2.2 Evaluation of and selection between different options

As a general recommendation, the third working group of the Intergovernmental Panel on Climate Change (IPCC) notes that to counteract the threat of climate change, countries should proceed by "implementing strategies which have multiple social, economic and environmental benefits, are cost-effective, are compatible with sustainable development and make use of market forces in the best way possible".[26] It is useful to keep this recommendation in mind when trying to select between the various options. There is no unidimensional criteria by which the measures can be evaluated and ranked. A reasonable way of proceeding, however, is to establish whether the measure will achieve the environmental goal within an acceptable time limit. Then one should address the variety of both quantitative and qualitative considerations, which may be divided into three broad categories; feasibility, cost-effectiveness and dynamic effectiveness.[27]

The study of a measure´s *feasibility* includes questions concerning the technical or practical likelihood for successful implementation of the measure. The questions to be asked to determine the feasibility of a measure, should include the following:

- Will the measure be acceptable to politicians ?
- Is implementation by the proper departments or agencies feasible ?
- Will monitoring and/or enforcement costs be reasonable ?
- Is the policy fair? If the policy has undesirable social effects, are inequities resolvable through government action ?
- If the measure relies on market forces, is it sure that markets will function ?

Dynamic effectiveness concerns how the measures will give incentives to restructuring and development over time, both in private and public sectors. Questions to consider include:

-Will the policy be flexible in the face of changes in tastes, technology, or resource

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23 IPCC, Working Group III, June 1990

24 Hoel, M.

25 Ibid.

26 IPCC (1990)

27 This following section is based on Project 88 - Round II, Rapport fra Den Interdepartementale Klimagruppen (DIK 1991), IPCC Working Group III, June 1990, and Bohm, P and C. Russel (1985)

use?
-Will the policy give industry incentives to develop new environment-saving technologies, will it encourage change in existing inefficient plants?
- Will the policy provide government agencies and private decision-makers with needed information?
- Will the purpose and nature of the strategy be broadly understandable to the general public?

Finally, the notion of *cost-effectiveness* is important to address. A measure is cost-effective if it ensures that a specific environmental goal is reached with lowest possible costs to society at large, or, alternatively; that the biggest possible reductions of emissions are obtained with the minimum use of resources. Assessing the costs of various strategies for stabilising or decreasing net carbon dioxide emissions is difficult, but if an abatement strategy is to be pursued, it is in the interest of society that the least expensive measures are implemented first, all other things equal.

The table below gives a brief summary of how the options presented rate on the three evaluation criteria.

MEASURE	EVALUATION CRITERIA COST * EFFECTIVENESS	FEASIBILITY	DYNAMIC EFFECTIVENESS	COMMENTS
Reforestation	not rated	?	?	Will programmes be extensive enough to really help? Positive side-effects (for instance on employment and soil protection), and planting trees now means generating capital for future generations
Geoengineering	not rated	?	?	Important uncertainties
Add-on pollution control technologies		Yes	?	Give no incentives for regarding the total fuel -cycle
Alternative energy	Rated more favourable than nuclear power, but not as well as energy efficiency.	Yes	Yes	Positive spinn-offs from R&D Costs are relatively high today, but expected to diminish rapidly
Nuclear Energy	Rated as most expensive by all three studies			Security? Safety? Waste disposal? Important unsolved problems
Increasse cost of fossile fuels (to induce substitution) for instance by C02 taxes or by reducing subisdies			Gives incentives to development of alternative energy sources	May cause economic recession in the short run if taxes are not revenue neutral and they raise energy prices substantially (UK White paper, 1990)
Tradable emission permits		Negociating costs Administration costs	Low flexibility?	How will markets function? Monopolies ?
Energy conservation or improved energy efficiency (including clean technologies)	Rated as least expensiveby all three studies	Is there a potential? What are the barriers which prevent exploitation? Can barriers be overcome at reasonable costs?	Positive development of R&D over time, Incentives to private sector. Flexible. Ideas may spread fast after initial investment.	Positive effect on other environmental problems, such as acid rain Positive spinn-offs from R&D Beneficial to the economy even if there is no greenhouse effect Reduces dependence on import of energy Small positve effect on employment

* Based on estimates derived from State of the World 1990, Keepin, B. and Kats, G. (1991) and Jackson, T. (1991), Jochem, E. (1991)

As the comments in the table show, there are difficulties attached to each of the options examined. A complete evaluation of the strategies is beyond the limits of this discussion, but two of the possible response strategies will be regarded in somewhat more closely. These are increased use of nuclear power and improved energy efficiency, which have received considerable attention in international literature lately.

2.3. Two interesting options: improved energy efficiency and nuclear power

Two of the most widely discussed strategies for reducing greenhouse gas emissions are pursuing nuclear power, or the improving energy efficiency. Although nuclear power seems to be a popular strategy with many governments[28], studies have not ranked this option

28 The French government wants to increase the use of nuclear power. The view of the French government was

favourably when it comes to cost-effectiveness.

In a recent comparative analyses of nuclear and efficiency abatement strategies, it is found that increased use of nuclear power in the USA cannot contribute significantly to abating greenhouse warming.[29] In scenarios of moderate to high energy growth, under highly favourable assumptions for nuclear power, it has been found that even if nuclear plants with a power of 1000 MW could be built every one to three days (which is not likely) global CO_2 emissions would still continue to grow. In effect, it does not seem to be practically feasible to curb global warming by constructing more nuclear plants. Furthermore, improving the efficiency of energy use is nearly seven times more cost-effective than nuclear power for abating CO_2 emissions.[30] These interesting results are found in studies of the American economy. They are based on the assumption that energy saved by increased electric efficiency or by generating nuclear power is used to displace current coal-fired power. Weighted average costs for efficiency improvements are estimated at 2 cents/kWh. The cost of electricity generated from new nuclear power plants in the USA is approximately 13,5 cents/kWh. For each dollar invested in *nuclear electricity*, only 7,4 kWh of coal-fired electricity could be displaced. For each dollar invested in *energy efficiency*, 50 kWh of coal-fired electricity could be displaced. 50 divided by 7,4 is 6,75, which implies that each dollar invested in efficiency displaces nearly seven times more carbon than a dollar invested in nuclear power. Therefore, it is concluded that "the construction of nuclear power stations represents a serious misallocation of resources in any *bona fide* attempt to ameliorate global warming." [31,32]

In other countries, researchers have come to similar conclusions. In Germany, an Enquête Commission on "Preventive Measures to Protect the Earth´s Atmosphere" of the German Bundestag initiated a broad study on technical measures to reduce greenhouse gases.[33] The measures studied included rational energy-use, substitution of fossile fuels by alternative energy, increased use of natural gas, and direct reduction of greenhouse gases. The Commission concluded that the highest potential for emission reduction within the next few

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expressed by Brice Lalonde, Minister of environment, at a conference held at Ecole des Hautes Etudes Commerciales (HEC), Paris, May 22, 1991 and in Lalonde, B. (1990). Great Britain´s former minister of environment, Nicolas Ridley, has said that if we want to stop the greenhouse effect, we should concentrate on a massive increase of the power of the nuclear stations. Quoted in Brown, L. et al (1990)

[29] Keepin, B. and Kats, G. (1991)

[30] Ibid., p. 552.

[31] Jackson, T. (1991), p. 43

[32] It is important to note that these results are based on numbers from the American economy. If one expects marginal costs of energy efficiency to increase as a higher degree of efficiency is obtained, the difference between nuclear power and energy efficiency abatement strategies is likely to be smaller in other countries. This is due to the fact that in the USA, energy efficiency is currently relatively low. Nevertheless, this result could be valid also in other countries, even if the difference between the two options would probably be less important than in the USA.

[33] Jochem, E. (1991), p.121

decades could be achieved by more efficient energy use and energy conversion, as well as by modification of consumer behaviour. A recent UK study concluded that a combination of energy-efficiency measures and high efficiency gas fired generation would be most effective in the UK.[34]

2.4. Energy efficiency : a no regrets option ?

It is not surprising that many countries regard increased energy efficiency as an interesting option for reducing CO_2 emissions. In effect, energy conservation and improved energy efficiency rates very favourable on both cost-effectiveness, feasibility and dynamic effectiveness. Furthermore, if it is possible to improve energy efficiency, it is a policy that could be adopted on unilateral basis. No international agreements would be necessary.[35] "Everybody (...) appears to be agreed that improving energy efficiency represents the most obvious immediate response strategy." [36]

Some economists even argue that measures to improve energy efficiency could be a *no regrets option* for curbing GHG emissions. These economists claim that net costs associated with implementation of energy conservation measures may be non-existent, or even negative. This implies that even if the risk of global warming, or its related costs, should turn out to be negligible, society would never regret having implemented such policies. Clearly, if it is possible to achieve a higher degree of energy efficiency, that is; to provide the same goods and services demanded by society with the use of less energy, this would be a no regrets policy. The environment would be better off since society would consume less of nature´s resources and simultaneously pollute less, consumers and producers would be better off, sharing the economic profits and enjoying the benefits of a cleaner environment. In other words; a win-win-win situation. The logical questions to be examined are; could there really be an unexploited potential for improved energy efficiency? If so, how big is it?

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[34] Ibid.

[35] Project 88 - Round II (1991)

[36] Ian Brown, Editor of Energy Policy (April 1991)

III.THE POTENTIAL FOR ENERGY EFFICIENCY

3.1. A perfect market economy

In a perfect market economy, there is a market for every good, with corresponding prices, and there are no market imperfections. The economy is in a general equilibrium. Actors are rational, and their goal is to maximize profit. There is perfect information, and no transaction costs. All sectors are operating efficiently, using the smallest amount possible of input (raw-materials, labour, capital, energy) to produce a given amount of output.

In such an economy, improved energy efficiency can only be obtained by means that will increase the costs of production. In equilibrium, the marginal cost (MC) is the cost each individual actor faces if he attempts to reduce his energy consumption with one more unit. The costs of reducing energy use - and thereby reducing CO2 emissions - can be described as in figure 1.

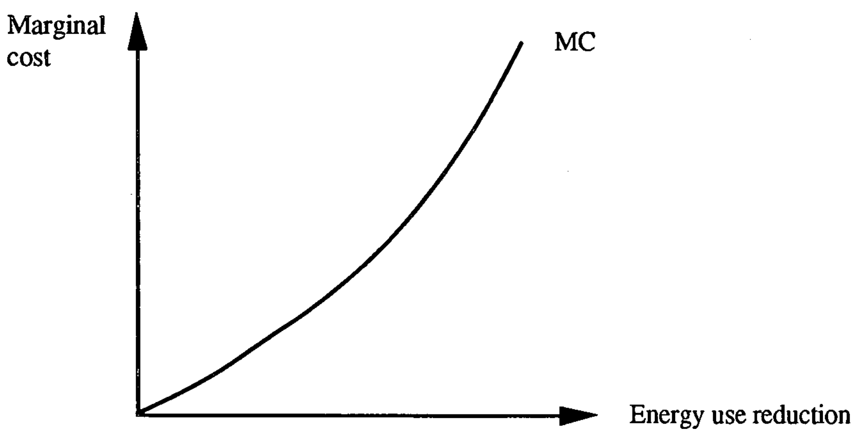

Figure 1. Cost function for energy conservation in an equilibrium economy

In a perfect market economy, all opportunities for energy conservation have already been exploited, since profit maximizing actors are ready to evaluate all opportunities, rank them in order of cost-effectiveness, and ensure that they are implemented. Any consumer of energy will have two possible sources from which he can obtain additional energy; he can either implement energy conservation measures, so that energy saved in one operation can be used for other purposes or sold, or he may simply buy one extra unit from the market to consume. A rational actor will adapt so that on the margin, these two options inflict exactly the same cost; marginal cost of implementing energy conservation measures will equal the cost of buying one additional unit of energy. In a perfect market economy, there is no such thing as a *no regrets option* for curbing GHG emissions. No costless options for reducing energy use may exist; there is no possibility of saving money by implementing more extensive energy conservation measures. The rationale is that if such possibilities had existed, they would have been identified and exploited immediately by profit-seeking entrepreneurs. [37] - [38] - [39]

3.2. An economy with market imperfections

In an imperfect economy, however, the situation may be different. In an economy where market imperfections exist, the costs of increased energy efficiency may more accurately be described as in figure 2 below.

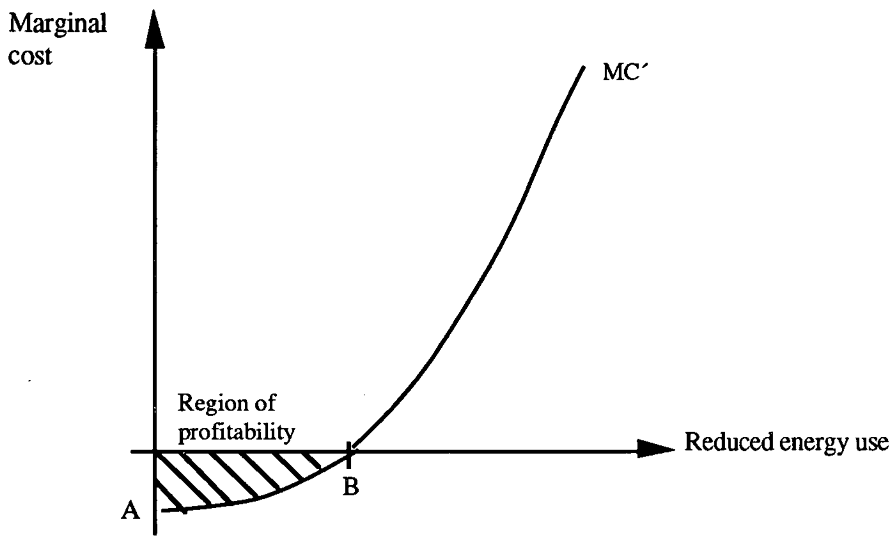

Figure 2. Cost function for energy conservation
in an economy with market imperfections

The x-axis measures reduction in energy use. Initially, the private actor may find himself in point A. In A, the marginal cost of reducing energy use with one unit is negative. It is less expensive on the margin to undertake an investment in order to reduce energy consumption, than to buy an extra unit of energy from the market. In effect, if the private actor would make an investment, for instance in more energy efficient equipment, he could reduce his energy consumption. The cost of this investment would be so low that the income derived from the saved energy would be able to give the investor a return on his investment equal to, or higher than, what he could have received had he invested his money in another project with comparable risk. The marginal cost curve (MC) is increasing, to indicate that the first units of energy saved yield high profits to the investor. As the quantity of energy saved increases, the room for additional investments becomes more scarce, and less profitable. When point B is reached, an additional investment to save one more unit of energy will no longer yield a profit

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37 Ruff, L.E. (1991), p.803-812.
38 Ayres, R.U. (1991b), p.363
39 Ayres, R.U. (1991a)

that is comparable to what the investor can obtain elsewhere. Therefore, the optimal strategy of a private actor, operating in an imperfect economy, would be to undertake investments until he reaches point B. When he has reached point B, the private actor operating in an imperfect economy faces the same marginal cost curve as a private actor operating in a perfect market economy. Of course, no rational profit maximizing actor would position himself voluntarily in A. If an actor is situated in A, it must be due to some sort of imperfection, for instance incomplete information.

One easily identified type of market imperfection which may exist, is government subsidisation of energy. If this subsidisation of energy were eliminated, the private actor would no longer face the cost function marked MC´, but the cost function marked MC, as illustrated in figure 3.

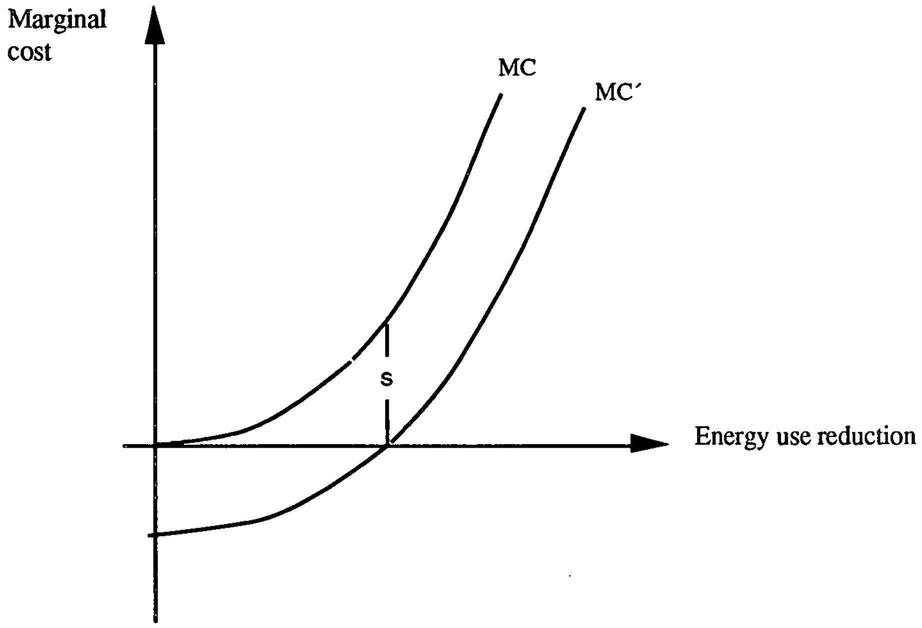

Figure 3. Cost function for energy conservation in an economy with subsidised energy

The difference between the two cost functions is the amount of subsidisation; s. As long as energy consumption is subsidised, but the economy functions perfectly in all other respects, there is no reason for the individual actor to improve energy efficiency. If subsidies were eliminated, however, investments in energy efficiency would yield higher profits. The marginal cost curve faced by the consumer would shift to the left, so that the shadowed area, which illustrates the unexploited potential for energy conservation, would be eliminated.

Society´s marginal cost curve for reductions in energy consumption will be positioned to the right of the private actor´s cost curve, so that for society as a whole, the potential for costless reductions of energy use is even greater than for the private actor. This is due to the fact that reduced energy consumption has positive external effects. In my discussion of the potential for increased energy efficiency, I will mainly concentrate on reductions that can be realized by the private sector of the economy.

If figure 2 gives a correct description of an imperfect economy, it means that there is a potential where measures to improve energy efficiency can be justified purely on private economic reasons, because improved energy efficiency will save money. Obviously, in an imperfect economy, a strategy aiming at realizing the potential illustrated in figure 2 would qualify as a no regrets policy for reducing the risk of global warming; reduced energy use would reduce the risk of severe climate change, by decreasing the emissions of greenhouse gases. At the same time, realizing the potential would make the economy operate more efficiently. Companies would produce the same amount and same quality of goods and services as before, but with the use of less energy. Therefore, even if the risks of global warming - or its associated costs - should turn out to be negligible, society would still be better off having implemented policies which aim at exploiting such a potential. The question is only; is it reasonable that this potential exists ? Furthermore, are there particular sectors of the economy where the possibilities for increased energy efficiency are abundant, and where they may realistically actualize? And if the potential does exist, how big could it possibly be?

3.3. A focus on end-use in industry

In the following section, I will examine the potential for improved energy efficiency in the Norwegian economy. The discussion will be limited to *end use* of energy in the *industrial sector* of the economy. There are several reasons why I believe that end-use of energy in the industrial sector constitutes the most interesting area to search for opportunities to improve energy efficiency.

The rationale for focusing on *end use*, and not on energy production or distribution, is clear; Analysis carried out by the OECD, as well as results from OECD case studies, have indicated that it would be desirable for governments to adopt to a greater extent the end-use perspective in energy/environment planning.[40] Sensitivity analyses and uncertainty studies with global models have shown that end-use energy efficiency is the single most important technological factor determining future energy consumption levels, and therefore also future CO_2 emissions.[41]

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[40] The OECD report (1983) states that "more attention to the type of energy service required at the point of end use, and the way in which this service might be supplied in a more efficient manner, goes hand-in-hand with increased environmental acceptability."

[41] Reilly, J.M. et al. (1987). The paper presents the results of a detailed analyses in the IEA/ORAU model. Labour productivity, rate of improvement in end-use efficiency, and the income elasticity of demand for energy in the developing world were found to be the three most important determinants of variations in CO2 emissions.

I have decided to focus on *industry* as an interesting end-user, because industry can clearly be argued to have a special role in improving energy efficiency. This is mainly due to three facts; First of all, industry is a big consumer of energy itself. In 1973, industry accounted for 33% of total final energy consumption in nine OECD countries, including Japan, the USA, the Federal Republic of Germany, France, Italy, the UK, Denmark, Sweden and Norway. In 1987 this share had increased to 38%.[42] Industry consumes a larger share of end-use energy than the service sector, which accounts for 10% to 15% of final energy use in OECD countries. The residential sector consumes 15% to 20% of final energy use, and the transportation sector is the consumer of 15% to 20%.[43]

The second reason why it is interesting to focus on industry, is that it is the provider of the technology and equipment with which other firms produce, thus influencing other companies´ use of energy.[44] If industrial companies become aware of possibilities for increased energy efficiency in their own production, this may have favourable effects for instance on R&D, allocating resources to development and widespread commercialisation of processes which are more energy-efficient.

The third reason why industry can play a special role in improving energy efficiency, is due to the fact that industry produces the consumer goods that use energy during their life-cycle and in their disposal. If industry manages to find ways of reducing energy use in their own production, the next logical step might be to try to gain competitive advantage by increasing energy efficiency in their products. There is an important potential for increased energy efficiency in consumer products. For home appliances, for instance, technologies are known which may decrease energy use substantially - often with more than 50%.[45] Some companies, such as Germany´s Braun, have already started emphasising that their products are energy efficient, using this concept as a means of attracting "green" customers.

In addition, existing market and institutional barriers, which prevent policies for energy efficiency from being implemented, are low in industry compared to other sectors of the economy (cf. table 1). Industry has both the incentives and the means to monitor and minimise energy use, in order to keep costs down. Compared to households, for instance, industry has much lower - some would claim more realistic - discount rates.[46] The fact that many companies compete in global markets, may provide a strong incentive for rapid adaptation of

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42 Numbers are from OECD and IEA (1989) as referred to in Torvanger, A. (1991)
43 Numbers are taken from Schipper, L. (1991)
44 Colombo, U. (1991)
45 Schipper, L., Hawk, D.V. (1991b)
46 Households often demand pay-back periods of less than a year in order to accept investments.

new technologies that improve productivity, product quality and throughput rates.[47] This means that industry has a relatively high turn-over of capital equipment, compared to for instance households. Therefore, energy efficient technologies are likely to be implemented more quickly in industry than in many other parts of the economy.

Economic opportunities for efficiency improvements of selected electricity end-uses

	Share of total electricity final consumption (%)	Total savings possible	Existing market/ institutional barriers	Potential savings not likely to be achieved	Time frame for savings (years)
Industrial motors	27.0	Low/medium	Few/some	Low	10-20
Commercial space heating	9.9	Mixed	Some/many	Mixed	20 or more
Residential space heating	4.7	Medium/high	Some/many	Mixed	More than 20
Residential water heating	5.4	Mixed	Some/many	Mixed	10-20
Residential refrigeration	6.8	High	Many	Medium	10-20
Lighting	16.7	Very high	Many	High	10-20

Source: McInnes and Unterwurzacher (1991)

All these factors taken together suggest that focusing on energy efficiency would have a higher likelihood of success in industry than in other end-use sectors, and that an awareness created in industry, showing that energy efficiency is both desirable and profitable, could have multiple effects throughout the economy.

But how big are the potential savings in energy use likely to be? Are we talking about savings of 5%, or is the number closer to 30% or 50%? Even if a great deal of uncertainty is connected to estimates of the exact size of these regions, some indications can be made.

During the period following the oil shocks, some energy savings were realised in the OECD countries.[48] This period showed that the link between economic growth and growth in energy demand could be broken. The decoupling of energy demand from GNP growth is the result of two types of changes:[49]

- improvements in energy conversion, distribution and end-use efficiency
- structural changes in consumption patterns towards activities and products that are less energy- and materials-intensive

Norway, however, did not improve energy efficiency as much as many other countries did after the oil shocks. The energy/GDP ratio fell only slightly for the Norwegian economy in the 1970s and 1980s, so that at the aggregate level, Norway exhibits less evidence of increased

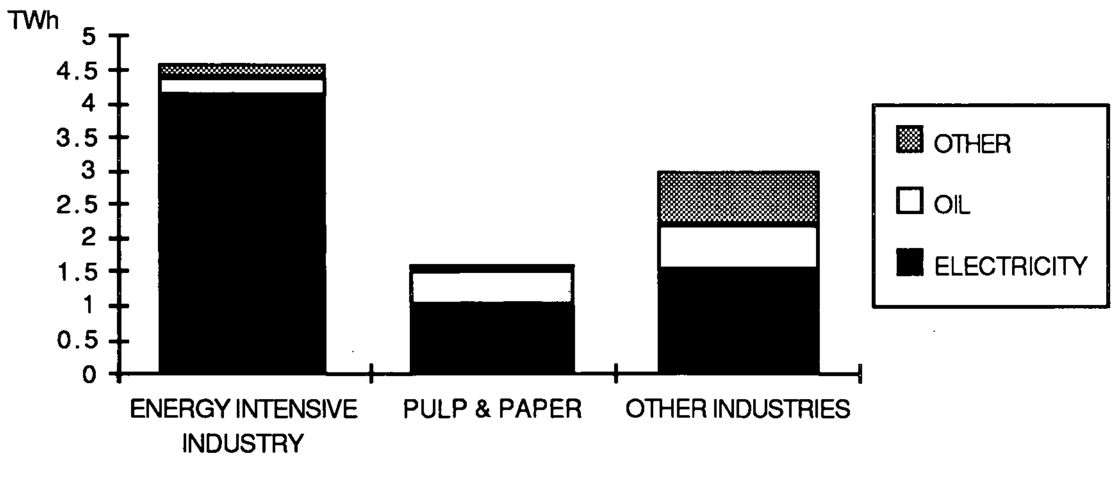
[47] Gellings, C.W., Faruqui, A. and Seiden,K. (1991)
[48] Schipper, L. (1987)
[49] See IEA (1989) or Mills, E. , Wilson, D and Johansson, T.B. (1991)

energy efficiency than do other countries.[50]

3.4. The potential for energy savings in Norwegian industry

In the following, I will try to examine the potential for energy savings in the Norwegian economy. Calculations for the Norwegian economy show that the potential for energy savings that are economically justifiable for society is relatively big. [51] All savings are calculated solely as costs saved from the reduction of energy use. Estimates of the profits that could be derived from reducing CO2 emissions, or emissions of other pollutants originating from the consumption of energy have not been taken into account, in other words; external costs of pollution have been disregarded.

It is important to note that the potential discussed here is the *economic potential* for increased energy efficiency. The economic potential includes improvements that could be realized if all sectors of the economy were to implement the best technology known and widely commercialized today. The *technical potential* is bigger than the economic potential, since it includes all improvements that would be made if all actors were to use the best technology developed, but not yet commercialized. For industry, the Norwegian Oil and Energy Department have estimated savings that would be profitable for society amounting to a total of 9.2 TWh/year. Most of the potential for saved energy consists of electricity, as illustrated in the figure below.



Source: Stortingsmelding nr.61 (1988-89)

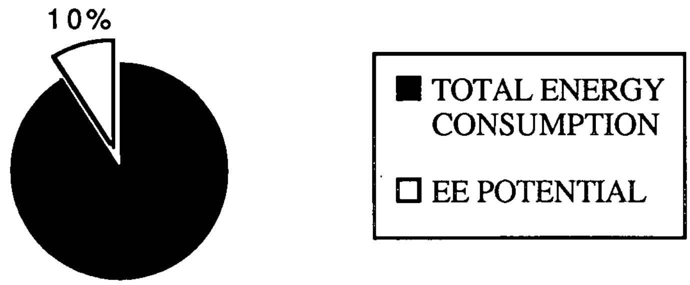
The figure shows that the most important savings can be made in the form of reduced electricity consumption. This is not surprising, considering that electricity prices in Norway

[50] Howarth, R., L. Schipper, and D. Wilson (1989)
[51] Stortingsmelding 61 (1988-89)

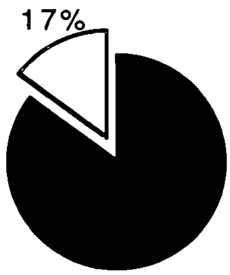
have been highly regulated and subsidised. In particular, companies operating in the energy intensive industry have been granted very low electricity prices. The price paid by users in the energy intensive industry is approximately 45% lower (after being corrected for differences in transfer costs) than prices paid by companies in the service sector.[52] Obviously, such low prices hardly stimulate investments in energy efficiency.

For the energy intensive industry, the Norwegian Oil and Energy Department (OED) estimates that energy savings equal to approximately 10% of this industry´s total consumption in 1986 would be economically profitable for society.

ENERGY INTENSIVE INDUSTRY



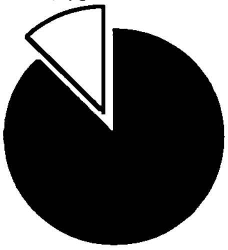
PULP & PAPER



For the pulp and paper industry, it has been estimated that the profitable potential for saved energy for society is in the order of approximately 17% of this sector´s total consumption in 1986. For "other industries", the potential was estimated to be approximately 14% of 1986-consumption.

52 Bye, T. and T.A. Johnsen (1991)

OTHER INDUSTRIES



The potential for energy savings that are economically justifiable is dependent on several assumptions, including the price of energy (i.e. electricity, oil, other), investment costs for new, more energy efficient technologies, the quantity of energy that can be saved by using new technologies, life expectancy of new equipment. Changes in one or more of these factors will, of course, change the estimated potential. Two assumptions are worth commenting on. First, it is interesting to see that the calculations are based on current energy prices prevailing in the markets. For energy intensive industries and the pulp and paper industry, a price of 0.15 NOK/kWh was used, and for other sectors the calculations were based on a price of 0.35 NOK/kWh. The potential would have been greater had the calculations not been based on subsidised prices. Second, it is interesting to note that the OED has distinguished between a "social" potential for energy efficiency, and a private economic potential. The social potential is based on calculations with a real interest rate of 7%, and the private potential is calculated with an interest rate of 20%. No explicit explanation is given for the choice of these rates, but it is reasonable to believe that the difference between the rates is related to a judgement of risk.[53] The risk associated with investments in energy efficiency is likely to be higher for a private actor than for society, so that it is reasonable that a private actor, operating in an economy with imperfect risk markets, demand a higher risk adjusted interest rate. The project-specific risk is probably negligible for society, since it probably holds a widely diversified portfolio of projects. For instance, a private actor faces the possibility of bankruptcy, which may result in a loss of the capital he has invested in energy efficiency before he realizes any savings with it. On an aggregate level, however, such risk is irrelevant, because the more energy efficient equipment would be taken over by another operator.

For each individual consumer, i.e. households or companies, investments to achieve greater energy efficiency have to be justifiable on economic grounds. That is; the costs saved by decreasing the use of energy have to be big enough to give a return on investment which is at least equal to the best alternative. The individual consumer will not have incentives for taking

[53] For a discussion of the concept of private versus social risk, see Sandmo, A. (1983)

into consideration the positive external effects of reduced energy consumption, because a unilateral action from his side would give only infinitely small improvements.

3.5. The impact of increased energy efficiency on the greenhouse effect

One important question, which I have not yet dealt with, is to what extent improved energy efficiency will help abating the risk of global warming. Energy-efficiency improvements will normally lead to environmental benefits in the form of reduced CO2 emissions in two ways.[54]

First, reducing energy input required per unit of output will generally reduce the quantity of pollutants generated from each unit of useful work. For pollutants such as CO2 and SO2, emission levels vary directly with the amount of energy used. For certain other pollutants - NOX, CO, VOC- the relationship between emissions and energy use is not linear; it depends essentially on the technology used. Since pollutants vary by energy source, the absolute environmental benefits derived will depend on the type of energy being saved.[55] Nevertheless, any reduction in the use of energy will lead to reduced emissions of pollutants.

Second, improved energy efficiency can have a strong cumulative effect on the overall volume of energy activities, by reducing the need to carry out a number of related activities. End-use of energy is only one aspect of the environmental impact of energy activities. To identify the cumulative impact, it is necessary to look at all stages of the cycle, including production, refining/processing, transformation and conversion, transport and distribution to consumer, and consumer usage - including disposal.[56] These positive secondary effects of increased energy efficiency will lead to greater environmental improvement than what is recognized by a brief, first glance. In some cases more than half of the emissions from fossile fuels occur before the point of fuel combustion.[57] This implies that when evaluating the impact of improvements in energy efficiency, it is of crucial importance that the total fuel-cycle is taken into consideration, not merely end-use. If one estimates the benefits to the environment of reduced energy use solely by regarding how the end-use emissions will decrease, the estimate will be clearly too small.

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[54] IEA (1989), p.91
[55] OECD (1985)
[56] Ibid., p.192
[57] Mills, E., Wilson, D., Johansson, T.B. (1991), p.527

IV. CASE STUDIES

4.1. Hidden costs

According to general economic theory, if investments in energy efficiency are as profitable as some economists claim that they are, then a lot more of these investments would have been made. In a perfect market economy, projects for investments in energy efficiency would be identified, ranked in order of profits, and implemented by profit maximizing managers until no more costless options of reducing energy consumption existed. This, however, cannot have happened if there are unexploited opportunities for saving energy and saving money while doing so.

Some economists belive that his apparent "paradox" may have a very simple explanation. In effect, the seemingly high rates of return may be over-valuing the profits if investments have associated *hidden costs*. Hidden costs can be defined as costs that are not known or extremely difficult to estimate a priori, when a project´s profits are being evaluated, but will appear as the project is implemented. It does not seem unreasonable to claim that managers have more extensive knowledge of the cost structure and possible savings of their specific company, compared to economists, whose task is often to make a general assessment of the saving potential at the aggregate level of the economy. Therefore, economists may overlook the hidden costs that managers perceive and rightly take into account. If such hidden costs exist, they may explain why profit maximizing managers do not implement more energy saving projects. The projects may indeed seem an alluring option on paper, but in reality managers know that the hidden costs are most likely too high for the project to give a positive economic return.

4.1.1. Desire to minimize production disruption

In many cases, the installation of a new, more energy efficient technology necessitates a disruption of current production. Given that companies seek to maximise number of production days, their desire of minimizing production disruption might delay investments otherwise considered as profitable.[58] Naturally, the cost of restraining from production is a real cost to the company, but it may be a hidden cost since it is hard to quantify before disruption actually occurs.

4.1.2. Lack of skills

Not having the right personnel available to implement new technical measures or organizational measures appears to be an obstacle to more efficient energy use, especially in small and medium sized companies.[59] 24% of managers in a recent German survey claim that they do

58 IEA (1989), p.103
59 IEA (1989), p.94

not have the right personnel available to realize more energy saving measures.[60] A recent Norwegian survey by *Opplysningsaksjonen for Energiøkonomisering* suggests that 5 to 10% of the energy used in big buildings could be saved, if operating personnel were adequately trained.[61] In the processing industry, training of operating personnel is estimated giving savings at a cost of less than one hundredth NOK/kWh,[62] which is very low compared to what these companies would have to pay for an additional unit of energy if they were to buy it from the market. The fallacy here may be that the training may induce indirect costs that may be easily overlooked. Of course, all costs caused by the training are real costs, and they must be taken into account when calculating the profitability of measures to increase energy efficiency.

4.1.3. Tester's costs

Another cost which is easily overlooked, is the cost associated with being the first to adopt a new energy saving device. As the first, or one of the first, companies to adopt a relatively complicated new measure, the firm is a tester. It has no possibility of learning from the experiences of others, and no way of avoiding beginner's mistakes. Such costs may be described as hidden costs, since they are difficult to quantify, and may therefore be omitted from or forgotten in calculations.

If companies believe that the hidden costs associated with energy efficiency investments are likely to be high, it is understandable that relatively few projects are started. Obviously, if hidden costs are too high, the projects are indeed not profitable. If this is the case, profit maximizing managers are acting in a perfectly rational manner when they decide not to undertake these projects.

Nonetheless, the cases I have studied, which will be presented in this section, indicate that at least some companies have been able to implement projects for investment in energy efficiency that are very profitable. Surprisingly, in the literature I have only been able to find one single study describing how profitable investments of this category could be to an individual company. (The literature is abundant, however, with estimates of the potential for energy efficiency on national levels.)

In 1981, the Louisiana division of Dow Chemical started an "energy contest", to find capital projects costing less than $200.000 with payback times of less than one year. In 1982 the company invested $1,7m in 27 different projects: the return averaged 173%. The contest

60 Gruber, E. and Brand, M (1991), p.281

61 The calculations are made by Svein Erik Dørum, Opplysningsaksjonen for energiøkonomisering, and cited in Enøk & miljø 3/91, p.8.

62 Stortingsmelding nr.61, 1988-89, p.22

continued, and in 1988 as many as 95 projects were selected, of which the average return was as high as 190%. Clearly, these projects were profitable. Such rates of return are considerably higher than what most firms achieve on their normal operations.

Perhaps Dow Chemical operated in an extremely inefficient manner before the energy contest started. That may be the explanation. Another possible explanation is that real opportunities exist for companies to improve the efficiency of their energy related operations. In this section, I will present case studies which aim at answering some questions related to a few Norwegian companies´ investments in energy efficiency or in energy conservation measures. All investments studied were implemented during 1990, and they were all subsidized by the Norwegian state. The studies are based on information and data obtained from the *Institutt for Energiteknikk* (IFE) in Norway, as well as telephone interviews with some of the companies. The pertinent question, which I want to examine, is whether these investments would have been profitable to the companies based on pure private economic criteria, disregarding all subsidies received from the state, and without taking into consideration the positive external effects that reduced energy use would have on the environment.

4.2. A Norwegian case study: Låne- og tilskuddsordningen

In January 1990, the Norwegian government started a project aimed at giving companies incentives to make investments in energy efficiency and energy conservation. The project, named *låne- og tilskuddsordningen,* offered loans and subsidies for investments in industry and in commercial buildings. Within the frameworks of the project, Norwegian companies that undertook investments in this category were given an offer of receiving a maximum of 20% of the investment needed as subsidies from the state. In addition, the companies could apply for loans amounting to a maximum of 50% of the total investment. Loans were given on current market conditions.

The project was directed by the Norwegian Oil and Energy Department (OED), and the practical work was organized by the *Institutt for Energiteknikk* (IFE) and a state owned bank, the *Industribanken.*. During 1990, the project received 154 applications for support, of which 124 were selected and only 17 were refused. A total of 54 million NOK were handed out as subsidies during 1990, and another 82 millions were given as loans. Investments selected varied from support for new production equipment or ventilation equipment, to equipment which make use of excess electricity and heat from condensators, or investments in improved insulation or better windows. In general, the projects supported did not make use of any new, revolutionary technologies. The techniques use were often well-known, but sometimes they were implemented in industries where such technologies were not widespread.

During the project it was decided that approximately 10% of the 124 implemented investments should be the subject of accurate follow-up control in order to try to establish how successful the projects had been. The investments to be followed up were selected on a random basis. For these investments, equipment was installed to perform accurate measures of the amounts of energy used both before and after the investment was implemented. Thereby, the exact amount of energy saved could easily be determined. The case studies presented in this section of the paper are based on the data gathered for these investments. In total, the investments of 26 companies have been thoroughly documented.

4.3. Estimated savings of energy and its impact on CO2 emissions

A total of 297 GWh of energy per year was estimated to be saved by the 124 investments implemented with support from *Låne- og tilskuddsordningen.* The estimated saved energy was distributed with 94 GWh/year for electricity, 158 GWh/year for oil, and 45 GWh/year from other sources. The actual savings realized may have been higher or lower than the total estimate of 297 GWh, because a complete follow-up was not demanded for all the projects. The goal of the project was to obtain savings amounting to 500 GWh, by government spendings of 111.4 million NOK. This goal was reached, since 54 million NOK was spent through the project, and savings of energy equivalent to 297 GWh were obtained.

Since electricity in Norway is produced from hydroelectric power, which hardly gives any pollution, the calculated reduction in CO2 emissions were estimated on the basis of savings of oil. The IFE estimated that a total of 17.000 tons of oil would be saved each year by the investments implemented. In total, these reductions in the consumption of oil were estimated giving reductions in CO2 emissions of 54.000 tons per year. The corresponding reductions in environmental costs were estimated at 21 million NOK per year.[63]

4.4. Presentation of the input data

In appendix 1, data from 26 Norwegian companies is presented. Column A indicates the name of the companies, and in column B the amount invested by each company is listed. The investments listed are the actual investments made, not the ones that were estimated *ex ante.* Investments are measured in thousands NOK (Norwegian kroner). Since the aim of my analyses was to determine whether investments in energy efficiency or energy conservation could be profitable for the companies on pure private economic criteria, I have not separated the subsidies given by the state from the money invested by the companies themselves. Therefore, the amounts listed in column B are the investments which each company would have had to make had they *not* received any type of support from the Norwegian government. Consequently, the net present value (NPV) calculated and listed for each project in column L is

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[63] SSB (1990)

the pure private economic profit which would have been realized had the companies not received any subsidies. Of course, the fact that the companies received subsidies made the investments more profitable to them. The interest here, however, is to establish whether these investments could have been profitable even without this support.

Column C gives the amount of electricity saved in thousands of kWh per year, and column D lists the price of electricity per kWh. The electricity price listed is the price each company has reported paying. It is worth noting that prices reported vary considerably, from a minimum of 0.07 NOK/kWh to a maximum of 0.62 NOK/kWh. This is partly due to the fact that electricity prices in Norway vary considerably, both according to user and depending on which region of the country the energy is bought. [64]For instance, in column E, the savings made from reduced electricity use is calculated in thousands of NOK.

Column F lists tons of oil saved. Column G gives the oil price in thousands of NOK per ton, and in column H the savings in NOK are calculated. Savings other than oil and electricity are gathered under the heading *other savings* in column H. These vary from savings of public fees because of reduced water-use, to reduced taxes from diminished emissions of SO2 and other pollutants. In two cases, the investments resulted in slightly increased operating costs. These are also marked in column H, but with a negative sign. It is important to note that savings in the form of reduced health costs or improved indoor climate, which may for instance reduce absence and thereby save costs for the companies, have *not* been incorporated under the heading *other savings*. The only costs that have been included in *other costs*, are savings which have been proved to be saved as a direct consequence of the investment. Column J is the sum of all saved costs (i.e. electricity costs, oil costs and other costs).

All cases studied are characterized by one single cash outflow (the initial investment in column B), followed by steady cash inflows in the form of saved costs (column J) over a period of ten years. Investments are assumed to occur at the beginning of year one, and cash flows are assumed to materialize at the end of each year.

The cash flow for year one is found by measuring the quantity of electricity and oil saved, multiplied with their respective prices. Added to these are the *other savings* from column H. The quantities of oil and electricity saved are based on measures during the first twelve months after the investment was implemented. The quantities are assumed to remain the same for each of the subsequent years. Relative prices are also assumed to remain constant during the whole ten years. Cash flows are in real terms.

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[64]Bye, T and T.A. Johnsen (1991), p.35

In all calculations, taxes are disregarded. For all cases studied, the investments have led to reduced costs. Therefore, the companies´ reported earnings should increase and consequently corporate taxes could be assumed to increase. There is, however, an element of higher depreciation, resulting from the increased investments, which will lead to lower taxes. Therefore, the influence of taxes remains unclear. To avoid the problem of taxes, the interest rate employed is assumed to be before taxes. Furthermore, since cash flows are in real terms, the interest rate is a real interest rate. The question concerning how big the interest rate should be, will be discussed later.

Life expectancy of each investment is estimated to be ten years. This is based on statements from the engineers who consulted the companies implementing the investments. In some cases, however, the engineers had indicated a more likely life expectancy of 15 years. Therefore, a life expectancy of ten years will not overestimate the profitability of the projects.

The net present value of the projects is calculated simply as:

$$NPV = - I + \Sigma \, (P_e Q_e + P_o Q_o + O) \, / \, (1+R)_t \quad , \quad t = 0,...,10$$

I = initial investment, column B
P_e = electricity price that the companies reported paying, column D
P_o = oil price that the companies reported paying, column G
Q_e = quantity of electricity saved, column C
Q_o = quantity of oil saved, column F
O = other savings, column I
R = real interest rate

4.5. Profitability of the projects

Based on the data presented above, the profitability of each projects has been calculated. The results are presented under the heading net present value in appendix 1 (column L and M, page 2 of the appendix). As can be seen, almost all the projects are highly profitable. With a life expectancy of ten years, and a real interest rate of 8%, only 5 of the 26 projects examined were unprofitable. The exact data are printed in column L, page 2 of appendix 1. 21 out of 26 projects gave positive net present values under these conditions. Some of the projects gave extremely high rates of return. More than half of the cases studied revealed internal rates of return that were higher than 15%, and four of these even had internal rates of return of more than 60%. Internal rates of return for all the cases studied are listed in column K of appendix 1, page 2. Remember that rates of return are in real terms. One project implemented in a bakery (number 15) gave a real interest rate of 83%, a rentability that is rarely observed for any type of investment. The project reduced the energy cost by lowering the effect component of the electricity cost. Another project (number 5) gave a net present value of more than 5 million NOK for an initial investment of less than 1.5 million NOK. The profitability of the projects is often exceptionally high. Therefore, it is surprising that companies seem to be willing to undertake them only if they receive subsides.

If one assumes that possible hidden costs have materialized, so that the profits reported by the companies are indeed the profits they have realized, it seems difficult to explain why so few investments of this type are implemented. Is it possible to explain the reluctance towards the investments without concluding that companies do not act in a rational manner?

4.6. Risky projects?

One possible explanation to the apparent paradox is that investments in energy efficiency or energy conservation give highly uncertain returns; that is, that they are very risky. For investments with a considerable amount of risk, it is rational for actors to demand high risk adjusted rates of return to compensate for the risk they carry, so that it may, in effect, be rational for them to forego investments with high, but uncertain profits.

In the Norwegian economy today, it is possible to obtain a risk free interest rate of approximately 10% - 11% by investing the money in a bank. The current rate of inflation is the lowest in many years, approximately 3%, so that it is possible to receive a risk free real rate of return, before taxes, of around 7% to 8%. After taxes, the real rate of return is lower. The effective corporate tax rate is approximately 28%, so that a real rate of return after taxes for a risk free investment is currently in the region of 5% to 6%. This real rate of return is the highest in a long time. Even though it may be expected to decrease, current investments should be compared to this rate. If investments in energy efficiency or energy conservation were considered to be risk free, then they should be evaluated by using a real interest rate of 7% to 8% before taxes. The calculations in appendix 1 show that the investments examined are clearly profitable based on a real interest rate, before taxes, of 8%. Only 5 of the 26 projects gave a negative net present value with a real interest rate of 8%.

But investments in energy efficiency or energy conservation are not risk free, and investors ought to be compensated for the risk they carry when they undertake these investments. The interesting question is just how risky the investments are, and how high risk adjusted real rates of return a rational actor would demand to invest in projects of this type. For the projects I have studied, the profitability is so high that even if investors should demand a risk-adjusted real rate of return of 18%, which gives a risk premium of 10%, most of the projects would still be profitable. In effect, 16 of the 26 projects examined yield a positive net present value even with a real interest rate of 18%.

But is it possible that the risk associated with the projects could be so big that exceptionally high risk premiums could be justified? Is it possible that investors are acting in a rational manner when they forego investments with real rates of return of up to 80% ? In order to answer this question, I will examine the risk relevant for the observed investments in energy efficiency and energy conservation.

4.7. Evaluation of risk

If investors are assumed to be risk averse, they will prefer projects with low risk to projects with high risk when their profitability is the same. In general, two factors are important in determining a project´s variability of return, which is a measure of the project´s risk. First, an investment´s net present value will be altered if the conditions on which the calculations are made should alter. Therefore, it is important to estimate the *probability* of a change in these basic assumptions. Second, it should be determined how *sensitive* the investment´s profitability is to changes in the assumptions. These two factors combined; probability and sensitivity, will determine the investment´s variability of return. A high probability of a departure from the estimated value of an input variable combined with a net present value which is very sensitive towards changes in the input variable, would indicate a risky project.

I have tested the second factor, sensitivity, by examining how each projects´ net present value (NPV) alters as a response to changes in the underlying assumptions on which the calculations are based. If the net present value of each project varies considerably with only marginal changes in the underlying assumptions about life expectancy of equipment, initial investment, quantity of energy saved, and energy prices, then this adds to the uncertainty of the projects.

Sensitivity is calculated as: $S = (NPV_2 - NPV_1)/(X_2 - X_1) * X_1/NPV_1$

Where

X_1 = underlying assumption as stated in base case

X_2 = altered underlying assumption

NPV_1 = initial net present value, as calculated on the basis of the base assumptions

NPV_2 = net present value, after a change in the the underlying assumption

A high degree of sensitivity adds to the uncertainty of the project. Projects with a high degree of sensitivity, combined with a high probability of changes in the input factors are risky. Companies may be rational when they avoid implementing such projects unless they give very high risk-adjusted rates of return.

A low sensitivity, combined with a low probability of change in the input variable, would indicate that the projects do not have uncertain returns; that they are not very risky. If this is the case, it does not seem to be rational for the companies to avoid undertaking the investments. If projects are not risky, and they give high rates of return, other reasons must be sought to explain why companies do not invest in energy efficiency.

The *probability* of experiencing a change in the value of an input factor, combined with the net present value´s *sensitivity* towards the altered input value will determine the project´s risk premium. For the investments I have studied, the following input factors should be examined to determine the risk of the project; life expectancy of equipment, size of the initial investment, quantity of energy saved, and future energy prices. I will discuss each of these factors separately.

4.7.1 Risk related to life expectancy of equipment

The data presented in appendix 2 show that for the cases examined, assumptions concerning the life expectancy of the equipment implemented are relatively important when determining a project´s net present value. The calculations show how net present value changes when life expectancy of equipment increases with one year. All calculations are made with a real interest rate of 8%. When life expectancy increases from 10 to 11 years, net present value increases with an average of 26% (column V). If life expectancy should increase from 11 to 12 years, the average net present value would increase with 16% (column W). With an increase from 14 to 15 years the average net present value increased with 11%. As expected, the higher the initial life expectancy of equipment, the less importance has an additional increase of another year. This can easily be explained by the discount factor, whose effect is to give less weight to cash flows in later years than in earlier years.

These observed changes in net present value are not insignificant. For the investments examined, net present values seem to be relatively sensitive to changes in life expectancy. This means that the underlying assumptions of life expectancy of the equipment employed seem to be important when determining an investment´s net present value. Whether this sensitivity implicates that the *risk* faced by the companies is high or not, depends on how difficult it is to find a correct estimate for the life expectancy of the equipment - in other words; the probability of making an incorrect judgement.

When determining the probability of making an incorrect judgement, it may be useful to distinguish investments based on completely new technologies from investments based on well-known technological solutions. For investments based on completely new and unknown technologies, it may be difficult to determine exactly how many years the equipment may be used. For well-known and widely tested technologies, on the other hand, it is reasonable to expect that it is not very difficult or costly to obtain information to establish the equipment´s life expectancy with sufficient certainty. Therefore, the associated risk for well-known technologies is probably not very important.

A factor which increases the risk regardless of which type of technology is used, is the fact that investments in increased energy efficiency are often implemented as part of a larger investment project undertaken by the company. Therefore, the energy efficient equipment is often only one small part of the production equipment as a whole. When this is the case, the risk of the "energy investment" is not only related to the life expectancy of this equipment, but just as much to the life expectancy of the rest of the production equipment. If the rest of the production equipment has to be changed after only a few years, the energy efficiency investment may be of no value.

If this result holds as a general conclusion, that is; if investments in energy efficiency are very dependent on the life expectancy of the equipment, it seems reasonable that investors demand high risk adjusted interest rates, and, consequently, that few investments involving new and unknown technology are undertaken. But such uncertainty does not exist when the technology that is to be used has already been widely commercialized and tested. This is indeed the fact for much of the equipment available for companies today. Therefore, it does not seem likely that uncertainties related to life expectancy can explain why so many investments of this latter category are not implemented.

4.7.2. Risk related to size of the initial investment

The probability of making an incorrect estimate of the size of the initial investment was not very high for the cases studied. For all the projects within *låne- og tilskuddsordningen*, the actual initial investments were only 3% higher than the estimated investments.[65] The cases studied do not indicate that it is difficult to make a good estimate of the initial size of the investment, so the probability of making an incorrect estimate seems to be low.

In appendix 3, calculations are made which show how sensitive the investments are towards changes in the initial investment. All calculations were based on the initial investments that the companies themselves had reported. For all the cases studied, the real initial investment was increased with one percent. Afterwards, the percentage change in net present value was calculated while keeping the real interest rate and the life expectancy of equipment constant at

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65 IFE (1991)

respectively 10 years and 8%.

The calculations in appendix 3 show that for a one percent increase in the initial investment, the average net present value decreases with more than one percent. The median net present value decreases with only 1.3%.

It seems reasonable to conclude that for the cases studied, the risk related to the size of the initial investment, was relatively low. First, because the probability of making an important error in the estimate of the size of the initial investment was low, and second, because even if an incorrect estimate should be made, the median project did not alter its net present value considerably. Therefore, this risk does not seem to justify particularly high risk adjusted rates of return for investments in energy efficiency.

4.7.3. Risk related to price sensitivity of electricity

In appendix 4, calculations are made which show how the net present value of investments change as response to changing electricity prices. For all the cases studied, the electricity price was increased with one percent compared to the price that the company itself had reported paying. Afterwards, the percentage change in net present value was calculated while keeping the real interest rate, the life expectancy of equipment, and the initial investment unchanged. An interest rate of 8% and a life expectancy of 10 years was used.

The cases studied do not seem to be very sensitive to changes in energy prices. On the average, the net present value of the investments increased with a little more than 2% for each one percent increase in electricity prices. The median project´s net present value decreased with only 1.4%. Therefore, the sensitivity of the projects studied towards changes in the electricity price was not very important.

In addition, the probability of experiencing an unexpected change in electricity prices in Norway, is not very high. Electricity prices have been controlled by the state, and contracts are usually negotiated on a long term basis. This situation may, however, change in the future. A more market base approach, with flexible prices, has been advocated by economists.[66] Flexible prices would increase the risk for companies, but theoretically, such a risk could be eliminated if futures markets were created where users could hedge their position.[67] More importantly, a market based approach would make investments in energy efficiency more profitable, because electricity prices would rise if subsidies were eliminated.[68]

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66 See, for instance, Førsund, F. et al. (1991)
67 Berg, M, K.P. Hagen, and E. Hope (1986)
68 Ibid.

The low sensitivity of net present values related to increases in energy prices, combined with the low probability of a sudden change in prices, makes it seem unreasonable to conclude that companies demand high risk-adjusted discount rates in order to compensate for this risk.

4.7.4 Risk related to sensitivity of electricity quantity

Making good estimates of how many units of energy that may be saved by a particular investment may be difficult. Especially small companies may lack the competence to make such evaluations, so that the probability of errors may be high. For the projects that were subsidised by *låne- og tilskuddsordningen*, the real quantum of energy savings made turned out to be 15.6% lower than the estimated savings. In total, energy savings were estimated in the order of 38 698 MWh/year, while realized savings were only 32 571 MWh/year. Of course, such errors in estimating volume saved has implications for the risk of the investment. Therefore, it is interesting to examine how sensitive the investments´ profitability is towards these changes.

In appendix 5, calculations are made which show how the projects´ net present value responds to changes in the quantum of electricity saved. For a real interest rate of 8%, and a life expectancy of 10 years, the projects analysed responded to an increase in quantity saved of 1%, with an average increase in net present value of 1.9%. The median increase was 1.3%. Even though this influence cannot be neglected, it does not seem reasonable to claim that it is an extremely high sensitivity. For the cases studied, there seems to be a relatively high probability of errors in the estimated quantum of energy saved, but it does not seem as if such errors would greatly influence the projects´ net present value, since the NPV is not very sensitive towards changes in volume saved.

4.7.5. Risk related to savings of oil and oil prices

Only a few of the cases studied reported savings of oil. Therefore, it is very difficult to evaluate how changes in the quantity saved or changes in oil prices influence the profitability of a "typical" project. Oil prices are, however, more volatile than electricity prices, so that the risk related to savings of oil may be more important than the risk associated with electricity.

4.8. Weaknesses of the analyses

The most serious weakness of these case studies is probably related to the accuracy of the data collected. Measurements of energy use before and after the investment have been executed by the companies themselves, as this was a part of the criteria set for receiving subsidies from the state. In some cases, relatively important amounts of money have been used to facilitate accurate measurements. Nevertheless, it is not unlikely that errors in measurements may have occured.

Moreover, it is important to recognize that saved costs are based on reportings from the companies themselves. The different companies have reported paying electricity prices that vary so much from one company to another that the highest price paid is almost nine times higher than the lowest price (0.62 NOK/kWh versus 0.07 NOK/kWh). Some of this difference can be explained by the fact that some industries receive important amounts of subsidies from the government, thereby reducing their cost of energy. In effect, the electricity price paid by the energy intensive industry in Norway (corrected for differences in delivery costs) was only 45% of the price paid by companies in the service sector.[69]

Some of the differences in prices may be explained by the fact that some companies base their electricity use on excess electricity, which is very cheap, while others are dependent on a steady supply, for which prices are considerably higher. Since energy prices are reported by managers, another possible explanation may be that these managers do not have perfect information as regards their own energy cost. Or, perhaps, they are not completely sure of which price is relevant when they are to make an investment analysis. If this is the case, that is in itself an interesting conclusion, since it is an indication of lack of information and/or skills in order to make a rational investment decision.

For all types of research, it is a well-known phenomenon that increased attention to the matter studied may in itself alter the situation. In the cases studied here, the companies have been forced to closely monitor their energy use, and this fact may in itself have led to reduced energy consumption. This means that part of the savings may have been possible to realize even without investments in physical equipment, merely as a result of increased attention. Remember that in the simple calculations made, savings are supposed to remain constant, in real terms, over all years. If some savings are obtained as a result of increased focus on energy consumption, and if this attention should vanish as time goes by, the profitability of the projects as calculated here would be overestimated.

Furthermore, there may be biases pertinent to self-selection. It is not unlikely that the companies represented in these case studies differ from an "average" company. All companies applying for support had to fill in documents with relatively detailed information, proving that there was a potential for improved energy use. The companies examined here may have a greater potential for reduced energy consumption than the Norwegian economy as a whole. Moreover, they may be better skilled than most companies when it comes to estimating amounts of energy saved or initial investment needed.

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69 Bye, T and T.A. Johnsen (1991)

Obviously, conclusions concerning the potential for reduced energy use for the economy as a whole cannot be made solely on the basis of such a limited number of case studies. Nevertheless, it is interesting to note that almost all the companies which applied for support, received subsidies or loans, or both. Of the total of 154 applications, only 17 were refused. The high rate of acceptance may hint that possibilities for profitable investments can exist also in other companies.

4.9. Concluding remarks

Despite the limited number of investments examined, and the plethora of weaknesses that exist in the data collected, it is possible to draw some conclusions from the cases studied. Even though there are risks associated with investments of the category examined in these case studies, the projects examined do not seem contain an element of risk that could justify the extremely high discount rates that investors implicitly are seen to demand today. The cases studied do not seem to incorporate very high amounts of risk. Neither the quantity of energy saved, the energy prices or the size of the initial investment appear to have a very important impact on the profitability of the projects.

The only factor whose exact determination may be complicated, and whose altered value appears to have a relatively important impact on the investment's profitability, is the life expectancy of equipment. For projects that are dependent on using brand new and complicated equipment, the investors may be right to demand high risk-adjusted real rates of return. But the risk would not be very high if companies employed technologies that are already well-known and commercializeed, so that engineers have a fairly good knowledge about the minimum life-span of the equipment. In effect, very important savings of energy could be realized if companies would only use the best available technology that is commercialized today. They do not need to undertake investments with equipment that has not yet been widely tested. As discussed in section IV, the potential for investments seems to be so big that it would have a very favourable impact if companies would simply make use of very uncomplicated and uncontroversial techniques.

In summary, the cases studied do not seem to be very risky. Moreover, the investments are clearly profitable even if they were to be evaluated using a very high risk-adjusted discount rate. As the calculations in appendix 1, page 2 show, a majority of the projects are profitable even if a real interest rate of 18% is used. Therefore, it does not seem reasonable to explain the lack of investment by private companies in energy efficiency as a rational attitude, fostered by extremely high risks related to the projects. It may be reasonable to conclude that there must be some sort of barriers which prevent companies from investing in energy efficiency. Such possible barriers will be examined next.

V. BARRIERS TO ENERGY EFFICIENCY

Many economists tend to discern environmentalists´ discussions about profitable investments to increase energy efficiency as wishful thinking. The economists´ attitude is often compared to the one of a man whose friend draws attention to a ten-dollar bill lying on the sidewalk; "It can´t be ", is the economist´s comment, "If it was, somebody would have picked it up.

Nevertheless, the case studies of Norwegian companies in section IV seem to support to the notion of unexploited possibilities for profitable investments in energy efficiency. It seems clear, however, that the fact that economists point to the unused opportunities, and even the fact that companies have saved important amounts of money on such projects, give no guarantee that the opportunities will be exploited by other firms. If one does accept the cases studied suggesting that there are big, unexploited possibilities of both profitable and technologically feasible investments in energy efficiency, then why aren´t these investments made by more companies? If so many opportunities for profitable savings exist, then why don´t companies adopt them?

Environmentalists claim that it is the existence of numerous barriers that prevent companies from exploiting the unused opportunities. These are *real barriers*, not hidden costs. The barriers hamper the functioning of markets, thereby preventing firms from consuming the "free lunch" consisting of investments in energy efficiency. If such barriers had not existed, companies would have been able to reduce their energy consumption by the amounts calculated by economists. I have distinguished between two types of barriers; barriers that arise if economies depart from the assumed perfect competition, and institutional barriers. The first category of barriers arise from imperfections in the markets. In various ways, they prevent a company from operating efficiently in the market.. Institutional barriers, on the other hand, may be characterized as barriers which prevent companies from functioning in a perfect manner internally. A single barrier may, however, also be a combination of these two types.

5.1 Distortions to the assumption of perfect competition

5.1.1 Subsidisation or price fixing by regulatory agencies

For some energy sources, such as oil, prices are normally set by supply and demand in international markets. Other energy prices, as the price of electricity, are often determined not as a result of the market forces of demand and supply, but of a variety of other reasons. State owned electricity utilities usually set prices with the goal of obtaining zero profits.[70] Often, electricity prices are not based on current replacement or market value of utility assets, but on

70 Stortingsmelding nr.61, 1988-89, p.22

historical accounting costs. This tends to undervalue the true cost of electricity. In addition, consumers are given no incentives to reduce their consumption during peak periods, since prices are time-invariant.[71]- [72]

In many countries, certain forms of energy use are subsidised through taxation of alternative energy sources, financial incentives and other artificial means.[73]-[74] Subsidies of energy prices lead to higher levels of energy consumption than would be the case were prices to reflect realistic market prices or world prices.[75] In Norway, prices for processing industries and the pulp and paper industry are at least partially determined as a consequence of specific goals related to employment and to population of rural areas.[76] The subsidisation of selected industries distorts efforts of energy conservation, since companies that face low energy prices will have weak incentives to invest in energy efficiency, while firms with high energy prices might invest too much in such measures. For society as a whole, an optimal allocation of energy conservation measures would be distributed differently. In other words, total investments will not be allocated in a way that assures that reduction in energy consumption through improved efficiency is obtained with least costs or highest profits.[77] A cost effective reduction of energy use is not assured. Additionally, subsidies will often favour existing companies, which may be assumed to use equipment that is less energy efficient than that of potential newcomers, thereby postponing improvements even more.[78] All forms of intervention in markets which lead to energy prices that are lower than they would be in a free market, constitute barriers towards increased energy efficiency by reducing incentives for implementing measures to lower energy consumption.

5.1.2. Imperfect information

The International Energy Association (IEA) regards lack of information as an important source to the current under-investment in energy efficiency.[79] The classical assumption of perfect information is distorted mainly in two areas: First, companies may simply not be aware of the existing technological opportunities for investments. A recent study by a Norwegian consultancy revealed that knowledge of technology that is already developed and ready for use,

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71 Sioshani, Fereidoon P. (1991), p.233

72 For a discussion of optimal tariff structures, see Brand, M. (1990). Brand suggests that since theoretical requirements clearly indicate the advisability of time-of-use rates, such rates should be tested in field experiments.

73 Sioshani, Fereidoon P. (1991), p.233

74 Ayres, R.U. (1990), p.366, gives as an example the oil and gas allowance in the USA, which was "a direct subsidy to the petroleum and gas producers, and an indirect subsidy to consumers."

75 Nordhaus, W.D. (1991b)

76 Stortingsmelding nr.61, 1988-89, p.22

77 Ibid

78 Ayres, R.U. (1991)

79 IEA (1989), p.103

is fairly low.[80] When asked whether they knew alternative technologies which could be used to improve energy efficiency in their company, and thereby reduce the impact of higher energy prices, the answer was no from almost 60% of the managers interviewed. In certain sectors, the no rate was almost 75%. Surprisingly, in the highly energy intensive metal industry, where energy costs amount to an important percentage of total costs, only 25% of managers claimed to have knowledge of such new technologies.

Additional support to the theory of imperfect information is given by a recent study of five hundred small and medium sized companies in West-Germany by E. Gruber and M. Brand[81]. According to their findings, 40% of the companies claim that the reason why they do not implement more energy conservation measures, is simply that "information about the right measures is missing". Only half of the firms interviewed thought the available information on energy conservation to be adequate.[82] Moreover, lack of communication between companies in different sectors of the economy may prevent the diffusion of measures which have proved to be successful in one industry, and which could probably be implemented with success in other contexts.

Secondly, it is not unlikely that in the real world, companies do not have complete control over their use of energy. This lack of information complicates calculations for establishing whether investments are profitable or not. Firms tend to know the total cost of energy consumed, but the means for controlling energy use in each specific activity are often not implemented. Minor investments in control equipment that monitors energy use, have often realized savings of 3% to 5% of total energy costs.[83] Together, these findings clearly undermine the classical assumption of perfect information. Lack of information or improper information may indeed prevent companies from performing more efficiently.

5.1.3. Low share of energy costs in total costs

Managers are presumably forced by competition to analyse all costs carefully, and to make constant efforts to minimize costs. It is argued that in companies where energy is an explicit and non-trivial element of operating costs, energy efficiency is more likely to be obtained than in circumstances where energy consumption has a small share of total costs.[84] -[85] For the same reasons it is assumed to be easier to realise energy saving measures when operating on a large scale, compared to the operations of a small company. The Gruber and Brand survey

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80 Eckbo, J.E. (1990), part III, appendix IV
81 Gruber, E. and Brand, M (1991), p.281
82 Ibid, p.282
83 IFE (1989)
84 Ayres, R.U. (1991b)
85 Ruff, L.E. (1991)

finds empirical support for this view. Additional support is found in a recent study by the Institute for Energy Technology in Norway. The survey shows that on the average, energy costs make up less than 3.0% of value added for a company. Industries where energy cost is a relatively important part of total costs, have experienced a stronger decrease in energy use during the period from 1982 to 1986 than industries where energy costs have a relatively insignificant share of total costs.[86] Savings of energy that seem to be too small for the companies, may therefore amount to relatively important amounts at the aggregate level of the economy.

5.1.4. Liquidity constraints

Problems of raising cash for new investments may prevent the realisation of many profitable projects. This is a general problem of imperfect capital markets, however, not one that ought to be specifically related to investments in energy conservation relative to other investments. Nevertheless, it is possible that when facing a liquidity constraint, managers give priority to investments that are absolutely necessary in order to continue production. Investments in energy efficiency usually do not fall into this category. Of the companies examined by Gruber and Brand, 53% of the managers said that "the money is needed for more important investments" when asked they had not realized more energy-saving measures. Therefore, lack of capital may create a barrier preventing profitable investments from being made.

5.1.5. Economics of scale favouring existing enterprises

If economics of scale are realized in an industry, new firms, using new technology, will have problems establishing themselves. Since technological development may be assumed to give new equipment that is more efficient than older versions, the stock of existing equipment will be less up to date in a market with economics of scale than in a market with perfect competition. Thus, economics of scale may constitute a barrier towards realization of a more energy efficient industry. This simple notion, however, has been given hardly any consideration in the existing literature, and no attempts of empirical verification has been found.[87]

5.1.6. Uncertainty about future energy costs

Uncertain realised savings for each measure is claimed to be an important obstacle against profitable investments in energy efficiency.[88] Prices of energy, especially oil, are relatively unstable compared to the prices of other goods and services. This instability nurtures uncertainty, and causes problems in estimating potential future savings related to specific investments. Such uncertainty will be particularly constraining when investments are large scale

86 IFE (1989), p.8, table 1.3.
87 A similar view is expressed by Ayres, R.U. (1991)
88 Schipper, L. (1991)

and irreversible in the short to medium run. 42% of the managers in Gruber and Brand's report give this uncertainty as the reason why they have not realised more energy-saving measures. Energy prices that do not evolve in volatile world markets are often established by government regulation. Thus, companies face a political risk related to an unannounced change in preferences for intervention and determination of energy prices. In addition, problems of forecasting future maintenance costs for new equipment may play a role.[89] As discussed in section V, such uncertainty would not be a constraint if managers were rational, acting in order to maximize their profits. As shown in connection with the case studies, rational managers would take this uncertainty into consideration by demanding high risk adjusted real rates of return. Then, investments that were profitable enough to compensate for the risk associated with the investment, and give a satisfactory return on the capital invested, would still be undertaken. Therefore, in order for this uncertainty to be a real barrier, managers must be assumed to act under constrained rationality.

5.1.7. Research and development

In R&D related to energy efficiency, as in any R&D projects, any single firm will have weak incentives to finance and conduct all the work necessary for developing a new technology as long as the benefits of that research will soon be available and adopted for free by its competitors. If a company cannot obtain some sort of advantage by being the first to capture the savings, it is likely to adopt a wait-and-see-attitude, hoping that somebody else will spend money on the R&D, and that anybody can subsequently benefit from their implementation.

5.2. Institutional barriers

5.2.1. Bureaucratic organisations

Companies do not necessarily function internally as markets. Important possibilities for energy conservation may be overlooked due to separation of tasks between departments and improper internal pricing.[90]

5.2.2. Split incentives

The institutional separation of interest between real-estate developers and users, or between manufacturers of capital equipment and buyers, may weaken incentives for energy efficiency. For instance, if a real estate developer's prime motivation is to keep the original purchase price

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[89] Eckbo, J.K.(1990), p.27
[90] Ayres, R.U. (1991)

low, he will tend to invest in the lowest capital-cost option.[91] Thus, the user will avoid a high initial investment, but he will face high operating costs. Such situations create problems on the condition that the user faces a liquidity constraint, which prevents him from making a loan in order to pay a higher initial cost and thereby avoid the unnecessary high operating costs. Similarly, in an owner-renter relationship, if one actor (the owner) pays for the energy efficiency improvement and another actor (the renter) reaps its benefits, there will be an under-investment in high-efficiency equipment.

In industry, it is the separation between builders and manufacturers of capital equipment on the one hand side, and users on the other hand side, which might weaken the marketplace for energy efficiency.[92] This is true, however, only on the condition that manufacturers of relatively energy efficient equipment do not succeed in convincing buyers that their more expensive equipment will save costs in the long run.

5.2.3. Rules and regulations

It is possible that government´s rules and regulations can function in a way which may prevent energy-efficient investments from being made.[93] This would be the case if regulations are inconsistent and if companies have reason to believe that they may change rapidly over time.[94]

5.2.4. Perception of risk

Managers are often risk adverse when it comes to adopting newer, innovative technologies or services.[95-96] Somehow, this risk aversion seems to be interpreted in the literature as being "incorrect". As discussed in section IV, if managers are risk averse, they may be perfectly rational to avoid investments whose rate of return they find unsatisfactory, compared to the risk involved. Therefore, for risk aversion to be interpreted as a barrier, it must mean that managers act inconsistently according to the risk they estimate that the projects have, i.e. that they avoid projects even if the risk is sufficiently compensated. It is claimed that development of a company culture that avoids risk is the result of a "bad experience".[97] In some cases, managers may find it easier to avoid taking action rather than illuminating the problem, because the company´s culture may punish unsuccessful attempts of cutting costs, while it would not even have recognized that there were possibilities of cutting costs, had the opportunity not been focused on in the first place. The reluctance is not only caused by incomplete knowledge of the

91 Sioshani, Fereidoon P. (1991), p.234

92 Schipper, L. (1991)

93 Stortingsmelding nr.61 (1988-89), p.35

94 OECD (1985b), p.77

95 IEA (1989), p.103

96 McInnes, G and Unterwurzacher, E. (1991), p.212

97 For an example, see Bisio, A. (1991), p.451

new technologies, there may also be a reluctance towards adopting new routines, towards changes in established patterns of cooperations with suppliers, service companies and other partners.[98] These behavioural and political forces inside organisations limit the nature of the changes in a plant that managers are willing to consider, and may significantly limit the profit a company can reap. "Many, if not most, managers feel more comfortable making a series of small steps (through smart engineering) that lead to immediate benefits, rather than considering a major new process with significant capital requirements."[99]

If all these proposed barriers to energy efficiency are indeed existent in an imperfect economy, market forces alone are unlikely to see the desired improvements in energy efficiency come about without some sort of help. In effect, it is claimed that as much as 70% of the estimated technical potential[100] for improved electricity end-use efficiency is likely to be untapped within a seven-year period,[101] if market forces are given no support in the form of stronger pressure from consumers, or some sort of government or intervention, in the form of economic incentives or direct regulation.

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98 Eckbo, J.K.(1990) gives a brief discussion of these problems
99 Ibid, p.450
100 The technical potential for improved energy efficiency describes the reductions in energy consumption that can be achived if all sectors of the economy would adapt instantly the best technology that is known today. This technology may be known, but it is often not yet commercialised.
101 The Alliance to Save Energy (ASE) (1988)

VI. IMPLICATIONS FOR PUBLIC POLICY

A clear majority of the case studies examined in section IV were profitable. Therefore, profit maximizing companies should undertake such investments on their own account. Evidently, companies do not always make these investments - if they did, there would be no possibilities for earning net profits by implementing energy efficiency or energy conservation measures. The most common conclusion drawn from this fact, is that companies do not undertake such investments simply because they do not know of their existence, or because of other barriers. If that is the case, public policies aimed at dismantling barriers, increasing the flow of information and enhancing the diffusion of new innovations make good sense. As the analyses of the cases in section IV indicated, the investments´ profitability was relatively sensitive towards changes in the assumption of life expectancy of equipment. This implies that policies targeted at reducing the uncertainty related to such estimates may prove successful. Perhaps a greater emphasis on information and distribution of results, and less focus on direct subsidies, could have a favourable impact.

But what if companies are aware that profitable investments exist? Could it be possible that companies know of the opportunities for investments in energy efficiency, but that they engage in a strategic game with policy makers ? This is an intriguing question. If managers know that their government is committed to reducing greenhouse gas emissions, they may intentionally postpone investments of this category, hoping that the state will hand out subsidies later. This does not imply that public policy makers should not intervene in the domain of energy efficiency, but it indicates that policies should be carefully designed in order to avoid nurturing unintended responses.

APPENDIX 1

	A	B	C	D	E	F
1		*INITIAL INVESTMENT*	ELECTRICITY SAVED	*ENERGY PRICE*	*ELECTRICITY*	*OIL SAVED*
2	*NAME OF COMPANY*	*measured in 1000 nok*	*(1000 kWh/y)*	*(measured in nok)*	*SAVED (nok)*	*(TONS)*
3						
4						
5	**VIKODDEN BRUK**	1 450	6	0,62 kr	4	
6	**TRYSIL TRE**	1 360	1 000	0,14 kr	143	
7	**SØNNICHSEN A/S**	371				
8	**ARJO A/S**	260	126	0,19 kr	24	
9	**BØNDERNES SALGSLAG**	3 250	3 100	0,20 kr	620	
10	**NAMDALSMEIERIET**	1 650				75
11	**SERIGSTAD A/S**	200	277	0,19 kr	53	
12	**RICH ANDVORD A/S**	160				
13	**NORFOLIER A/S & CO**	4 800				410
14	**JACON A/S**	1 300	822	0,45 kr		
15	**GOMAN-BAKERIET A/S**	117			98	
16	**ARTHUR SOLTVEDT A/S**	145	250	0,44 kr	110	
17	**HERDLA FISKEMAT**	280	350	0,45 kr	158	
18	**A.S.STEPHANSEN**	1 778	460	0,35 kr	161	
19	**TROMS TREFOREDLING**	2 304	914	0,19 kr	177	2 132
20	**A/L ISKREM**	1 627	890	0,20 kr	178	
21	**TRONDHJEM PRESERVING A.S**	1 265	244	0,46 kr	112	-27
22	**A.S. MELBU FISKEINDUSTRI**	1 300	828	0,44 kr	364	
23	**BRØDRENE BØCKMANN**	798	595	0,23 kr	137	
24	**AGRO FELLESSLAKTERI**	1 080	64	0,45 kr	29	134
25	**HADELAND GLASSVERK**	944	810	0,33 kr	263	
26	**HENNING OLSEN IS A.S**	2 393	700	0,33 kr	228	
27	**STABBURET A.S, BRUMUNDDAL**	2 197	8 534	0,07 kr	614	130
28	**HØGSET MEIERI**	615	421	0,11 kr	46	
29	**FELLESKJØPET, BALSFJORD**	2 295	1 950	0,15 kr	293	
30	**JOHANSEN BAKERI A.S**	113	40			
31						
32	For investment number 17, Troms Treforedling, the oil saved is measured in kWh,					
33	and the price is measured in nok per kWh.					

APPENDIX 1

	G	H	I	J	K	L	M
1	*OIL PRICE*	*OIL SAVED*	*OTHER SAVINGS*	*SUM SAVINGS*	*Internal rate*	*NET PRESENT VALUE*	*NET PRESENT VALUE*
2	*(measured in nok)*	*(1000 nok)*			*of return*	*Real interest rate=8%*	*Real interest rate=18%*
3							
4							
5			1 007	1 011	69%	5 331	3 091
6				143	1%	-400	-717
7			135	135	35%	535	236
8				24	-1%	-99	-152
9			150	770	20%	1 917	210
10	1,1	84	235	319	14%	491	-216
11			44	97	48%	452	237
12			100	100	62%	511	289
13	1,5	615	120	735	9%	132	-1 497
14			296	296	19%	689	32
15				98	83%	537	321
16				110	76%	593	349
17				158	56%	777	428
18				161	-2%	-698	-1 054
19	0,1	298	84	560	21%	1 452	212
20			90	268	10%	171	-422
21	1,2	-32	173	253	15%	435	-126
22			70	434	31%	1 614	651
23				137	11%	120	-183
24	1,6	214		243	18%	552	13
25				263	25%	822	239
26			572	800	31%	2 972	1 200
27	1,5	196	-20	790	34%	3 104	1 353
28			-16	30	-11%	-414	-480
29				293	5%	-332	-980
30			55	55	48%	256	134
31							
32							
33							

	V	W	X
1	*CHANGE IN NET PRESENT VALUE WHEN LIFE EXPECTANCY INCREASES WITH 1 YEAR:*		
2	*(real rate of return is constant, at 8% for all calculations)*		
3			
4	*FROM 10 YEARS TO 11*	*FROM 11 YEARS TO 12*	*FROM 14 YEARS TO 15*
5	8%	7%	5%
6	15%	17%	25%
7	11%	9%	6%
8	10%	11%	12%
9	17%	14%	8%
10	28%	20%	10%
11	9%	8%	5%
12	8%	7%	5%
13	239%	65%	18%
14	18%	14%	8%
15	8%	7%	4%
16	8%	7%	5%
17	9%	7%	5%
18	17%	13%	8%
19	67%	37%	15%
20	25%	18%	10%
21	12%	10%	6%
22	49%	30%	13%
23	19%	15%	8%
24	14%	11%	7%
25	12%	10%	6%
26	11%	9%	6%
27	3%	3%	3%
28	38%	56%	79%
29	9%	8%	5%
30			
31	*AVERAGE PERCENTAGE CHANGE IN NET PRESENT VALUE FOR AN INCREASE IN LIFE EXPECTANCY OF 1 YEAR*		
32	**26%**	**16%**	**11%**
33	*MEDIAN PERCENTAGE CHANGE IN NET PRESENT VALUE FOR AN INCREASE IN LIFE EXPECTANCY OF 1 YEAR*		
34	**12%**	**11%**	**7%**

APPENDIX 3

	U	V	W	X	Y	Z
1	*PERCENTAGE CHANGE IN NET PRESENT VALUE CAUSED BY AN INCREASE*					
2	*IN INITIAL INVESTMENT WITH 1%*					
3		The calculations show how net present value of the investments change when the initial investment is increased with 1%.				
4	*Real interest rate=8%*					
5	-0,3					
6	-3,4	The average change in net present value is a decrease of 3.3% for each 1% increase of the initial investment.				
7	-0,7					
8	-2,6					
9	-1,7					
10	-1,5	The median change in net present value is a decrease of 1.3% for each 1% increase of the initial investment.				
11	-0,4					
12	-0,3					
13	-36,4					
14	-1,9					
15	-0,2					
16	-0,2					
17	-0,4					
18	-1,0					
19	-1,6					
20	-9,5					
21	-2,9					
22	-0,8					
23	-6,6					
24	-2,0					
25	-1,1					
26	-0,8					
27	-0,7					
28	-1,5					
29	-6,9					
30	-0,4					
31						
32	**-3,3**	Average				
33	**-1,3**	Median				

APPENDIX 4

CHANGE IN NET PRESENT VALUE CAUSED BY A PRICE INCREASE OF 1%

Real interest rate=8%			
0,0			
2,4			
1,6			
2,2			
0,8			
0,8			
1,2			
1,4			
1,5			
0,8			
7,0			
1,7			
1,5			
7,6			
0,4			
2,1			
0,5			
1,3			
0,8			
5,9			
Average change in NPV			
2,1			
Median change			
1,4			

	Q	R	S	T	U
1			Percentage change in net present value caused by an increase in volume of electricity saved by 1%		
2					
3	*Initial NPV*	*NPV after volume saved increased with 1%*			
4	*Real rate of return=8%*	*Real rate of return=8%*			
5	5 331	5 331	0,00		
6	-400	-391	0,00		
7	-99	-98	1,62		
8	1 917	1 958	2,17		
9	452	456	0,79		
10	506	512	1,32		
11	3 171	3 196	0,78		
12	593	600	1,24		
13	777	787	1,36		
14	-698	-687	1,55		
15	1 452	1 464	0,82		
16	171	183	6,97		
17	435	443	1,73		
18	1 614	1 638	1,51		
19	120	130	7,63		
20	552	554	0,35		
21	822	840	2,15		
22	2 972	2 987	0,51		
23	3 104	3 145	1,33		
24	-414	-411	0,75		
25	-332	-313	5,91		
26					
27			**1,93**	Average	
28			**1,33**	Median	

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