CCS from the gas-fired power station at Kårstø? A commercial analysis[1]

by

Petter Osmundsen* and Magne Emhjellen**

* *University of Stavanger*

** *Petoro AS*

Summary

The article presents a commercial investment analysis of the carbon capture project at the Kårstø gas processing plant in south-western Norway. We update an earlier analysis and critically review the methods used – including those applied for cost estimating. Our conclusion is that carbon capture and storage (CCS) at Kårstø would be a very unprofitable climate measure with poor cost efficiency. It would require more than USD 1.7 billion[2] in subsidies, or in excess of USD 133 million per year. That corresponds to a subsidy of roughly USD 0.1 per kilowatt-hour on the power station's electricity output. The cost per tonne of carbon emissions abated is about USD 333, which is about 20 times the international carbon emission allowance price and many times higher than alternative domestic climate measures.

* Petter Osmundsen, department of industrial economics and risk management, University of Stavanger, NO-4036 Stavanger, Norway E-mail: Petter.Osmundsen@uis.no, home page: http://www5.uis.no/kompetansekatalog/visCV.aspx?ID=08643&sprak=BOKMAL

** Magne Emhjellen, Petoro AS, P O Box 300 Sentrum, NO- 4002 Stavanger, Norway. E-mail: Magne.Emhjellen@petoro.no

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[1] Thanks are due to Johan Gjærum, Per Ivar Gjærum, Kåre Petter Hagen and Knut Einar Rosendahl for constructive comments. We would also like to thank a number of specialists in business and the civil service for useful comments and proposals.

[2] Monetary amounts have been converted from Norwegian kroner (NOK) to US dollars (USD) at an exchange rate of NOK 6 = USD 1.

1. Introduction

The article analyses the carbon capture project at Kårstø from a commercial perspective. This development has earlier been studied in socio-economic terms by the Norwegian Water Resources and Energy Directorate (NVE). See NVE (2006). The planned capture project at the Mongstad industrial complex north of Bergen has reportedly been downgraded to cover only the gas-fired power station there, and not the oil refinery, while operator Statoil has talked about substantially lower capacity utilisation in the power station.[3] The case we analyse is therefore also relevant for the Mongstad project.

McKinsey (see for example *Pathways to a Low-Carbon Economy*, vol 2, 2009) has assessed the costs of various climate measures. That work includes the preparation of a global marginal cost curve for greenhouse gas abatement. Confer figure 1, which illustrates both the abatement potential and the abatement unit cost. Carbon capture for new gas-fired power stations is the most expensive measure in the figure. Retrofitting a capture plant at an existing

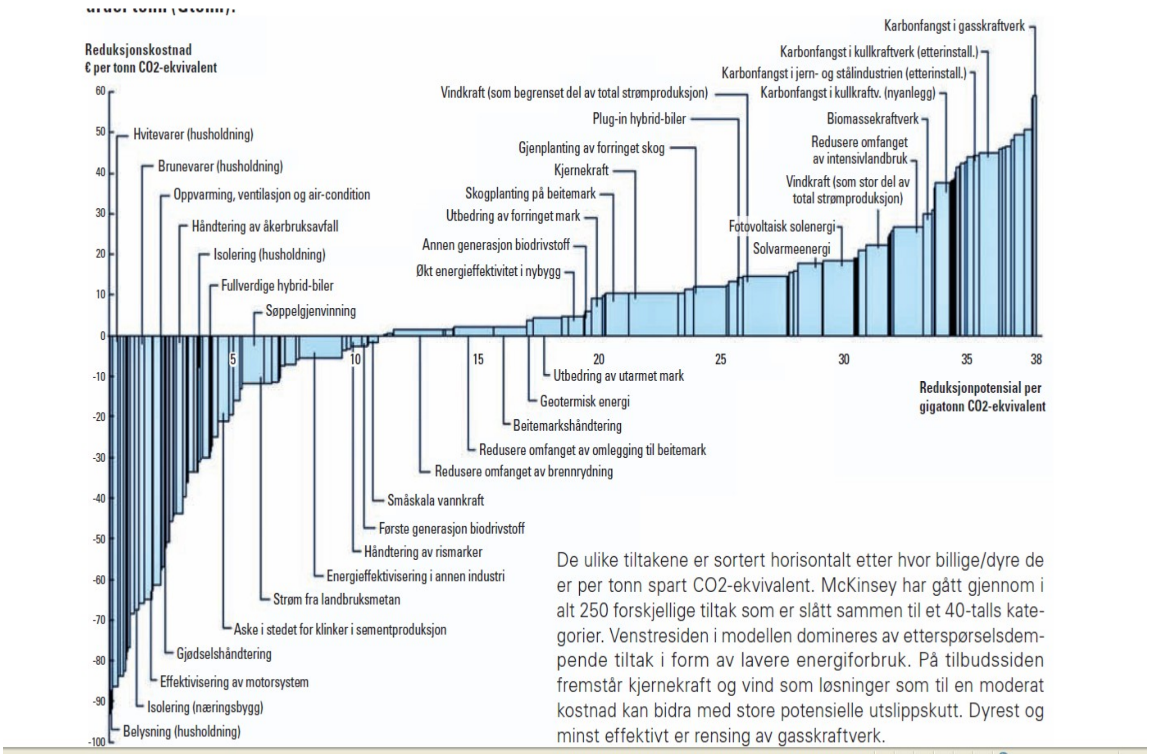

Figure 1. Global marginal cost curves for various climate measures. Abatement unit costs and potentials are illustrated by the height and width respectively of the columns. Source: McKinsey (2009).

[3] *Dagens Næringsliv*, 23 December 2009, p 8.

gas-fired power station – the approach studied at Kårstø and subsequently postponed – is so expensive that McKinsey has not even bothered to include it in figure.[4]

As a case study in climate economics, we calculate the costs of a possible CCS project at Kårstø. Abatement unit costs – in other words, the cost per tonne of carbon emissions avoided – for a CCS plant at this location will depend critically on its uptime. The business concept for the gas-fired power station at Kårstø is primarily based on being a swing generator of electricity, which covers market peaks by supplying power when this is profitable and otherwise standing idle (switching option). The station will accordingly have a limited uptime per year, which has also been confirmed by experience to date.

The CCS appeared for a long time to fulfil all the classic recipes for cost overruns:[5]

a) the project is based on novel technology
b) the client is in a hurry
c) few possible contractors are available
d) the contractors have weak financial incentives
e) the government is paying
f) the project is large
g) the decision has already been taken, the developer has little strategic room for manoeuvre
h) the supplier market is overheated and capacity stretched.

However, some development aspects modify this impression. By postponing a decision on CCS at Kårstø, the government has shown that it is able to call a halt. That also increases the strategic room for manoeuvre. In addition, the supplier market also shows some signs of price reductions, despite considerable inertia.

The article has the following disposition. Section 2 outlines the case and presents unit cost calculations for carbon abatement. The net present value (NPV) analysis is reviewed in section 3. Section 4 presents a number of supplementary considerations, and section 5 rounds off with a discussion.

[4] A number of measures in figure 1 have ”negative abatement unit costs”. These are commercially profitable. The most important of them relate to enhancing energy efficiency in industry and insulating commercial buildings, blocks of flats and individual houses, waste recycling and fertiliser management.

[5] See Osmundsen (2007).

2. Case – CCS at Kårstø

White Paper no 1 (2006-2007) referred to the commitment in the government's political platform (known as the Soria Moria declaration) that work would begin immediately on establishing a carbon capture plant at Kårstø, and that the government would help to finance it. The declaration further stated that a transport and storage solution would be established in association with the capture plant. It was made clear that CCS is not profitable at today's costs, and that the realisation of a capture plant at Kårstø would thereby require substantial state aid. The problem with this approach is that the government has selected a major carbon capture project without this being matured to a point where it can be properly evaluated, and without it being measured against alternative treatment projects. In other words, the government has started at the wrong end. The right approach would be to begin with the treatment targets and then identify how these can be met as cost-effectively as possible.

In its revised national budget for 2008-2009, the government writes that it "proposes to halt the procurement process for awarding a contract to build the carbon capture plant until a clearer picture has been obtained of the operating pattern of the gas-fired power station or of other solutions which will give greater assurance of steady electricity generation and thereby carbon emissions."

The state-owned Gassnova company in intended to own and operate the planned CCS plant at the Kårstø gas-fired power station,[6] which is owned by Statoil and state-owned power generator Statkraft through Naturkraft. The Efta Surveillance Authority (ESA) has agreed that the government can meet the full cost of building and operating the plant, and takes the view that this support does not contravene the prohibition in the European Economic Area (EEA) agreement on competition-distorting state subsidies.[7]

A brief description of the project is provided below, based on the detailed report published by the NVE in 2006. We then explain the revised project calculations.

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[6] It took over from the NVE, see http://www.gassnova.no/gassnova-sf-overtar-ansvaret-for-co2-renseanlegget-pa-karsto/?publish_id=1286&active=

[7] See http://www.gassnova.no/esa-godkjenner-statlig-finansiering-av-co2-handtering-pa-karsto/?publish_id=1286&active=

2.1 The gas-fired power station

Flue gases from Naturkraft's gas-fired power station provide the CO_2 source for the capture process. The station will have a net capacity of about 420 megawatts and release up to two million normal cubic metres of flue gases per hour when operating at full load. The station is a "combined cycle" facility which uses the waste heat from the primary gas turbine to generate additional electricity from a steam turbine. It is equipped with an efficient treatment plant for nitrogen oxides which removes virtually all NO_x (residual emissions are expected to be five parts per million of ammonia (NH_3) and roughly 2 ppm NO_x). Emissions of sulphur oxides, unburnt hydrocarbons and particles will also be very low. The gas turbine burns natural gas with a large excess of air to avoid excessive combustion temperatures and to cool the internal turbine materials. The flue gas volume is therefore large, and the flue itself will have a diameter of about eight metres. The principal fuel gas components will be (vol %): nitrogen 75%, oxygen 12%, steam 8% and CO_2 4%.

2.2 Carbon capture plant

Carbon capture from the power station will occur in a chemical absorption plant ("post-combustion"). This facility will be amine-based. The principal disadvantage of an amine process are the high costs associated with energy consumption in the capture plant. It also involves some emissions of amines and other substances to the air.

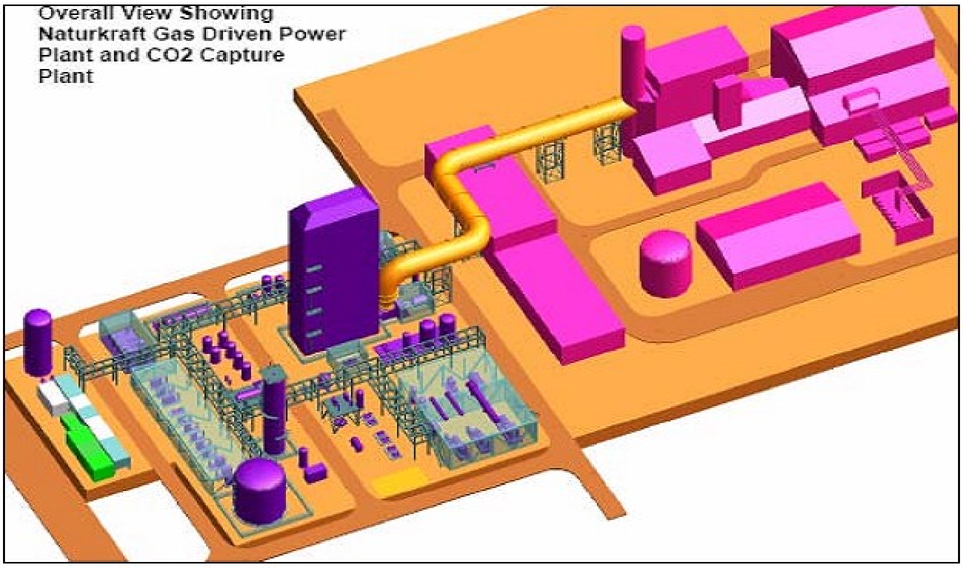

Figure 3: A capture plant (left) tied to a gas-fired power station (right). Note the size of the former.

In full operation, the plant will typically be able to capture about 131 tonnes of CO_2 per hour. That represents about 3 150 tonnes per day or roughly 1.05 million tonnes per annum, assuming an uptime of 8 000 hours. This means that the power station would release about 0.2 million tonnes of CO_2 per annum, rather than 1.25 million without carbon capture over 8 000 hours of uptime. The NVE report operates with 8 000 hours of uptime for the station – in other words, full capacity utilisation. That is completely unrealistic for this facility, which is meant to swing up and down in line with electricity prices, and must accordingly be adjusted. We have set uptime to 50%.

The main design principles for an amine-based capture plant will not vary much between different suppliers. This facility is based on flue gases from the power station and utilises an absorption fluid – either an amine or a blend of amines dissolved in water – which absorbs the CO_2 from the fumes. Electricity and steam are used as the energy sources for all rotating machinery (compressors, pumps and so forth). Power consumption by the actual capture plant is substantial. Compressing and pumping captured CO_2 also requires considerable energy. Total power consumption for the capture plant will be 27-30 MW. In other words, power station efficiency will be substantially reduced.

2.3 Transport and storage

In seeking to identify solutions for carbon transport and storage, the NVE has given weight to investigating the options which might be available without making a final concept choice. Figure 4 presents several alternative concepts.

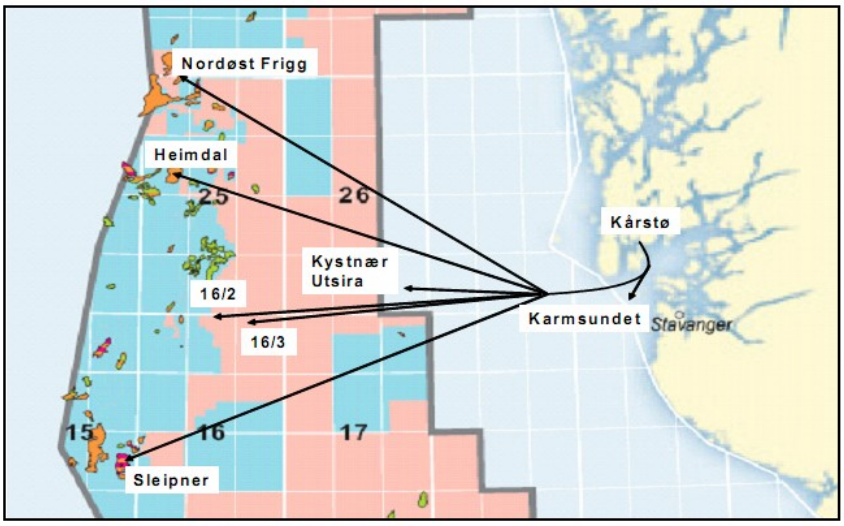

Figure 4. Alternative storage concepts.

Optimal storage security is achieved when CO_2 is held in abandoned oil or gas fields which have demonstrated their ability to retain natural gas for millions of years.

2.4 Cost estimation

In order to assess the CCS project at Kårstø in commercial terms, we must first establish a cost estimate in accordance with commercial standards. Official studies have applied a lower estimate of the cost of carbon capture than the figure utilised by Statoil for carbon capture from the Mongstad gas-fired power station. This variance could arise in part because the official calculations are not based on the methodology used by the industry. Even with this methodology, cost overruns are routine – particularly for plants on land. Kårstø, Mongstad and the Snøhvit gas terminal in northern Norway all provide well-known examples. It is also worth noting that the CCS test facility under construction at Mongstad is already seven times more expensive than originally estimated.[8] Conversion of existing facilities are among the projects with the biggest cost underestimates. The CCS project calls for modification not only to the power station but also to the offshore installations where the injection will take place. Such work is technically demanding, involves a great many players and creates downtime problems. The size of the project also plays a role. Novel technology and management challenges for mega-projects of this type are recurrent reasons for cost overruns. These factors appear to be very evident in the Kårstø CCS project. It will involve many complex interfaces, including the modification of existing installations, and a large number of players. Carbon capture on this scale will represent a groundbreaking project, and a number of technical challenges are faced – including problems with corrosion and water intrusion during carbon transport and injection. Furthermore, the political landscape is volatile.

Table 2.1 summarises investment and operating costs for the capture project (from the 2006 NVE report), depending on whether deposition will occur in the Utsira formation or closer to the coast. This table sums up total investment and operating costs.

[8] *Dagens Næringsliv*, 23 December 2009, p 8.

	Capex	Opex
CO_2 capture	607	57
Transport and storage	260	4
Sum	867	61

Table 2.1: Summed investment costs and annual operating expenditures.

One question is whether adequate account has been taken of an asymmetric cost distribution. When costs are asymmetrically distributed (overruns are more likely than underspending – a long right-hand tail in the distribution), and inadequate account is taken of this when estimating the costs, the estimates obtained will not be accurate in terms of expectations. This is a particularly relevant issue for immature groundbreaking projects like the CCS development at Kårstø. It has been considered in Emhjellen *et al* (2002, 2003). In practice, overruns are more likely than savings. Savings of 5% are regarded as good, but projects which go wrong could have overruns of more than 100%. One reason for this asymmetry is selection effects – only the most optimistic projects come through the project ranking process in the companies, and only the most optimistic bidders win supplier contracts.[9]

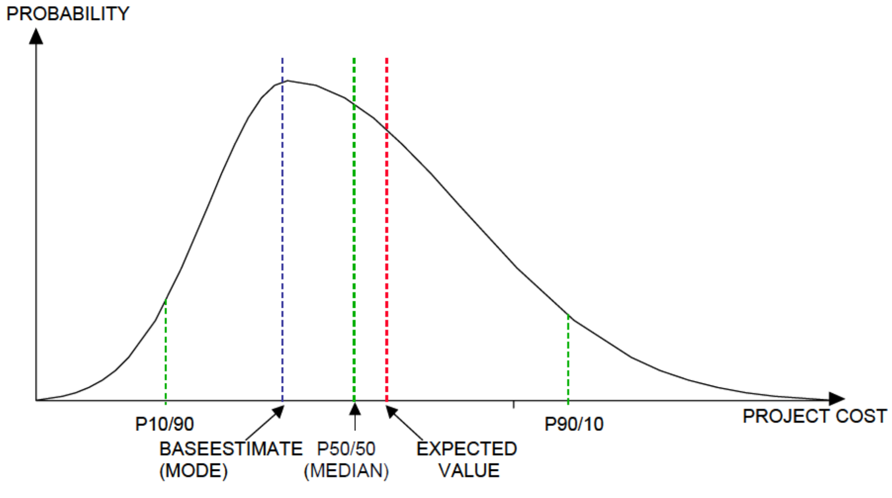

Figure 5: An asymmetric cost distribution

Figure 5 illustrates an asymmetric cost distribution. In such a distribution, the modal value, the median and the expectation value are different and of increasing size.[10] Emhjellen *et*

[9] McMillan (2002).
[10] Wonnacott and Wonnacott (1990).

al analyse a selection of developments on the Norwegian continental shelf (NCS) with an average cost overrun of 30%.[11] They find that 10% is attributable to underestimating costs by failing to take adequate account of imbalances in the cost distribution. We have accordingly chosen to reduce capital expenditure (Capex) in the Kårstø project by this amount. Given the long right-hand tail in immature projects, that represents a cautious adjustment for CCS. Developments of this nature are much more immature than the petroleum projects which formed the basis for the analysis of asymmetric cost distributions. The right-hand tail includes conditions where problems are encountered with the capture process. However, the project is to implement this on 10 times the scale of previous developments. Research and development projects of this type do not have the 100% probability of success implicitly assumed in NVE (2006). We do not operate with a lower success probability either, but accept on the other hand that problems in the execution phase could involve substantial costs.

International studies are available of mega-projects, defined as developments costing more than USD 1 billion – a category to which CCS at Kårstø must definitively be said to belong. Cost overruns for such projects are reported to average 40% in a number of industries.[12] Particular challenges related to mega-projects are that their size creates very special coordination problems which are difficult to manage. Large developments also normally experience bigger government interventions, which often represent a complicating factor in project terms. Such projects can also put pressure on costs because they are large in relation to local factor markets.

Another problem is whether the cost estimate has taken adequate account of utility systems and the early phase of projects. Parts of these are often outside the scope of work in the early phase. Utilities, including compressors and cooling systems, are often underestimated, for instance. To adjust for this, we have added 10% to Capex.

The NVE operates with a contingency reserve of 18%. A number of factors argue for a higher figure. 1) This is a mega-project involving substantial management challenges. 2) The plant will scale up existing capture facilities by 10 times their current size, and represents a groundbreaking technological development. 3) The project has a demanding interface with the political authorities, who give varying signals. 4) Contingency reserves are normally

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[11] Cost overruns are more the rule than the exception on the NCS. It is also worth noting that the largest overruns relate precisely to land-based plants. The Snøhvit gas liquefaction plant in northern Norway is a recent example, and Kårstø has witnessed a number of projects with very substantial overruns. See Official Norwegian Report (NOU) 1999:11 and Osmundsen (1999a, 1999b).

[12] The issue of mega-projects with close private sector/government interaction has its own literature. See, for instance, Flyvberg *et al* (2003). Management problems and cost overruns are recurrent themes.

higher in the early phase and decline as the project matures. We have adjusted the contingency reserve to 40%, which represents a normal overrun for this type of mega-project.

Cambridge Energy Research Associates (CERA) has a cost index for land-based petroleum fields, which has risen by 40% from 2006 to 2008. We have upwardly adjusted Capex by 40%.

We have increased Capex by 80% in relation to NVE (2006), comprising a 40% increase in industry costs since 2006, an increase of 20% in the contingency reserve, a 10% adjustment to obtain an accurate expectancy estimate and 10% for utilities. After rounding off, we apply the following investments in our project analyses:

Investment in treatment plants	1 000
Investment in transport and storage	500
Total	1 500

Table 2.2: Revised Capex estimate for CCS at Kårstø in USD million, 2010 value.

The project is expected to abate carbon emissions by about one million tonnes per year (the NVE estimate is 1.05 million tonnes). We estimate that the actual abatement will be only 50% of this level, since the gas-fired power station is expected to be operational for half the available time. Estimated operating costs in the NVE report totalled USD 62 million (including an anticipated 15.7% output loss for the power station). We round this up to USD 75 million in 2010 value per annum – again based on the immaturity and uncertainty of the estimate as well as some upward adjustment to the output loss, which is lower in the NVE analysis than in other estimates. Operating costs are thereafter discounted on a straight-line basis in relation to expected operating time. The NVE report expects the plant to have an economic life of 25 years. We assume a real required return of 6%.

Projects which incur the biggest overruns are often those with immature technology, pressure for an early start-up, regarded as having strategic value, and marginal profitability to start with. In such circumstances, cost estimates are frequently driven down. We fear that these factors are all applicable to CCS at Kårstø. More slack is often accepted in cost estimates for projects where the economics are good.

Have we been guilty of double-counting in our cost adjustments? We are basically seeking to adjust the cost estimates in such a way that they accord with the way a private company would have made them. We have first sought to calculate a best estimate for costs at the estimation date, and have then increased this by cost inflation in the industry. When calculating our best estimate, we have included elements which fall outside the original scope of work, we have adjusted for the fact that this type of project has an asymmetric cost distribution in practice, and we have increased the provision for unforeseen expenses. These represent separate adjustments in principle, but overlaps – between the last two adjustments, for instance – cannot be excluded. However, the conclusion that the project is extremely unprofitable is very robust. At our estimated Capex of USD 1.5 billion, the project has a negative NPV of almost USD 1.7 billion. In other words, the project economics are also very poor even with a much smaller increase in Capex – and actually without any adjustment at all.

The oil industry is criticised from time to time for taking a conservative approach in its investment analyses, including applying an excessive contingency reserve to cope with unforeseen costs and being too restrained in estimating revenues. However, empirical evidence indicates that the average project nevertheless experiences cost overruns. A pertinent question is whether the companies are sufficiently *varied* in tailoring their practice to the individual project, or largely use the same methods to assess both big immature projects such as CCS and circumscribed and mature developments such as supplementary work on producing fields. A number of observations indicate that the risk allowance made by the companies is too small in immature projects and excessive in small and mature developments. Devising simpler and quicker evaluation procedures is also important for the latter.

Our revised cost estimates are similar to the figures reached in the Climate Cure report, and it is not our impression that the estimates are controversial. A contribution in our approach is to explain in some detail how we have adjusted the costs, thus indicating how it was possible for NVE to seriously underestimate the costs four years ago.

2.5 Abatement unit cost

We make a further adjustment where abatement unit costs are concerned. These are calculated as annual cost annuities based on the economic life of the facilities divided by the annual volume of carbon emissions *avoided*.[13] Certain reports operate instead with the volume of CO_2 *captured*. As the figure indicates, substantial differences exist between these two measures.

[13] For a general overview of commercial principles for climate projects, including the correct calculation of abatement unit costs, see Osmundsen and Emhjellen (2010).

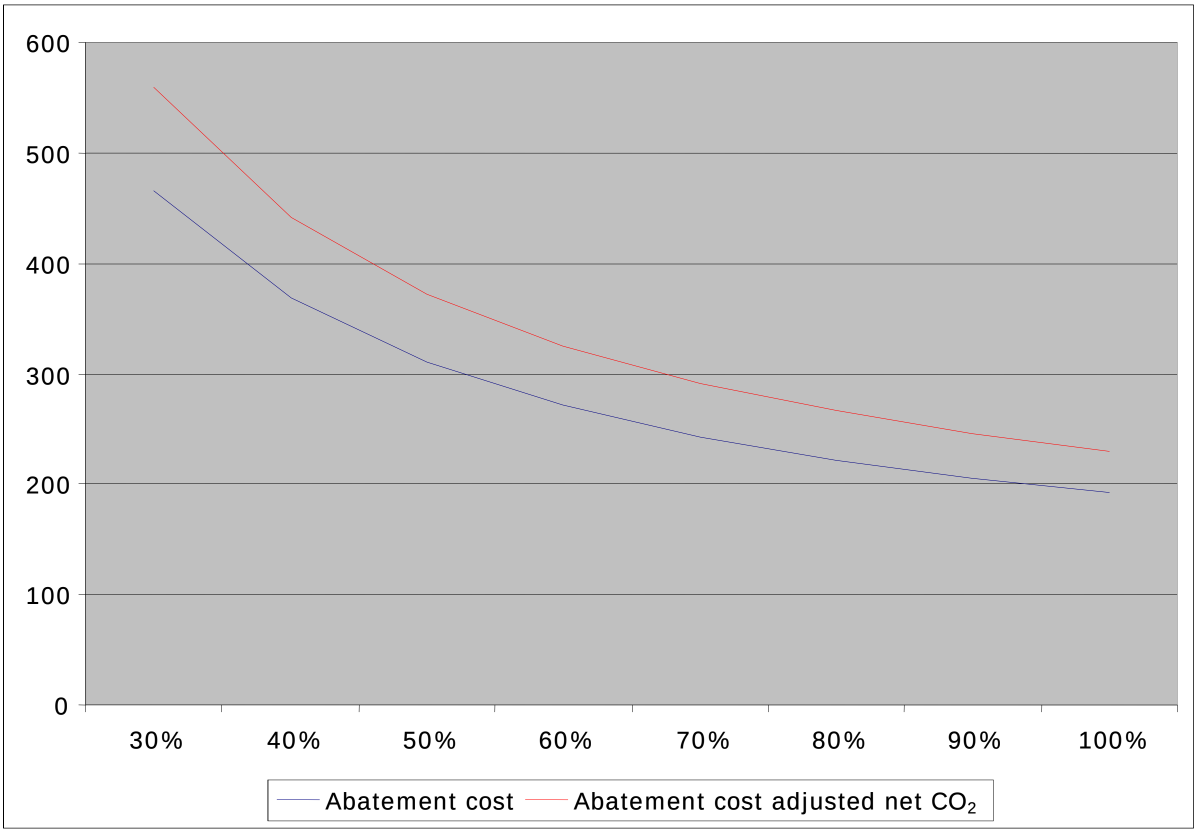

Figure 6: Abatement unit cost for carbon capture at Kårstø with varying percentages of uptime.

Figure 6 shows that the abatement unit cost will rise substantially with reduced uptime. Capture, transport and storage systems must be dimensioned for maximum capacity to ensure that all CO_2 can be captured when the power station is in operation. This requires a very substantial investment in relation to average uptime, and results in a very high capture cost: USD 333 per tonne at 50% uptime. Even when operating at full capacity, CCS at Kårstø is a very long way from being a cost-efficient climate measure (USD 192 per tonne in our estimate).

3. Valuation using the NPV method

We apply a basic assumption of 50% capacity utilisation at the power station (of 8 000 hours in total). The value of carbon abatement projects is closely related to expectations of the value of future carbon abatement. With an allowance market established in Europe, part of the basis has been laid to obtain a market price for carbon abatement. However, the commercial profitability of carbon abatement projects is very negative with most of the scenarios for future allowance prices unless other significant support is provided. The three scenarios produced by Norway's Climate Cure programme[14] are presented below.

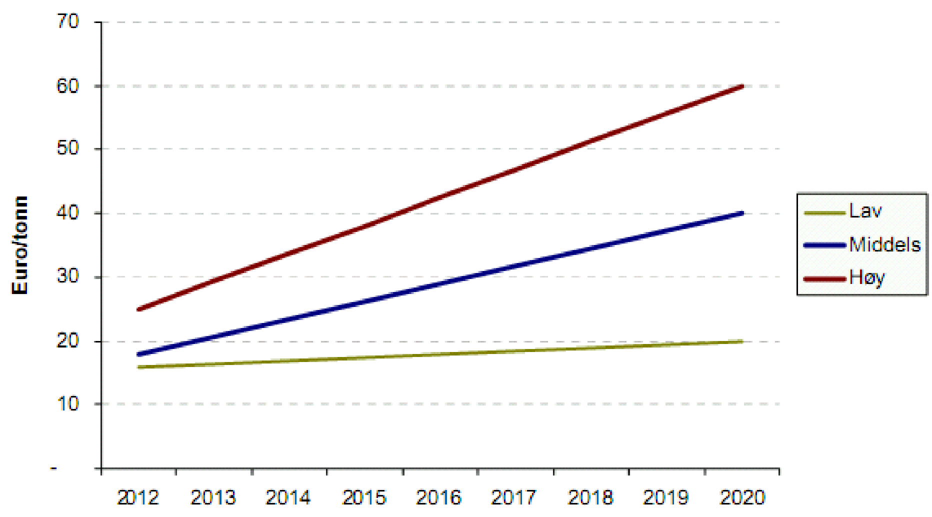

Figure 7: Climate Cure: scenarios for allowance prices. Source: www.klimakur.no

Price scenarios for carbon abatement differ widely, because a short history and the political uncertainty (which produces many structural shifts) make prediction difficult in this area. Figure 8 shows cash flows to the project under the three allowance price scenarios, where we have assumed a 5% real rate of growth in the price from 2021 to the end of the project's economic life. The extremely large investment in relation to revenue means that the project's NPV is very negative for all scenarios. Other developments in the energy sector also involve heavy front-end investment. The feature which distinguishes CCS from other projects is that cash flow will also be negative in the operating phase – in other words, this is a case of spending money to lose money. Even if the huge investment outlay is ignored, the project will have a negative NPV. One reason for this is that the substantial amounts of electricity and gas required to power the capture process have a substantially higher value than the allowance value of the captured CO_2.

[14] Climate Cure 2020 is assessing possible ways to reduce Norway's greenhouse gas emissions by 15-17 million tonnes by 2020 as the basis for a government evaluation of national climate policy. The work is being done by a set of government agencies. See section 6 for more details.

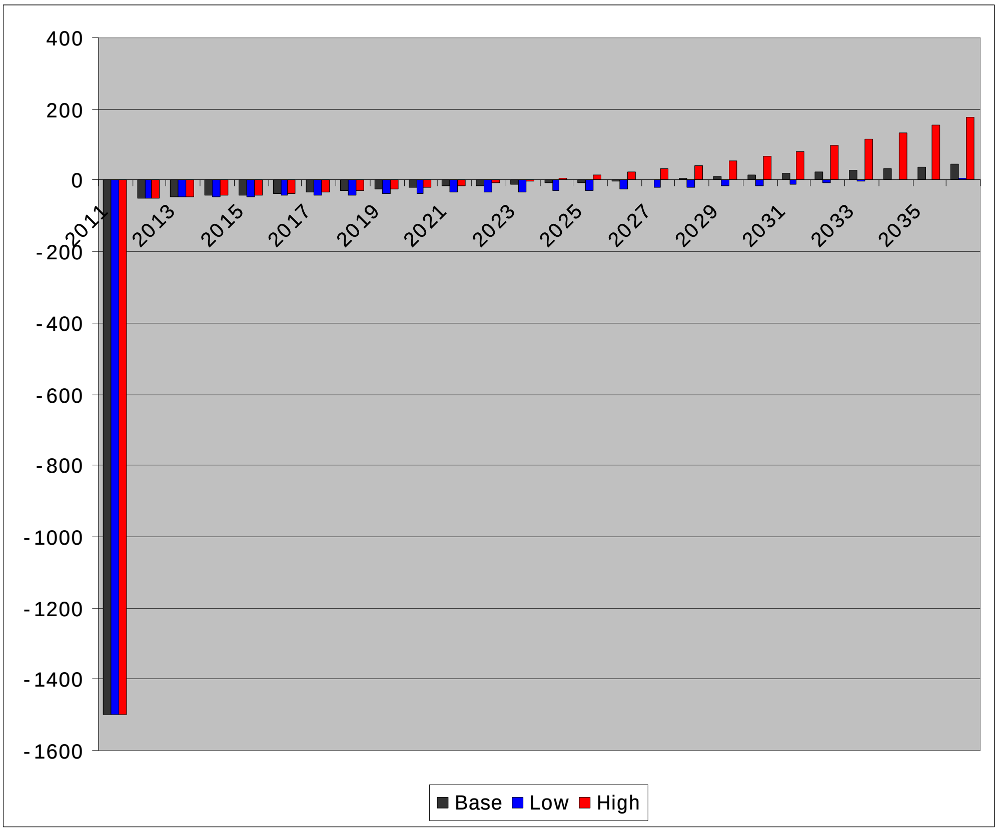

Figure 8: Cash flows before tax.

Given our assumptions, the NPV for the Kårstø project is negative at USD 1.7 billion (with the median allowance price scenario in figure 7 and 5% real growth after 2020).[15] We would emphasise that these are rough estimates – uncertainty is great over both revenue and cost parameters. The NPV is negative at USD 2 billion and USD 1.3 billion with the low and high allowance price scenarios respectively. With a Capex of USD 1.5 billion, these NPVs are not perhaps surprising, since Capex totally dominates cash flow in relation to operation and the latter also fails to make a positive contribution until far into the future (after 2020 even with the highest allowance price scenario). Note that the whole cash flow is negative with the low allowance price scenario. The median scenario first yields a positive cash flow in 2029.

Since we have applied international allowance prices as revenues in the calculation, the USD 1.7 billion will also provide an estimate of the additional cost for Norway of abating carbon emissions through this particular cost-intensive measure rather than buying

[15] Should the company have other taxable revenues in Norway, the annual losses would be somewhat reduced through tax consolidation and the NPV would not be quite so negative.

allowances. The NPV corresponds to an annuity of just over USD 133 million, which provides an estimate of the annual subsidies required to implement CCS at Kårstø. It could be interesting to calculate how large a subsidy would be required per kWh generated by the station. Generating capacity is 420 megawatts, or 354 MW after adjusting for the loss of output from CCS. Assuming 50% capacity utilisation, this yields an annual electricity output of 1.4 terawatt-hours. Realising a development with a negative NPV of more than USD 1.7 billion would therefore require a fixed asset subsidy (one-off payment) of just under USD 1.2 per kWh of expected annual output. Alternatively, this support could be provided in the form of roughly USD 0.1 per kWh spread over the whole economic life of the facility.

It is otherwise unclear whether the estimate used by the Climate Cure for future allowance prices takes full account of the latest trends in this area. An annual increase of 10% in allowance prices might seem optimistic today. The inability to reach agreement on a new climate agreement in Copenhagen, a cold winter, a politically weakened President Obama and scientific criticism of the Intergovernmental Panel on Climate Change are not encouraging for a rise in allowance prices. The financial crisis has also caused a decline in carbon prices (and emissions) because the economic recession has weakened the ability and willingness to implement cuts. A steady growth curve for carbon prices accordingly seems unlikely. A company considering whether to invest in a climate project which involves irreversible investments will probably apply relatively conservative estimates for allowance price developments. This makes it not unlikely that the lowest curve in the Climate Cure scenarios would be the one chosen by such a company.

We have made conservative estimates for operating costs in calculating NPV. Like NVE (2006), these are kept fixed in real prices. That contrasts sharply with the revenue side, which increases by 10% per annum. Operating costs largely comprise electricity, gas and payroll. It is reasonable to assume real price growth for these. And a sharp rise in carbon allowance prices and constant prices for electricity and gas do not necessarily appear mutually consistent. A company is unlikely to make these assumptions, and its estimate of the commercial NPV would probably be below rather than above the one we have calculated.

We have investigated how NPV varies with changes in the required rate of return. Because the cash flow is totally dominated by Capex, and the project generates only a small cash flow during its operating phase – see figure 8 – the NPV alters very little when changes are made to the required return. A rather unusual result is that the NPV actually *rises* (becomes less negative) when the required return increases. This is because net cash flow in the operating phase is negative. For the same reason, NPV goes up when uptime declines. On the other hand, the abatement unit cost rises with an increase in the required return, but its level is determined first and foremost by uptime.[16]

How high must the allowance price be over time for the project to be profitable? If we assume a price development in line with the highest estimate in the curve above – EUR 26 per tonne in 2012 – and that the price rises by 14.5% per annum to EUR 670 per tonne in 2036, our example project will yield a marginally positive NPV with a 6% real required return. In other words, the allowance price in 2036 must be the equivalent of USD 617 per tonne for the project to pay. This is very unlikely, and substantially above the highest estimate made by the Climate Cure. The unrealistic allowance price scenario will be outside figure 7, with an allowance price of EUR 77 per tonne in 2020 and EUR 151 per tonne as early as 2025.

Even with quota prices at this level, however, it is not given that the project will be realised. This is because one forgets that these projects can be initiated at a later date when more information has become available. There is basically little point in analysing the option value of waiting when a deterministic NPV analysis shows that the project is highly unprofitable (would not be commenced in any event). However, it could be relevant to demonstrate in general terms that, even with an expected positive NPV, climate projects will not be launched when uncertainty over the value of carbon abatement is high. Postponing a decision on CCS at Kårstø would give access, for instance, to new and improved technology, a clarification of the feasibility of integrating capture with transport and storage, and more information about developments in energy and allowance prices. When retrofitting in an existing power station, on the other hand, allowance must be made for the fact that the generating facility has a limited economic life.[17]

4. Additional considerations

A key challenge for carbon capture at Kårstø is the low regularity of the power station. But capture, transport and storage systems must be dimensioned for maximum capacity to ensure that all CO_2 can be captured when the station is in operation. This requires a very substantial

[16] We have assumed that operating costs are 50% lower at 50% uptime. This is probably an optimistic assumption.

[17] In cases of carbon abatement at new power stations, this type of time criticality is not relevant.

investment in relation to average uptime and results in a very high capture cost: USD 333 per tonne at 50% uptime. Even when operating at full capacity, CCS at Kårstø is a very long way from being a cost-efficient climate measure (USD 192 per tonne in our estimate).

We have sought to establish a best estimate of the costs involved. This type of groundbreaking project is difficult to cost, and there are many examples of large overruns. It is worth noting that the CCS test centre under construction at Mongstad is already seven times more expensive than originally estimated.[18]

Figure 8 presents the project's cash flow over time. Like other developments in the energy sector, CCS projects call for large front-end investment. What distinguishes CCS from other projects is that the cash flow is also negative in the operations phase – in other words, money is being spent to lose money. One reason for this is that the substantial quantity of electricity and gas required to operate the capture process is worth substantially more than the allowance value of the captured CO_2.

We see that this CCS plant (several carbon capture facilities are being studied in Norway) alone will require a contribution of USD 1.5 billion over the central government budget in its start-up years. By comparison, the total expenditure on Norway's railways – investment and operation – was just under USD 1.5 billion in 2009.

Although commercial costings are also relevant for the public sector, government project decisions are based on socio-economic costs. These will coincide almost wholly with the commercial costs we have calculated, but with two exceptions. 1) The socio-economic discount rate will normally be lower than its commercial counterpart. A 5% discount is applied by the Climate Cure for this type of project. That would give a marginally lower abatement unit cost than the one we have calculated. A socio-economic analysis, by contrast, includes the cost of tax financing (increased distortion losses in the economy) and the applicable rate is a financing cost of 20%. Given the very high share of government funding required to realise the Kårstø project, the overall socio-economic cost of CCS would accordingly be rather higher than the figure we have calculated.

A key element in socio-economic analyses of CCS which we have not discussed is technology development. For such immature technologies, large-scale testing is expected to yield valuable learning effects. We do not believe that individual companies will give much weight to this consideration in their profitability calculations. The gain is too far into the future and too uncertain, and it remains unclear whether it would accrue specifically to the

[18] *Dagens Næringsliv*, 23 December 2009, p 8.

company concerned. It is also debatable in a socio-economic sense how far this type of benefit will accrue to Norway, and it remains open to discussion whether the technological progress could perhaps best be achieved in other ways. The learning curve is in any event a key element in the debate on CCS. For the Kårstø project, however, the learning process looks like being taken better care of by the new test centre at Mongstad. Experience should be acquired here before building full-scale plants based on modern technology. Caution must also be exercised about building learning curves only into favourite projects. Many other climate measures also have the potential for learning curves, and a consistent comparison must be made here. When looking at the most optimistic learning curves for CCS, it could be worth recalling that carbon transport and storage account for about a third of the investment cost. These are mature technologies with a limited potential for cost savings.

To identify the real effect of a climate measure, it must be viewed over its whole life cycle. CCS comes out negatively here because the capture plant is so enormous. This is not generally appreciated. When people think about treatment measures, they envisage the catalytic converters installed in their cars. However, the carbon capture plant at Kårstø is almost as large as the power station itself, and occupies a two-hectare site. It is as if a catalytic converter had to be installed on a big trailer attached to each car. This unit would be almost as heavy as the car itself, and produce a substantial increase in fuel consumption. In addition come carbon transport and storage. A good deal of steel would be required in the construction stage of the CCS project, involving increased emissions which must be corrected for when calculating the net effect. According to Hanson *et al* (2009), a coal-fired power station with CCS abates its greenhouse gas emissions by 65-80 per cent and not by the 90 per cent often assumed. The real abatement unit cost is accordingly substantially higher for this specific measure.

In addition to major technological and financial challenges, the Kårstø CCS project also faces a number of unclear conditions related to health, safety and the environment. Questions have been raised about the health risks associated with handling amines, and doubts have also been expressed about the safety of storage and reservoir monitoring. Each of these concerns is a project stopper in itself, and they accordingly represent additional considerations which must be included in the commercial calculation. Potential local environmental emissions/discharges are also highly relevant for company assessments of whether this is a measure to which government will remain committed in the longer run. A one-sided focus on carbon emissions, while ignoring local pollution, has subsequently created problems in maintaining political support for wind turbines on land and the transition from petrol- to diesel-driven cars.

5. Discussion

In the NPV calculation, we have entered the value of the international allowances obtained for the volume of carbon emissions abated by CCS as revenue and assumed 50% uptime for the plant. We must strongly emphasise that the estimates for both income and costs are uncertain, but the project is clearly very poor in commercial terms. It has a negative NPV of roughly USD 1.7 billion, or about USD 0.1 per kWh generated by the power station after the installation of CCS. The abatement unit cost is roughly USD 333 per tonne. The question is then whether financial support from the government could achieve the realisation of the project. A company which might consider becoming involved in this project must estimate the size of such state backing. Since income from the emission allowances saved is marginal, the revenue side for this type of project consists in reality of Norwegian politicians. The company must accordingly seek to estimate future climate policy.

A starting point for establishing expectations about the government's future climate policy is to read the official economic studies undertaken in this area. NOU 2009:16 argues that Norwegian climate policy must be harmonised with the international market for greenhouse gas allowances (global efficiency). However, the "climate compromise" agreed by the Storting (parliament) calls for very substantial emission abatement , with two-thirds of the 40% reduction target by 2030 coming from domestic measures. In this case, economists would recommend an allocation of measures which minimised costs, with the cheapest implemented first and all sectors treated equally. NOU 2009:16 notes that the current use of instruments provides very different incentives for emission abatement, depending on which sector or energy commodity is the source of the emissions, and concludes that this illustrates a failure to comply with the requirement for cost efficiency in seeking to reduce carbon emissions.

The government has seen the need for a more unified climate policy, and the Ministry of the Environment has commissioned the Norwegian Climate and Pollution Agency (Klif) to head the group of agencies known as the Climate Cure 2020.[19] In addition to Klif, this group includes the Norwegian Water Resources and Energy Directorate, the Norwegian Public

[19] See http://www.klimakur2020.no/Templates/Public/Pages/Article.aspx?id=130&epslanguage=en.

Roads Administration, Statistics Norway and the Norwegian Petroleum Directorate. As part of its mandate, the Climate Cure is to prepare cost estimates for various climate measures. This work shows very clearly that CCS is one of the most expensive instruments for abating climate emissions, and accordingly not to be recommended in terms of normal criteria. However, the findings of the Climate Cure are only advisory and the politicians are free to opt for their pet projects. The Norwegian Institute of Transport Economics has long been compiling similar cost-benefit rankings for infrastructure projects in Norway's transport sector, but the list supported by the politicians looks very different. Like transport developments – with their varying geographical profiles – climate policy has become an area where the political parties can stake out positions. One might imagine that such positions were synonymous with cost-efficiency, since that would maximise overall emission abatement. But more complex considerations are involved. Different climate projects also affect the division of resources between regions and industries – dimensions which occupy a very central place in Norwegian politics. Climate policy thereby also becomes an instrument for attaining other goals. An important consideration in this context is that climate measures appear to be an exception to the general prohibition on state subsidies to industry within the EEA. That has encouraged a strong politicisation of the climate debate. Where CCS projects are concerned, the political picture must accordingly be analysed in order to assess the likelihood of political support. Kårstø lies in a part of Norway which normally attracts little in the way of state industrial support, and the project does not fall within industries which usually receive preferential treatment, including agriculture and the process industry. Development of CCS, on the other hand, is intended to represent a new priority area for Norwegian industry, and this is openly cited as one of the objects of the project. A crucial question is accordingly whether the amine technology to be utilised represents the future for CCS. Many specialists are highly critical here – this is becoming a mature technology. Although Aker Clean Carbon's amine technology is one of the two solutions to be tested in the government-funded centre at Mongstad (and Aker Clean Carbon is also regarded as the only relevant Norwegian supplier of capture technology to Kårstø), chief executive Simen Lieungh at the parent Aker Solutions group is another of those with little confidence in the prospects for this solution. [20]

Confidence in Norwegian government support for climate measures has weakened after the governing centre-left coalition resolved to impose fuel duty on biodiesel. The debate on that decision focused to a great extent on the environmental impact of this biofuel. One

[20] According to an interview he gave to *Dagens Næringsliv* on 14 October 2009.

aspect which received very little coverage in the media was cost. According to Klif, it costs USD 167-217 to cut a tonne of carbon emissions with the aid of biodiesel. This is more expensive than most other Norwegian climate measures. It is also roughly twice the figure which the International Energy Agency (IEA) has estimated that allowance prices must reach in 2030 to prevent global temperatures rising by more than 2°C.[21] This is probably the principal reason for revoking the duty-free status of biodiesel. It would accordingly be surprising if the government were to support CCS at a Kårstø power station with a low level of utilisation, where the estimated abatement cost is USD 333 per tonne.

The debate on biodiesel underlines the importance of establishing a stable and predictable climate policy framework *at an early stage*, as in the rest of industry.[22] From that perspective, it was not wrong of the government to change the taxation of biodiesel now. It would have been much worse to act later, when more companies had invested in this area. The criticism should accordingly be directed more at the decision to exempt biodiesel from duty in the first place. Given the row over this issue, the government's reputation has taken a knock in any event. Private players will accordingly demand direct refunding of their costs when initiating major climate measures, and will not wish to enter into agreements which would involve making large irreversible investments up front against the promise of payment per tonne of carbon emissions abated. Companies will be fearful of changes to support schemes along the way. The demand for direct refunding of costs will make it difficult to achieve contracts which provide good incentives in the climate area, and that is likely to push up costs even further.

This vacillation in climate policy gives the impression of an ad hoc approach which produces few results in the form of emission abatement. A significant additional disadvantage is the substantial costs incurred by private companies in anticipation of financial support which then fails to materialise. Alexandra Bech Gjørv, head of new energy at Statoil, made this plain in a comment to Oslo business daily *Dagens Næringsliv* (12 January 2010, p 16):

"The problem is that Norwegian governments have been saying for 10 years that they want wind power development and that acceptable frame conditions will be introduced, trust us. Many companies have devoted huge amounts of time and resources to studies driven by confidence in these political signals, but little has happened so far."

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[21] *Dagens Næringsliv*, 21 November 2009. http://www.dn.no/forsiden/kommentarer/article1787012.ece

[22] That applies particularly to measures involving large and irreversible front-end investments. See Osmundsen (2008).

In the same newspaper report, foreign minister Jonas Gahr Støre attacks those who believe that a commitment to wind power should be made in Norway rather than the UK. He points out that the proportion of renewables in Norwegian energy production exceeds 60% and is less than 2% in Britain. Since Norway already has a high element of renewable energy, it is more reasonable that the UK makes a commitment to wind power. Støre maintains that Norway should concentrate instead on CCS because this represents a cost-effective commitment. We agree that wind power is not a natural route for Norway to take, since we have good electricity supplies, land-based wind turbines represent a substantial environmental intrusion, and they are very expensive. The level of support required for offshore wind power projects in shallow water off the UK is about USD 0.17 per kWh – in other words, several times higher than Norwegian electricity prices. This support will need to be substantially higher in deep water off Norway, and developing such generating capacity with a view to exports will clearly be a major loss-maker. In other words, the government rejects extensive support for biodiesel and offshore wind power because they are cost-inefficient. However, we find it difficult to understand how CCS can be supported on the basis of cost-efficiency, since this measure is twice as expensive per tonne of carbon emission abated.

A more integrated policy based on a consistent application of the cost-efficiency principle would have many benefits. These include the ability to realise more measures within specific budgetary limits, while industry would face a predictable and transparent system for supporting climate measures. In such a context, CCS projects would not be realised. Norway has a number of far cheaper climate measures to pursue, including enhancing the energy efficiency of existing buildings, facilitating reduced energy use in new buildings, developing district heating and converting oil-fired boilers to run on bio-energy.

Because it is the world’s second-larges gas exporter, and because its output of this commodity is rising and set to remain high for many years, Norway has a national interest in contributing to efficient carbon capture from gas. (However, the value of this is difficult to calculate.) The reason is that this will help to safeguard the economic rent in Norwegian gas reserves. If the problem of carbon capture is overcome for coal but not for gas, it would have a negative effect on gas prices. However, nothing prevents Norway supporting research projects related to carbon capture abroad if more appropriate facilities are available there.

Norway’s performance on carbon emission abatement is mediocre, and contrasts sharply with work to cut the release of NO_x. The difference is that the latter efforts are pursued through industry’s NO_x fund. Companies pay a levy to this body, where a professional board allocates development funds on the basis of cost-efficiency. Credibility is achieved here through 1) transparent allocation criteria and 2) the funded format. The latter ensures that finance is available, unlike political support which depends on appropriations over each annual budget. This format ensures the necessary depoliticisation of the allocation process. Since NO_x and carbon emission reductions are often interconnected – and must be coordinated – incorporating the planned carbon emission abatements in the NO_x fund could be a good idea.

Even with today's ad hoc approach, the government has begun to have reservations about CCS because of the sharp rise in costs and a recognition that the plants will have low capacity utilisation. It is natural to study measures to reduce emissions for some of the country's biggest point sources of CO_2, but ambitious domestic emission abatement plans could paradoxically be a project stopper for CCS because of the need to think cost-efficiently in order to reach national reduction targets.

A company must normally seek to predict market developments for the product it manufactures and sells. Revenues for climate measures derive from allowances and government grants. The challenge is consequently to establish expectations about national and international political decisions. We have performed a commercial calculation of the cost of CCS at Kårstø. When a company comes to evaluate a measure which could be subject to a political decision, the commercial costs are also relevant since these indicate how much must be appropriate over the government budget to realise the project. One concern in this context is that the appropriation of billions of dollars for CCS look unrealistic for a number of reasons. The size of this single measure is disproportionate to other environmental measures. The government boasts in part that it has appropriated no less than USD 150 million for research into offshore wind power, yet had problems finding room in the budget for USD 6.7 million for the Hywind offshore wind turbine project. A relevant comparison could also be that the cost of the maintenance backlog on the Norwegian rail network – which leads to big delays and many cancelled trains – is estimated to be USD 1.3 billion. This spending must be spread over many years. The big sum required for CCS also seems to be on a collision course with the finance minister's expressed goal of tightening the budget and re-establishing control over spending in line with the "fiscal rule", which limits the spending of oil revenues in any one year. In the unlikely event that the project is approved, it would probably crowd out most other climate and environmental projects, which would mean a very one-sided commitment and breach advice on cost-efficiency. Nor is it likely to be possible to achieve the goal on emission abatement set by the Storting's climate compromise.

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