Rate of return requirement for climate versus petroleum projects[1]

by

Magne Emhjellen* and Petter Osmundsen**

** Petoro AS*

*** University of Stavanger*

Many sosio-economic rates of returns for climate projects have been used in analysing the present value of the climate benefit. However, little attention has been devoted to profitability assessments based on commercial considerations. Economic valuation of climate projects, seen from the perspective of a commercial company, is the subject of this article. In particular, we examine the required rate of return for a project where the uncertainty in the CO_2 quota price is the main market uncertainty. We complement the existing climate literature by examining the required rate of return of a climate project in a Capital Asset Pricing Model (CAPM) setting. We find that the CO_2 quota price has slightly more systematic risk in the period calculated than the oil price, and estimate the nominal required rate of return for the value of CO_2 reduction to be 7.3 percentage points.

Keywords: Climate projects, decision analysis, CO_2

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

** Petter Osmundsen, department of industrial economics and risk management, University of Stavanger, NO-4036 Stavanger, Norway. E-mail: petter.osmundsen@uis.no, home page: WWW.uis.no/Osmundsen

1. Introduction

Many sosio-economic rates of returns for climate projects have been used in analysing the present value of climate benefits or effects, e.g., Stern (2007). However, little attention has been devoted to profitability assessments based on commercial considerations. Climate projects will normally be executed by private players, for whom decision criteria developed from a commercial perspective are important. If for instance an oil company is to invest in offshore windmills, it needs to evaluate the risk in this project relative to exploration and development of petroleum resources. Commercial criteria are also important for the government in calculating the size of subsidies required for various measures. One critical factor in commercial valuation of climate projects is the correct required rate of return. Since many climate projects are capital intensive and have long lead times, e.g., CCS and offshore windmills, capital costs constitute a major part of the costs. The revenue from a climate project is the value of the climate benefit produced. In the case of a CCS project the revenue is the value of the expected net C02 reduction as a result of the project. The present value of this expected net C02 reduction is a function of the expected market price for C02 reduction times C02 volume discounted at the correct discount rate. In addition to the crucial assumption on expected future price the importance of the discount rate is evident.

“The normatively acceptable real interest rates prescribed by philosophers, economists, or the British government are irrelevant to determining the appropriate discount rate to use in the actual financial and capital markets of the United States, China, Brazil, and the rest of the world.” Nordhaus (2007)

Literature on the subject of the required rate of return for a climate project have argued for and used varying discount rates. Weitzman (2001) states that "The most critical single problem with discounting future benefits and costs is that no consensus now exists [..] about what actual interest to use..". For example, in the Stern report the discount real rate used was 1.4% (Stern 2007). In comparison, in the Nordhaus model (2008) the real rate used was 4.1% - a much higher rate. Others have argued that projects with a very long horizon (more than 50 years) should have a lower discount rate (Gollier and Witzman, 2010). A substantial climate project is likely to have a long horizon since the amount of CO_2 must be large over many years to be able to carry the large investments needed (an example is a Carbon Capture and Storage project). However, due to depreciation of investments it is unlikely that a project would have maturity beyond 50 years. New investments and decisions would then have to be made.

Because of the popularity of the concept of “abatement unit costs”, we first discuss calculation of CO_2 abatements. Since many climate projects have high initial capital investments, a vital input is the cost of capital. We proceed by examining the required rate of return for a climate project .We complement the existing literature by applying the common practice in a commercial setting - the use of the CAPM model in estimating the required rate of return. In particular, we estimate the required rate of return for a climate project where the major systematic uncertainty is the value (the market price of the allowance) of the reduction in CO_2.

For comparison, we calculate the systematic risk in climate projects versus petroleum projects. The relative risk of climate projects versus petroleum projects has been a major topic in the petroleum companies, which have included climate projects in their portfolios. Most noteworthy is British Petroleum, which in 1997 established a company-wide target to reduce its emissions of greenhouse gases.[2] In 2000 they introduced a new slogan, "Beyond Petroleum". BP's investment in green technologies peaked at 4% of its exploratory budget, but they have since cut back on such investments and closed their alternative energy headquarters in London.[3]

The article has the following disposition. Section 2 explains unit costs for carbon emission abatement and gives some examples. In section 3 we estimate the required return for a climate project related to CO_2 in a Capital Asset Pricing Model framework. Section 4 concludes.

2. Abatement unit costs

Two types of economic calculations are conducted in climate analyses: 1) NPV analyses 2) calculations of cost annuity, known as abatement unit costs. The first of these represents the normal decision criterion for projects in both public and private sectors, and provides an accurate impression of project economics. The second – much used in climate analyses to compare various abatement measures – is not really a decision criterion but can function as one under certain circumstances. The basis for this type of calculation is that the climate problem is global, so it makes no difference which source is used to achieve the emission abatement, or its location.

Annuities seem to have become an established standard for calculating environmental costs. One advantage is probably the educational aspect – abatement unit cost can be compared with the price of allowances, and projects of differing duration can be compared. But today's allowance price is not necessarily comparable with an annuity cost. Allowance prices will vary over time. Using annuities in a decision context presupposes a stable carbon price.

Another problem is that the annuity method as such is not actually used in climate calculations, but only a rough approximation of it. As we understand it, capital expenditure (Capex) is distributed over the economic life of a measure, but not operating expenditure (Opex). A reference year is chosen and the carbon price is compared with the annuity for Capex and Opex for a given

[2] "BP tackles climate change threat with £200m boost for energy efficiency". London: The Telegraph. 25 October 2005. Retrieved 9 February 2011.

[3] http://en.wikipedia.org/wiki/BP

expected capacity utilisation in the reference year. This is an arbitrary and discretionary approach, where much depends on the choice of reference year. Using this type of quasi-annuity in a decision context implicitly includes the assumption that carbon emissions in the project will reduce steadily over time.

In other words, the annuity criterion appears to be basically useful for choosing between various climate measures, since it permits the cost per tonne of carbon emissions abated to be compared for various measures. But this is not entirely straightforward because of differing volumes and time frames. Efforts can be made to overcome the problem by establishing a representative year, but that is incomplete and subject to discretionary choices. A better solution would be to calculate a genuine annuity for the costs – in other words, apportion the NPV of all the costs over the expected economic life of the measure.

Strictly speaking, an optimisation model must be used when allocating scarce investment funds in which total emission abatements are maximised within a given budget (linear programming).[4] A simplified method applied in the business sector is a NPV index. The NPV of the project is divided by the NPV of the investment to produce a common indicator for comparing projects. In a climate context, a NPV index could be similarly compiled, calculated per tonne of emission abatement.

The annuity cost will provide a good deal of information if correctly calculated but is insufficient. It is accordingly important to operate with both annuities and NPVs. In a number of contexts, the latter are also more informative for the general public, e.g., because it also conveys information on the scale involved. The portfolio of possible projects must be measured against available funds. This should be supplemented by a cash-flow analysis – overall and for individual projects – and an analysis which shows the burden on government budgets over time.

The discussion on annuity calculation for abatement unit costs will be illustrated more formally below. A company is indifferent about investing in a climate project if the NPV is zero – in other words, where the NPV of the carbon abatement gain (expressed as the NPV of quantity times value) is greater than the NPV of the abatement cost (expressed as the NPV of investment and operating costs):

$$\sum_{t=0}^{T} \frac{1}{(1+r)^t} v_t X_t = \sum_{t=0}^{T} \frac{1}{(1+r)^t} \left(I_t + C_t \right) , \tag{1}$$

where X_t is tonnes of CO_2 in year *t* and v_t is the price/value of carbon abatement in year *t*, I_t is investment and C_t is operating cost in year *t*. If we keep the price/value of CO_2 and the abatement

---

[4] See Emhjellen et al (2006).

cost (in real value) constant over time, and divide by the NPV of quantity on both sides of the equation, we get the following expression for the abatement unit cost:

$$v = \frac{\sum_{t=0}^{T} \frac{(I_t + C_t)}{(1+r)^t}}{\sum_{t=0}^{T} \frac{X_t}{(1+r)^t}} \qquad (2)$$

The NPV of costs divided by the NPV of the volume of carbon emissions abated expresses the abatement unit cost – in other words, the average value of carbon abatement required for the value to equal the costs, given the required return *r*. An alternative method for calculating the abatement unit cost is to calculate an annual annuity on the basis of investment and interest rates and to assume a normal year or an average carbon emission abatement, so that the abatement unit cost is the annual cost in the reference year divided by the annual emissions abated. With a fixed annual emission abatement (steady level of activity), the figures will be very similar for the two methods. On the other hand, should the level of activity vary – as is the case in the real world – the differences could be very substantial. That provides a strong argument for using equation (2) rather than a simplified calculation based on a "normal" year.

Abatement unit costs are calculated as annual cost annuities based on the economic life of the facilities divided by the annual volume of carbon emissions *avoided*. Certain studies operate instead with the volume of CO_2 *captured.* This is completely wrong from a climate perspective, since the capture process itself often is energy-intensive (e.g., CCS) and produces its own emissions. The latter must naturally be deducted in order to establish the net abatement provided by the measure. In other words, the real abatement unit cost – in both commercial and socio-economic terms – will be higher. In a commercial calculation, the carbon emissions avoided represent the relevant figure, since the option to sell free allowances means that CO_2 has an opportunity cost (defined by the allowance price) whether the company is a net buyer or seller of allowances.

As with the NPV method the abatement cost estimation requires an estimate of the correct required rates of return in discounting the cash flows. This is the topic of Section 3.

3. CAPM return in discounting climate projects' cash flows

Current expectations of future allowance prices for CO_2 and of development and operating costs will be crucial for project economics. This because of the large initial capital outlays required and the substantial lead times. In addition it is important to establish a good estimate for the required rate of return. The capital asset pricing model (CAPM)[5] has become an established theoretical method for calculating required rates of return in a commercial context:

$$E(R_i) = R_f + \beta_i \big(E(R_m) - R_f\big), \qquad (3)$$

where $E(R_i)$ is the expected return on a project *i*, R_f is the risk-free interest rate, $E(R_m)$ is the expected return on the market portfolio and β_i is the covariance in return between project *i* and the market portfolio, divided by the variance in the return on the market portfolio

$$(\beta_i = \frac{Kov(r_i, r_m)}{Var(r_m)}). \qquad (4)$$

From equation 4 it is clear that a risk adjustment is required only for risk which cannot be diversified away [that is correlated with the rate of return on the market portfolio (r_m)]. A generally accepted theory accordingly exists for estimating a required rate of return. Many different approaches can be taken in applying the model, however, and no standard solution is available. The required return will depend on the time periods and time resolution adopted for calculating the risk-free interest rate and market risk premium. Should short-term government bonds be used as an estimate? Is it not the case that different projects have differing commitment periods and therefore different time premiums? Some people argue for today's short-term government bond rate, whilst others urge the use of today's long-term government bond rate less a historical difference between short-term and long-term interest rates. Another view is that the most appropriate approach would be to apply the government bond rate which lies closest to the duration of the project, because that provides the most accurate reflection of the risk-free capital commitment for a given period. Where a market portfolio is concerned, the normal approach today would be to consider a world portfolio – often represented by a proxy, such as Morgan Stanley's world index. The question then is which currency should be used. Should this be the currency of the project country or the one in which the bulk of the costs or revenues is denominated?

Despite differing views on the principles for selecting the correct risk-free interest rate and market premium, model users will in practice often opt for estimates based on figures from historical periods and today's financial markets. The same will have to be done for estimating beta, with an *ex post* estimate used to specify an *ex ante* estimate for beta based on share prices in a listed company. However, a practical problem arises when no representative listed company is available with virtually the same system risk as the project. What is then to be done? As far as we can see, no market data are available which can say anything about the way investors regard the net cash flow risk for a climate

[5] Sharpe (1964), Lintner (1965).

project. As a result, no exact basis exists for estimating the project beta. An alternative could be to look at the beta for different cash flows in a project.

It follows from the value additivity principle (Shall, 1972) that the NPV of a project is the sum of the NPVs of the project's subordinate cash flows:

$$V_i = \sum_{j=1}^{M_i} X_{ij} , \tag{5}$$

where X_{ij} is the NPV of the individual cash flow *j* in project *i* discounted by the correct required return for *j*, $E(R_{ij})$. M_i is the number of subordinate cash flows in project *i*. The expected return for a project is equal to the sum of the value-weighted expected return for the individual cash flows:

$$E(R_i) = \sum_{j=1}^{M_i} w_{ij} E(R_{ij}). \tag{6}$$

In equation (6), we have $w_{ij} = \frac{X_{ij}}{V_i}$ and $\sum_{j=1}^{M_i} w_{ij} = 1$. From the CAPM, the expected return for the individual cash flow *j* can be written as:

$$E(R_{ij}) = R_f + \beta_{ij} \lfloor E(R_m) - R_f \rfloor. \tag{7}$$

By integrating (7) in (6), β_i can be written as

$$\beta_i = \sum_{j=1}^{M_i} w_{ij} \beta_{ij} . \tag{8}$$

With a climate project for CO_2 where no observable required return can be found for a company or a project which makes it possible to estimate the investors' assessment of the systematic risk for the net cash flow, better information might be available on the risk for the subordinate cash flows in the project. These can then be valued separately.

3.1 Beta calculation for prices

The revenue side for a climate project related to CO_2 is the value of the CO_2 reduction, given by CO_2 quotas. Information available from the allowance market can be used to estimate the required rate of return for the value of the CO_2 reduction. To provide a comparison we also perform the same calculation on the Brent blend oil price. The required rate of return for oil exploration companies is a topic which is well known and where studies have been made. The beta of the Brent oil price might therefore indicate whether this revenue beta accounts for the major component of the adjustment for systematic risk in the project valuation. If it does, i.e. if cost betas are low, it is more likely that also the revenue beta of a CO_2 reduction project accounts for the main adjustment for systematic risk. With data from 2005 to 2011 we calculate the *ex post* beta of CO_2 removal based on the rate of change of the quota allowance prices per tonne CO_2 and the World Index as a proxy for the market portfolio. The prices are given in Table 1 in the appendix and the rates of change calculated are given in Table 2 in the appendix.

Using equation 5 the quota allowance price beta (β_1) and the Brent oil price beta (β_2) are given in equation 9 and 10 respectively,

$$\beta_1 = \frac{0.00199397}{0.002686} = 0.72 \tag{9}$$

$$\beta_2 = \frac{0.0017668}{0.002686} = 0.66 \tag{10}$$

The results show that the CO_2 quota price has slightly more systematic risk in the period calculated than the oil price. Using these *ex post* estimates as estimates for the *ex ante* betas, the results indicate that a CO_2 reduction project should have a somewhat higher discount rate for revenues than an oil exploration project.

3.2 Beta calculation for capital cost

Investment costs for climate projects comprise various capital cost expenditures. For example, a carbon capture and storage project will have large investments in facilities as well as transport and storage (injection below ground). Much of this risk will be unsystematic, but some parts of the capital expenditure like steel prices, equipment deliveries and hourly pay rates might have systematic risk components since these may be correlated with market portfolio return. We examine this by using the IHS/CERA Upstream Capital Cost Index (UCCI) as a proxy for capital cost from 2004 to 2011. The data and the rates of change of the UCCI and the Word Index (as proxy for the market portfolio) on the available twice a year basis are given in Table 3 below.

Table 3: UCCI and WI Index and Rates of Change

	Index		Rates	
	UCCI	WI	UCCI	WI
Q1 2004	107,8	1060,0	1,9 %	17,7 %
Q3 2004	109,5	1034,8	1,6 %	-2,4 %
Q1 2005	114,6	1156,7	4,7 %	11,8 %
Q3 2005	126,0	1202,4	9,9 %	3,9 %
Q1 2006	148,0	1319,2	17,5 %	9,7 %
Q3 2006	167,4	1353,2	13,1 %	2,6 %
Q1 2007	179,2	1501,6	7,0 %	11,0 %
Q3 2007	197,8	1587,0	10,4 %	5,7 %
Q1 2008	210,0	1587,0	6,2 %	0,0 %
Q3 2008	230,0	1453,1	9,5 %	-8,4 %
Q4 2008	221,0	1298,0	-3,9 %	-10,7 %
Q1 2009	210,0	798,3	-5,0 %	-38,5 %
Q3 2009	202,0	1085,8	-3,8 %	36,0 %
Q1 2010	201,0	1151,1	-0,5 %	6,0 %
Q3 2010	207,0	1128,2	3,0 %	-2,0 %
Q1 2011	218,0	1331,6	5,3 %	18,0 %

Calculating the UCCI cost beta using the data in Table 3,

$$\beta_3 = \frac{0.021}{0.025863} = 0.08 \tag{11}$$

The Beta result of 0,08 demonstrates a quite low systematic cost beta and concurs with the results in Emhjellen (1999), who found cost betas below 0,17. The result indicates that the majority of systematic risk is in the revenues and that these should have a much higher risk discounting than the cost cash flow.

3.3 The Required rate of Return for a Climate Project

A required return is dependent on the point of time when it is estimated. In equation (3) both the risk-free interest rate and the expected return on the market portfolio is likely to change with time. Belief in the ex post betas as estimates for the ex ante betas is of course also important when estimating the ex ante required rate of return. As such, a required return estimate is a best estimate based on the information available at the time it is made. The current market situation is that of very low risk free rates. The government bond yields as estimates for the risk free rate is very low in the countries where the market considers the default risk to be low. The 10 year yields quoted the January 17, 2012 for countries like the UK (1.98%), the USA (1.86%), the Euro-countries (1.77%) and Norway (1.82%) are all below 2%. This is historically very low and also indicates that the inflationary expectations for the next years are unusually low. Based on these bond yields an estimate for the risk free rate of 2% would seem reasonable. However, the yield curve is normally upward sloping with time and the duration for a major Climate project (e.g., a carbon capture project) would probably be 30-40 years. In such a time frame an estimate of 3% is likely more correct.

The market risk premium $\left(E\left(R_m\right)-R_f\right)$ will change over time and its estimate will change depending on method and time period chosen (see Damodaran, 2011). Using historic geometric equity premiums (Dimson et al, 2008) for a large Euro currency country like Germany (5.9%) would give a reasonable estimate of 6% as equity market risk premium. Damodaran (2011) shows, in figure 1, equity market risk premiums over time both for historic geometric and arithmetic means as well as implied equity premiums for the US.

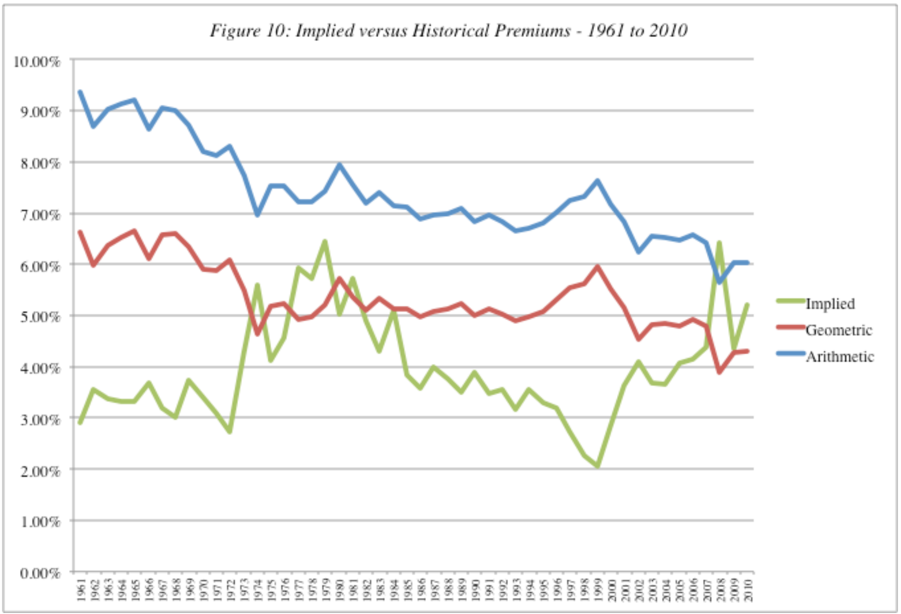

Figure 1: Implied versus historic risk premiums, 1961-2010. Source: Damodaran (2011).

The arithmetic mean equity risk premium is almost consistently the highest, while the implied and geometric risk premiums are higher or lower depending on the time period. In more recent times it seems that the implied equity risk premium shot above the geometric risk premium during the financial crisis and then fell somewhat back before rising again - probably due to the European debt crisis. The current estimate for the Implied Equity Market Risk Premium for US is 6.04% (Damodaran, 2011) and corresponds with the Historic Equity Risk Premium for Germany (6%).

With the use of equation (3), a 3% risk free rate and a 6% Market Equity Risk premium, the required nominal rate for the revenue based on the CO_2 quota price beta calculated in equation (9), is equal to

$$E\left(R_i\right)=3\% \ +0.72 \ \left(6\%\right)=7.32\% \qquad (12)$$

The estimated required nominal commercial rate of return for the climate project revenue of reducing CO_2 is then 7.32%. The low cost beta estimate in equation (10) indicates that risk free discounting of cost is a good estimate of the present value of cost. This would increase the present value of costs compared to the common practise of using an estimated required rate of return for the net cash flow of the project.

With different discount rates for cost and revenue cash flows, the abatement cost in equation 2 is expressed by equation (13),

$$v_t = \frac{\sum_{t=0}^{T} \frac{(I_t + C_t)}{(1+c)^t}}{\sum_{t=0}^{T} \frac{X_t}{(1+a)^t}} \tag{13}$$

where c and a are discount rates which reflect systematic risks for cost and the value of carbon emission reductions, respectively. A higher required rate for the value of the CO_2 reduction compared to the costs, has the effect of increasing the commercial abatement cost; the present value of cost will increase and the present value of the CO_2 reductions will be reduced.

Using the CCS project in Osmundsen and Emhjellen (2010) as an example, we calculate the abatement cost using equation (13). It is carbon capture project at the Kårstø gas processing plant in south-western Norway. Expected inflation is assumed to be 2%. The real rate of return for CO_2 reductions is then 5.32% and the real risk free rate is 1%.The investment cost estimate for CCS at Kårstø was 1100 Million Euro (1500 Million USD, here assumed occurring in year 0) and operating cost of 56 million Euro per annum (75 million USD) (figures in real 2010 values). The project should remove an expected 500.000 tonnes CO_2 a year for 25 years. Applying the real risk free rate for cost and the 5.32% for revenue cash flows in discounting, equation (13) implies the following cost per tonne CO_2 reduction

$$v = \frac{2333}{6.8} = 343 \quad . \tag{14}$$

Thus, the commercial abatement cost is 343 euro per tonne CO_2 reduction. If we instead use the societal discount rate of 1.4% in the Stern report (2007) and apply the traditional NPV method in equation (2), the cost per tonne CO_2 reduction is

$$v = \frac{2274}{10.5} = 217 \tag{15}$$

Our result shows that commercial abatement cost is much higher than calculated societal abatement cost. Our calculation is based on the calculated betas of revenue and costs, and where valuation is given by the sum of the NPVs of the project's cash flows. The societal abatement cost is based on the discount rate in the Stern report of 1.4% and the common practise of using an estimated required rate of return for the net cash flow of the project. If we had assumed a longer lead time with valuation and decision 5 years before actual investment, then the difference between the results would be even larger; 421 Euro per tonne compared to 216 Euro per tonne.

We now calculate commercial abatement cost by using the common practise of using an estimated required rate of return for the net cash flow of the project. Whatever the choice of investment evaluation method, our estimation of partial cash flows is still useful, as it demonstrates similar systematic risk of oil revenue and CO_2 allowances. Presuming the cost structure of the abatement project has the same systematic risk pattern as a petroleum project, which is a reasonable assumption in petroleum related projects like CCS, climate projects should in a commercial setting be valued analogously to petroleum projects.

Selected relevant industrial groups have different net cash flow betas estimated from the equity market, see Damodaran's website.[6] We believe that the oil and gas integrated industry group, with a beta value of 0.74, may provide a reasonable estimate for a net cash flow beta in a climate project. With the previous assumptions this will imply a real rate of return requirement of 5.44% and an abatement cost of 277 Euro per tonne CO_2 reduction. With the 5 year lead time the result would not change much (275 Euro per tonne) since the lower present value of the cost would be offset by the lower present value of the value of the CO_2 reduction. Thus, we find that also with this conventional approach to valuation, commercial abatement costs are considerably higher than societal abatement costs.

[6] http://pages.stern.nyu.edu/~adamodar/

4.0 Summary

We complement the existing literature of climate projects by examining the required rate of return of a climate project in a Capital Asset Pricing Model (CAPM) setting. We estimate the nominal required rate of return for the value of CO_2 reduction to be 7.3% and find very low systematic cost risk (beta 0.08). The results indicate that in a commercial setting the value of CO_2 abatements should be discounted at a higher rate than is commonly used in socio economic analyses.

Our findings may explain why it is hard for oil companies to justify climate projects in their portfolios – climate projects have similar risk pattern as petroleum projects and have to deliver the same return. We also provide a suggestion as to why the level of subsidies proposed by government may be insufficient to trigger commercial investments in climate projects - the commercial abatement costs are considerabley higher than the reported societal abatement costs.

[1] We would like to thank a number of specialists in business and the civil service for useful comments and proposals. Financial support from the Norwegian Research Council is appreciated.

References

Damodaran, A. 2011. Equity Risk Premiums (ERP): Determinants, Estimation and Implications – The 2011 Edition, Stern School of Business, adamodar@stern.nyu.edu

Damodaran, A. 2012. http://pages.stern.nyu.edu/~adamodar/

Dimson, E., Marsh, P. and Staunton, M. 2008. The Worldwide Equity Risk Premium: a smaller puzzle, Chapter 11 in the Handbook of the Equity Risk Premium, edited by R. Mehra, Elsevier.

Emhjellen, M. "Valuation of Oil-Projects Using the Discounted Cash flow Method." *A thesis submitted for the degree of Doctor of Philosophy at the University of New South Wales*, March 1999.

Gollier, C. and Weitzman, M.L. 2010. "How should the distant future be discounted when discount rates are uncertain", Economic Letters, 107, 350-353, Elsevier.

IHS/CERA, Capital Costs Analysis Forum – Upstream: UCCI

Lintner, J 1965. "Security Prices, Risk and Maximal Gains from Diversification", *Journal of Finance*, vol 20, pp 587-615.

Nordhaus, W.D. 2007. "A Review of the Stern Review on the Economics of Climate Change" *Journal of Economic Literature*, Vol XLV (September 2007), pp. 686-702.

Nordhaus, W.D. 2008. "A question off balance: Economic Modeling of Global Warming." Yale University Pres

Osmundsen, P., Emhjellen. M. 2010. " CCS from the gas-fired power station at Karstø? A commercial analysis", Energy Policy, Vol. 38, Issue 12.

Sharpe, W 1964. "Capital Asset Prices: a Theory of Capital Market Equilibrium Under Conditions of Risk", *Journal of Finance*, vol 19, pp 425-442.

Stern, N. 2007. "The economics of climate change", Cambridge University Press.

Weitzman, M.L. 2001. Gamma discounting. *American Economic Review*, 91 (1), 260-271.

Appendix

Table 1

	World Index	EU quota Euro/t	Brent USD/bbl
mai 31, 2005	1140,7	17,9	48,7
jun 30, 2005	1148,8	21,4	54,4
jul 29, 2005	1188,2	25,1	57,5
aug 31, 2005	1194,8	22,5	64,0
sep 30, 2005	1224,3	23,0	62,9
okt 31, 2005	1193,9	22,6	58,5
nov 30, 2005	1231,4	21,7	55,2
des 30, 2005	1257,8	22,0	56,9
jan 31, 2006	1313,2	21,6	63,0
feb 28, 2006	1309,5	26,5	60,2
mar 31, 2006	1335,1	24,3	62,1
apr 28, 2006	1373,4	28,3	70,3
mai 31, 2006	1322,2	21,4	69,8
jun 30, 2006	1319,9	20,0	68,6
jul 31, 2006	1327,2	19,5	73,7
aug 31, 2006	1358,9	17,9	73,2
sep 29, 2006	1373,4	17,3	62,0
okt 31, 2006	1422,9	15,7	57,8
nov 30, 2006	1455,2	16,7	58,8
des 29, 2006	1483,6	18,5	62,5
jan 31, 2007	1500,2	16,2	53,7
feb 28, 2007	1490,4	14,6	57,6
mar 30, 2007	1514,2	16,2	62,1
apr 30, 2007	1577,9	18,0	67,5
mai 31, 2007	1616,9	21,5	67,2
jun 29, 2007	1602,4	24,0	71,1
jul 31, 2007	1565,8	20,6	76,9
aug 31, 2007	1561,6	20,0	70,8
sep 28, 2007	1633,6	21,5	77,2
okt 31, 2007	1682,4	22,8	82,3
nov 30, 2007	1610,9	23,1	92,4
des 31, 2007	1588,8	23,1	90,9

*Monthly EU quota allowance price averages calculated from daily prices (CDM).
** Europe Brent Spot Price FOB (Dollars per Barrel), Source EIA.
*** World Index, source MSCI inc.

Table 1 continued

	World Index	EU quota Euro/t	Brent USD/bbl
jan 31, 2008	1466,3	23,0	92,2
feb 29, 2008	1455,6	21,7	95,0
mar 31, 2008	1437,4	23,0	103,6
apr 30, 2008	1509,0	25,5	109,1
mai 30, 2008	1525,7	26,7	122,8
jun 30, 2008	1402,1	28,8	132,3
jul 31, 2008	1366,7	28,0	132,7
aug 29, 2008	1344,9	25,6	113,2
sep 30, 2008	1182,4	25,9	97,2
okt 31, 2008	957,2	22,4	71,6
nov 28, 2008	892,9	18,3	52,5
des 31, 2008	920,2	16,3	40,0
jan 30, 2009	838,8	14,0	43,4
feb 27, 2009	750,9	10,5	43,3
mar 31, 2009	805,2	12,9	46,5
apr 30, 2009	893,0	14,6	50,2
mai 29, 2009	970,0	16,3	57,3
jun 30, 2009	964,0	14,6	68,6
jul 31, 2009	1044,8	15,1	64,4
aug 31, 2009	1085,6	15,8	72,5
sep 30, 2009	1127,0	15,1	67,7
okt 30, 2009	1106,2	15,1	72,8
nov 30, 2009	1149,0	14,3	76,7
des 31, 2009	1168,5	14,4	74,5
jan 29, 2010	1119,5	14,5	76,2
feb 26, 2010	1133,3	14,1	73,8
mar 31, 2010	1200,5	14,2	78,8
apr 30, 2010	1198,6	15,7	84,8
mai 31, 2010	1079,8	16,5	76,0
jun 30, 2010	1041,3	16,4	74,8
jul 30, 2010	1124,8	15,2	75,6
aug 31, 2010	1080,7	15,5	77,0
sep 30, 2010	1179,2	16,2	77,8
okt 29, 2010	1222,2	16,1	82,7
nov 30, 2010	1193,6	15,6	85,3
des 31, 2010	1280,1	15,0	91,5
jan 31, 2011	1308,1	16,0	96,5
feb 28, 2011	1351,6	16,5	103,7
mar 31, 2011	1334,9	18,4	114,6
apr 29, 2011	1388,6	19,1	123,3
mai 31, 2011	1354,6	18,9	115,0

Table 2

Rate change

	World Index	EU quota Euro/t	Brent USD/bbl
jun 30, 2005	0,7 %	19,4 %	11,7 %
jul 29, 2005	3,4 %	17,6 %	5,8 %
aug 31, 2005	0,6 %	-10,5 %	11,2 %
sep 30, 2005	2,5 %	2,2 %	-1,7 %
okt 31, 2005	-2,5 %	-1,7 %	-6,9 %
nov 30, 2005	3,1 %	-3,8 %	-5,6 %
des 30, 2005	2,1 %	1,3 %	2,9 %
jan 31, 2006	4,4 %	-1,9 %	10,8 %
feb 28, 2006	-0,3 %	22,8 %	-4,4 %
mar 31, 2006	2,0 %	-8,4 %	3,1 %
apr 28, 2006	2,9 %	16,2 %	13,2 %
mai 31, 2006	-3,7 %	-24,3 %	-0,7 %
jun 30, 2006	-0,2 %	-6,5 %	-1,7 %
jul 31, 2006	0,6 %	-2,7 %	7,5 %
aug 31, 2006	2,4 %	-7,9 %	-0,6 %
sep 29, 2006	1,1 %	-3,8 %	-15,4 %
okt 31, 2006	3,6 %	-8,9 %	-6,7 %
nov 30, 2006	2,3 %	6,0 %	1,6 %
des 29, 2006	2,0 %	10,8 %	6,3 %
jan 31, 2007	1,1 %	-12,4 %	-14,1 %
feb 28, 2007	-0,7 %	-10,0 %	7,2 %
mar 30, 2007	1,6 %	11,0 %	7,8 %
apr 30, 2007	4,2 %	11,2 %	8,8 %
mai 31, 2007	2,5 %	19,9 %	-0,4 %
jun 29, 2007	-0,9 %	11,2 %	5,7 %
jul 31, 2007	-2,3 %	-13,8 %	8,3 %
aug 31, 2007	-0,3 %	-3,3 %	-8,0 %
sep 28, 2007	4,6 %	7,6 %	9,1 %
okt 31, 2007	3,0 %	6,2 %	6,7 %
nov 30, 2007	-4,2 %	1,4 %	12,2 %
des 31, 2007	-1,4 %	-0,1 %	-1,6 %

Table 2 continued

	Rate change		
	World Index	EU quota Euro/t	Brent USD/bbl
jan 31, 2008	-7,7 %	-0,5 %	1,4 %
feb 29, 2008	-0,7 %	-5,8 %	3,0 %
mar 31, 2008	-1,2 %	6,1 %	9,1 %
apr 30, 2008	5,0 %	11,1 %	5,2 %
mai 30, 2008	1,1 %	4,7 %	12,6 %
jun 30, 2008	-8,1 %	7,7 %	7,8 %
jul 31, 2008	-2,5 %	-2,8 %	0,3 %
aug 29, 2008	-1,6 %	-8,5 %	-14,7 %
sep 30, 2008	-12,1 %	0,8 %	-14,1 %
okt 31, 2008	-19,0 %	-13,2 %	-26,4 %
nov 28, 2008	-6,7 %	-18,4 %	-26,7 %
des 31, 2008	3,1 %	-10,9 %	-23,8 %
jan 30, 2009	-8,8 %	-14,4 %	8,7 %
feb 27, 2009	-10,5 %	-24,6 %	-0,3 %
mar 31, 2009	7,2 %	22,8 %	7,4 %
apr 30, 2009	10,9 %	13,2 %	7,8 %
mai 29, 2009	8,6 %	11,2 %	14,2 %
jun 30, 2009	-0,6 %	-10,2 %	19,7 %
jul 31, 2009	8,4 %	3,4 %	-6,1 %
aug 31, 2009	3,9 %	4,5 %	12,5 %
sep 30, 2009	3,8 %	-4,5 %	-6,7 %
okt 30, 2009	-1,8 %	-0,3 %	7,6 %
nov 30, 2009	3,9 %	-4,9 %	5,3 %
des 31, 2009	1,7 %	0,4 %	-2,9 %
jan 29, 2010	-4,2 %	0,7 %	2,3 %
feb 26, 2010	1,2 %	-2,4 %	-3,2 %
mar 31, 2010	5,9 %	0,3 %	6,9 %
apr 30, 2010	-0,2 %	10,6 %	7,6 %
mai 31, 2010	-9,9 %	5,4 %	-10,5 %
jun 30, 2010	-3,6 %	-0,7 %	-1,6 %
jul 30, 2010	8,0 %	-7,4 %	1,1 %
aug 31, 2010	-3,9 %	2,2 %	1,9 %
sep 30, 2010	9,1 %	4,2 %	1,0 %
okt 29, 2010	3,6 %	-0,6 %	6,2 %
nov 30, 2010	-2,3 %	-3,3 %	3,2 %
des 31, 2010	7,2 %	-3,4 %	7,2 %
jan 31, 2011	2,2 %	6,2 %	5,5 %
feb 28, 2011	3,3 %	3,2 %	7,5 %
mar 31, 2011	-1,2 %	11,4 %	10,5 %
apr 29, 2011	4,0 %	4,2 %	7,5 %
mai 31, 2011	-2,4 %	-1,3 %	-6,7 %