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Analysing the role of decision-making economics for industry in the climate change era

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Abstract

Purpose – The purpose of this paper is to illustrate how project economics and decision making in industry can be affected by global climate change. When assessing the sustainability of any design or project, one of the key emerging considerations is the potential for the decision to contribute to greenhouse house gas (GHG) emissions. Changes in climate may also lead to new project risks with further economic implications.

Design/methodology/approach – Examination of the wider social economic implications of climate change provides the basis for considering individual projects within the context of the social costs of carbon emissions, the prospect of the gradual internalisation of those costs, and the costs and benefits of adaptation to protect against the impacts of global change on the project.

Findings – Emissions of greenhouse gases, still widely not priced in many parts of the world, drive the emerging observed and predicted effects of climate change on the planet. This damage has real value and can be monetised, allowing a notional social cost of carbon to be estimated. As climate change continues to manifest itself, societies start to react, constraining emissions and creating a market price or tax for carbon. If economic analysis for project decision making includes an explicit consideration of the likely future trajectory of carbon prices, and also examines the wider external social costs of carbon, the benefits of early adoption of revenue-positive measures to reduce emissions are revealed. In the same way, the financial costs of procrastination are made increasingly evident as regulatory and economic baselines shift. Designing for inevitable climate change will also help industry future-proof their operations.

Practical implications – At present, relatively few organisations examine the financial and economic implications of carbon emissions or the effects of a changing climate on their operations. To avoid unnecessary costs, and maximise benefit for stakeholders, decision making for business and government needs to incorporate an explicit economic treatment of the current and likely future implications of operating in a climate-constrained and climate-impacted world.

Originality/value – By conducting the kind of analysis proposed, organisations can not only help to reduce GHG emissions, but can also improve their own financial performance. The value of this analysis will only increase over the coming decades of the climate-change era.

Keywords Global warming, Economics, Decision making, Carbon, Costs, Product adaptation

Introduction

Climate change is only one part of a wider sustainability context that is becoming increasingly relevant for business. That wider context is underpinned by the fundamentals of a rapidly growing world population, currently at over six billion, and set to rise to over nine billion by 2050 (United Nations, 2002; US Census Bureau, 2008), and the legitimate aspirations of two billion of those people to rise above their current level of poverty. More people, with greater demands, puts increasing stress on the natural environment which provides the food, water and raw materials necessary for that prosperity. Recent surveys of global environmental health paint a gloomy picture

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of forest and biodiversity loss, significantly depleted marine resources, growing atmospheric pollution, and declining and polluted water resources (UNEP, 2002, 2007). And now there is clear evidence that climate change is beginning to affect the way the earth system operates (IPCC, 2007a; Worldwatch Institute, 2007; US National Science and Technology Council, 2008; CSIRO, 2007). Predictions are that these changes will only exacerbate the decline of our already weakened natural environment (IPCC, 2007a; Spratt and Sutton, 2008; UNEP, 2007; Worldwatch Institute, 2007)

The predicted effects of climate change, if emissions continue to grow unchecked over the next 30 years, are global in scale and pervasive in extent. Rising sea levels may threaten coastal areas with inundation, induce salinization of coastal aquifers, and impact coastal ecosystems, among other effects. Resulting population displacement could place considerable stresses on neighbouring countries, and elimination of low-lying agricultural lands would affect harvests (Green Cross Australia, 2008; IPCC, 2007c; Stern, 2006; Citibank, 2007; CSIRO, 2007). In turn, global security could be severely strained by civil unrest, refugee migration, and even war (Schwartz and Randall, 2003).

The latest science suggests that the majority of the planet's ecosystems and species cannot adapt quickly enough to the rate of warming predicted for the coming century, under business as usual conditions of unchanged emissions growth (Leemans and Eikhout, 2004; IPCC, 2007c). The implications for the planet's forests, grasslands, alpine habitats, tropical, boreal, freshwater and marine ecosystems which generate the oxygen we breathe and support the biodiversity which binds the intricate web of life on earth, are significant (Worldwide Fund for Nature, 2004; Thomas *et al.*, 2004; IPCC, 2007c; CSIRO, 2007). In short, the downside risks of climate change are too frightening to allow (US National Science and Technology Council, 2008; Stern, 2006; Garnaut, 2008; WBCSD, 2004; Flannery, 2005; International Academy of Councils, 2007).

In recent months, a significant body of research into the impacts of climate change is bringing a new sense of urgency to the issue. The warmest year on record in the arctic in 2007 has led to hugely accelerated melting of the polar ice cap, and recent studies now predict that if the current trends continue, the arctic will be ice-free in summer by 2015 (Maslowski, 2006; NOAA, 2007), 50 years ahead of the schedule set out in recent IPCC reports (Hansen, 2008). The implications of such rapid northern melting are significant – the flip in albedo from reflective white to heat-absorbing dark will accelerate the thawing of the permafrost, releasing significant quantities of methane into the atmosphere, further accelerating overall emissions and their effects. The earth system appears now to be responding much more rapidly to the effects of warming than previously predicted (Cox *et al.*, 2000; Hansen, 2008).

A climate change risk assessment for decision makers

The risk assessment process, practiced widely in industry, attempts to identify any and all possible risks associated with a project or activity, and then assesses them based on the probability of occurrence, and the magnitude of the expected effect. Risks with very high probability and low impact are deemed unacceptable and are mitigated against. Risks of catastrophic effect (which could put the company out of business or result in significant fatalities), and even very low likelihood, are also typically deemed unacceptable, and are mitigated.

The risks to organisations posed by climate change can be examined from two perspectives: first, risks of operating in a carbon-constrained world in which the cost of carbon will rise (discussed immediately below); and second, risks associated with adapting to a world increasingly being changed by the effects of climate change itself (Hardisty, 2008), which are discussed further below.

Mitigation risks are driven by increasing pressure from all parts of society, local and international, to be part of the effort to prevent the worst of the damage from climate change, by significantly reducing emissions of greenhouse gases such as CO_2 and methane (Table I). The scale of the mitigation challenge is monumental. According to the IPCC (2007c), Stern (2006), Garnaut (2008), and others, we need to decarbonise the world's economy by as much as 60 to 80 per cent by 2050, to give ourselves a reasonable chance of avoiding the worst effects of climate change. The scale of this change means that appropriate price signals will be put into place to progressively drive up the cost of carbon. Managing the introduction of widespread carbon taxation, in one form or another, is a key challenge for decision makers at all levels, in all types of organisations. Carbon-intensive operations will need to make profound changes to avoid large cost increases, and subsequent effects on profitability, competitiveness, and organisational sustainability. Introduction of cap and trade schemes will also mean that emissions will be restricted overall, preventing expansion and growth in emissions. Organisations of all types will have to develop expansion and growth strategies that work within these new limits.

Pricing carbon in business decisions

Including carbon management in effective decision making requires that carbon emissions be given a price. That price can be embedded in financial and economic analysis of projects, and used to understand present and future implications of various capital investment decisions. However, there are several different ways to examine the value of carbon, including market-based prices set within various trading schemes, the true social or damage value of each additional tonne of GHG emitted, shadow costs, and the marginal cost of abatement. Due to their relevance, they will be reviewed in turn.

The carbon markets

Carbon pricing, in one form or another, is quickly becoming commonplace. In Europe, the flourishing carbon market was worth over US$ 24 bn last year, trading over 1 bn tonnes of CO_2 equivalent (tCO_2e). The EU ETS (Emissions Trading Scheme) long term phase 2 average price now stands at about US$ 20-25/tCO_2e. The Clean Development Mechanism (CDM), established under Kyoto, traded over 500 million tonnes of CO_2 equivalent in 2006, worth over US$ 15 bn (World Bank, 2007). Other trading schemes, voluntary and regulated, are starting to appear around the world. In Alberta, Canada's oil and gas producing province and home of the Athabasca tar sands mega-reserves, the government has just announced a new CDN $ 15/tonne tax on GHG emissions exceeding mandatory reduction targets. The voluntary Chicago Climate Exchange has grown year-on-year since its inception, and the Montreal Stock exchange has announced a similar voluntary market in Canada. Also propelling carbon prices are carbon reduction and mandatory renewable energy targets (MRETs) being set by various governments worldwide, national, state and local. While many of the US States

Table I. Climate change mitigation risks for industry

Risk	Likelihood	Consequence	Mitigation measures
Carbon taxation	High over next ten to 20 years Already in place in some jurisdictions	Increased production costs, reduced profitability and competitiveness	*Reduce carbon intensity per unit of production* Energy and process efficiency measures Fuel switching, supply chain management Alterative energy sources and suppliers Carbon capture and storage Carbon offsetting Move production to lower carbon tax jurisdiction
Carbon emissions limits or caps	High over next ten to 20 years Already in place in some jurisdictions	Limitation on expansion of existing facilities, limitations on new facilities, reduced growth	*Reduce overall carbon emissions* Retrofit existing facilities to lower carbon footing (as above) Design and build new facilities for optimal energy efficiency Purchase permits or allowances from other firms Move production to higher emissions jurisdiction
Shareholder and investor scrutiny	High and rising over next few years	Greater difficulty in securing financing, higher borrowing costs, reduced profits	*Develop strategic plan to reduce shareholder risk from exposure of operations to carbon constraints* Implement carbon intensity reduction and overall emissions reduction plans as above Participate in carbon disclosure programmes, and other business sustainability indices
Public relations and corporate reputation damage	High and rising over next few years	Declining reputation in the market and with customer, declining sales, reduced profits	*Develop and enact corporate sustainability policies to manage risk of negative public sentiment* Take actions that will be seen as part of the solution, not as part of the problem Communicate with customers and community stakeholders on climate change, elicit feedback, incorporate into overall mitigation strategy

have their own significant renewable energy targets in place, full engagement of the United States on a federal level will have a resounding effect on the way the rest of the planet approaches carbon regulation in the coming decades. An Australian GHG cap and trade scheme, bolstered by state and commonwealth MRETs is now set to commence in 2010 (Commonwealth of Australia, 2008). All of these measures will increasingly impose a direct financial cost to organizations which emit significant amounts of GHGs.

The social cost of carbon

There is a fundamental difference between current market-based (in the case of cap-and-trade schemes) or tax-based carbon prices, and the real value of the damage caused by the emission of carbon into the atmosphere. The social cost of carbon (SCC) reflects the value of the damage caused by each additional tonne of GHG put into the atmosphere, in terms of the likely predicted impacts to the global economy caused by warming, rising sea levels, weather-related events, declining agricultural production, and loss of biodiversity, among others. Carbon markets or taxes only reflect the cost that government policies have imposed on emitters, and this cost likely represents only a fraction of the true value of the damage. Because warming is directly related to the concentrations of GHGs in the atmosphere, and because these gases are long-lived, the SCC is directly related to the total amount of GHG in the atmosphere – so the longer it takes to stabilize concentrations of GHG, the higher the SCC will rise.

Stern (2006) examines the economic implications for society of the predicted effects of climate change. On a macro-economic level, Stern estimates that the cost of taking action to stabilise GHG levels at below 550 ppm CO_2e, which gives us an even chance of avoiding warming greater than about 2°C on average, will cost about 1 per cent of global GDP each year. However, the cost of not acting to control emissions, and continuing on a business-as-usual emissions trajectory, will cost the global economy between 5 and 20 per cent of global product now and forever. Stern concluded that combating climate change is the pro-growth strategy.

However, Stern does not address specifically how these far-reaching findings affect businesses, investment decisions and business planning. Climate change poses risks, uncertainties and opportunities for business, as society increasingly demands action to regulate and reduce greenhouse gas emissions. Whether this takes the form of mandated carbon reduction targets and associated market structures, or some form of explicit carbon tax, the economic costs and benefits of actions taken by businesses to reduce emissions need to carefully considered, as the market cost of carbon (now in the order of US$ 5-25/tCO_2e) climbs towards the social cost, which Stern estimates at US$ 85/tCO_2e, for a business-as-usual emissions trajectory. It is worth noting, in addition, that since the Stern report was issued, world GHG emissions have accelerated markedly (IEA, 2007), suggesting that a similar analysis of SCC conducted today would yield an even higher SCC.

Recently, the UK government has identified a shadow price for carbon (SPC), which can be used on the margin to assess individual project decisions within the UK (DEFRA, 2008). The SPC is based on the realisation that a single nation cannot in isolation determine the trajectory of global emissions and thus the SCC. A more immediate value for carbon is required which reflects the UK government's current climate change goals and commitments. The SPC serves this purpose. Based on a global stabilisation of atmospheric CO_2 concentrations at 550 ppm, Stern (2006) calculated an implied SCC of US$ 30/tCO_2e. DEFRA (2003) have set the UK 550 ppm stabilisation shadow price for carbon at about US$ 50/tCO_2e, increasing at 2 per cent per annum from 2007, and recommend that for project decisions, the HM Treasury Green Book standard social discount rate of 3.5 per cent be applied.

The marginal abatement cost of carbon

Another way to express the cost of carbon is the marginal abatement cost of carbon (MAC), which is the cost of reducing emissions, rather than the value of the damage caused by the emissions. MAC also differs from the market price of carbon, which is determined directly or indirectly by policy objectives. MAC is based on the cost of technological and process measures to eliminate or reduce emissions. Recent studies by McKinsey (2007a) have developed MAC curves for the global economy, and for various countries including Australia, the USA, UK and Germany. National MAC curves of this type are necessarily high-level, and look at all sectors of the economy, from residential energy savings to commercial buildings upgrades, to power generation alternatives. In each case, these curves reveal a common pattern of significant available negative cost abatement opportunities, primarily from energy conservation and efficiency measures. While these overall trends are generally instructive, national MAC curves are not particularly useful for decision making within particular industries, or for particular projects or investment decisions. Here, industry must begin developing its own specific MAC curves, to better understand the scale of the abatement opportunities which exist.

Implications for decision making in industry

Business decision making can be profoundly affected by a comprehensive understanding of the implications of the convergence over time between the marginal and social costs of carbon (Hardisty, 2007). Examples from the petroleum industry and the mining sector illustrate how businesses can improve profitability by finding cost-negative carbon reduction opportunities, examining the effect of the social cost of carbon on energy efficiency opportunities, considering long-term investments in carbon abatement from a whole project life-cycle perspective, and adapting project design to manage climate change risks. In each case, a rational economic examination of the implications of operating in the climate change era reveal risks and opportunities for industry.

Understanding the social costs and benefits of GHG reduction

In many parts of the world, natural gas contains a substantial amount of CO_2, which has to be removed before the gas can be sent to market. Australia, Canada and Algeria, for instance, have high CO_2 content natural gas in some areas. Under current standard industry practice, removed CO_2 is vented to atmosphere after separation. A gas development exploiting reserves containing approximately 10 per cent CO_2, using a conventional design, at full operational capacity and venting CO_2 to atmosphere, produces approximately 7 million tonnes of CO_2 each year. In social economic terms, using Stern's US$ 85/t CO_2e, this would reduce the overall social value of the project by US$ 0.6 bn each year over an expected 30 year project life. Put another way, over 30 years, using a 3.5 per cent social discount rate, society is $ 11 bn worse off because of the CO_2 venting. Using the benchmark Alberta Government carbon tax of about

US$ 10/t CO_2e, the impact is still significant at US$ 0.1 bn/yr, or US$ 1.3 bn over 30 years. Anticipating that the external damages caused by GHG production will gradually come to be recognized and valued at some point during the life of the project, alternatives for reducing GHG emissions should be considered. Removing CO_2 from the gas stream and re-injecting it into the producing formation could be used to reduce the overall GHG impact. Through application of CCS (carbon capture and sequestration), GHG emissions can be virtually eliminated, at an estimated capital cost to the project of US$ 0.5 bn, a unit cost of about US$ 15/t CO_2e over the anticipated life of the project. This cost is low compared to other estimates for CCS (IPCC, 2005), largely because in this application, the cost of removing CO_2 from the gas stream must occur as part of the business-as-usual approach anyway, and so is not included in the CCS cost. Estimates of the cost of CCS involving pre- or post-combustion capture for power-plants, for instance, range from US$ 40-100/tCO2e (IPCC, 2005), with as much as 80 per cent of that cost attributed to separation and capture. Any discussion of the costs of CCS, however, should consider the paucity of commercial-scale experience with the technique, and the critical lack of published cost data.

Nevertheless, with conventional financial analysis, expenditure on geo-sequestration would be difficult to justify. However, the benefit of these measures to the rest of society are clearly considerable. Using the US$ 85/t CO_2e value in this example, society as a whole is more than $18 better off (in terms of damage avoided) for every dollar invested in the carbon sequestration project. Even at US$ 10/t CO_2e, the proposition is economic.

Industry-specific MAC curves and the NPV-IRR trap

One area where many industries can achieve significant revenue-positive reductions in GHG emissions, and thus future internalized carbon costs, is in energy and heat efficiency. Many energy and heat efficiency opportunities available right now are cost negative (McKinsey, 2007b). In a recent study of a mine expansion in Australia, a project-specific MAC curve was developed. A range of engineering design, equipment selection, transport and operational alternatives were examined for their potential to reduce GHG emissions at each stage in the project life-cycle. Compared to business-as-usual (how the mine would have been designed and operated if recent standard practices were employed), total GHG emissions can be reduced by over 2.5 $MtCO_2$e/yr, and average product GHG intensity reduced by 35 per cent, by selecting only negative cost measures (Figure 1). But this type of carbon abatement cost study, similar in nature to the national carbon abatement cost curves generated by McKinsey (2007a), paints only a partial picture. While these measures produce net cost-savings over the longer term, they all require some level of capital investment to be realised. Industry and business will therefore assess the payback of these investments, much as they would any other capital investment, before deciding on implementation.

Many firms require that process and equipment modification to achieve reductions in energy consumption or re-use waste heat meet financial hurdle rates which match, or in some cases actually exceed, those for new capital projects. In many instances, energy efficiency projects examined without carbon costs cannot provide internal rates of return which meet these hurdle rates, and are therefore rejected. The result is that many environmentally worthwhile projects are rejected by industry because they are NPV (net present value) negative – they are profitable (or cost-negative, as discussed

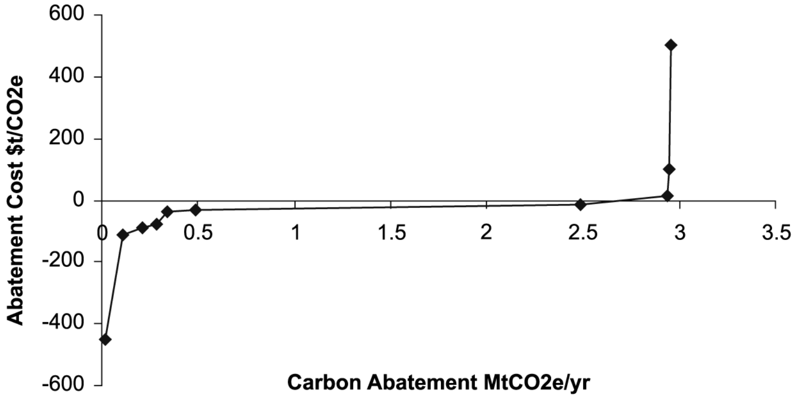

Figure 1.
GHG marginal abatement cost (MAC) curve

above), but not profitable enough to meet internal rate of return (IRR) targets. These calculations almost always exclude any accounting for environmental or social externalities, which might make the overall economics look starkly different (Hardisty and Ozdemiroglu, 2005; Pearce and Warford, 2001). This "NPV-IRR trap" is one of the biggest barriers to improving sustainability in industry.

An example from the petroleum industry in Canada, involving the recovery of waste heat from steam assisted gravity drainage (SAGD) oil sands mining operations, illustrates the NPV-IRR trap dilemma. In one such operation, steam is generated using power from the coal-fired electrical grid, and pumped into the reservoir to enable oil recovery. The oil and the condensed steam from the reservoir are produced to the processing plant at 150-180°C. This liquid is then cooled and the recovered heat is used to preheat the boiler feed water that is used to make the steam for injection. Approximately one-quarter of the energy produced in the steam generator is recovered within the plant's closed loop cooling system as low-grade heat at approximately 100-120°C. Because the water must be discharged to a nearby river after treatment, it must be cooled. This is accomplished with electrical grid-powered air coolers which send the heat to atmosphere. Without consideration of the costs of carbon associated with the energy required for cooling (and heating), business as usual provides the highest financial returns.

However, a brief examination of options for this operation reveals that this low level waste heat could be used to produce power utilizing an Organic Rankin Cycle (ORC) power generation system. For a capital investment of around US$ 9 m, using this readily-available technology, the 10 MW of waste heat can be used to generate up to 1 MW of electricity. The power can be fed back into the project, reducing power consumption from the grid. The IRR for this heat recovery project was estimated at about 8 per cent, using conventional financial analysis, based on the current $80/MWhr cost of power. The proposal was not implemented, however, because the company's own rate of return hurdle rate for assessing all projects was 11 per cent. The project fell into the NPV-IRR trap – it was profitable, but not profitable enough to appear as NPV positive within the company's project decision making paradigm.

Examination of this same proposition in the context of a carbon-constrained future, boosts the IRR considerably. Imputing a marginal cost of carbon, and considering even a modest trajectory of the MAC towards the SCC over the anticipated 30 year life of the project has a profound impact on project IRR. The energy savings predicted from implementation of waste heat recovery would result in a reduction of approximately 8,000 tCO_2e/yr in emissions from the coal-fired grid (Department of Climate Change, Australia, 2008). Using the current Alberta carbon tax level of US$ 10/tCO2e (which currently only applies to emissions over a set maximum annual amount, and so would not be incurred on this project as a direct financial cost), over the 20 year life of the project, the NPV of the project rises to 9.5 per cent. At the SCC value of US$ 85/tCO2e, the IRR of the heat recovery project is almost 15 per cent. Explicit consideration of the carbon externality, and its prospect of gradual internalisation, can lift the project out of the NPV-IRR trap, and into NPV-positive territory.

The marginal abatement cost of carbon (MAC) has been much discussed in recent literature (McKinsey 2007a,b). However, as discussed above, it paints only half of the story. The cost of any decision must be rationally compared to the benefits that are produced from that expenditure. Many of the benefits of carbon reduction, although certainly not all, are tied to society's need to reduce and stabilise overall GHG emissions. From this point of view, revenue positive sustainability can and should be considered in the light of the predicted progressive internalization of the marginal cost of carbon, and its trajectory towards the SCC, along with real rises in the costs of energy and water. These considerations alone could significantly alter the perceived economics of many worthwhile environmental improvement projects. In this way, profits from efficiency and energy savings in the near term can help to defray the costs of further, more difficult emissions reductions in the medium term. Decisions made today will have profound effects on a firm's ability to manage its carbon abatement over the next few decades, especially for projects with longer life-cycles and capital investment, where technology choices and engineering concepts are locked-in early. Here the SCC is a useful benchmark, indicating the potential for the internalised cost of carbon to rise in the future. Failure to take the rising cost of carbon into account is in itself a key business risk for industry, and in particular for the large resource-based industries.

Combining efficiency and carbon markets to improve financial performance

Even in developing countries of the Middle East and Africa, where there are no immediate plans to limit GHG emissions, industry will face increasing pressure to reduce clearly damaging practices such as flaring and venting of natural gas. In 2007, it is estimated that over 170 bn m^3 of natural gas, worth over US$ 30 bn, was flared or vented worldwide, creating over 400 mt CO_2e of greenhouse gases (World Bank, 2008). The Middle East region alone was responsible for over 50 bn m^3 of the total. This illustrates the huge opportunities available to industry. Efforts to reduce gas-related emissions can be profitable because recovered gas is a valuable commodity, and because access to the world's carbon markets may bring in additional revenue to fund emissions reductions measures. The Clean Development Mechanism (CDM), established under the UN Kyoto Accord, allows companies operating in developed nations to reduce their emissions by accessing equivalent emission reductions from projects in developing countries. This is done through a system of tradable permits. In 2006, over 500 million tonnes of CO_2 equivalent, worth over US$ 15 bn, were traded through the CDM (World Bank, 2007).

A recent example from Qatar illustrates the opportunities available to industry. The Al-Shaheen oil field in Qatar produces about 200,000 barrels of oil per day and about 180 million standard cubic feet per day (MMscfpd) of associated gas (CDM Executive Board, 2006). Previously, all but 5 MMscfpd of the gas was flared. This facility accounted for about one fifth of Qatar's flared gas. A gas recovery project was designed to divert hitherto flared natural gas to a nearby LNG facility, and dramatically increase on-site use for power generation. For a capital cost of about US$ 280 m, the project would reduce flaring to less than 40 MMscfpd, lowering the facility's GHG emissions by about 2.5 mtCO2e/yr. Without access to the carbon markets, however, the IRR of the project was only 9.7 per cent, below the 10 per cent maximum allowed under CDM. By accessing the CDM through approved methodology AM0009, the project's IRR was raised to 15.9 per cent, and became financially viable for the company (CDM Executive Board, 2006). Since the application was made in 2006, natural gas prices have risen considerably, which will have made the project even more financially attractive.

CDM requires that emission reductions meet the "additionality" test – in other words they must represent reductions which would not otherwise have occurred under business-as-usual in that country. As local regulations become more stringent, projects which are eligible for CDM credits today may become ineligible with time. This illustrates the procrastination penalty for industry. At present, significant opportunities to improve profitability and significantly reduce GHG emissions exist. To date, these opportunities have been widely ignored by industry because of the NPV-IRR trap, lack of regulation and enforcement in some countries, and a lack of understanding of the future of carbon costs and trading opportunities.

Considering likely future trajectories of the costs of energy, carbon, water and other key commodities, all of which are likely to continue to rise in the climate change era, can have a significant effect on decision making, and may reveal potentially useful strategic options for business.

Adaptation risks and costs

Industry also needs to consider the likely effects of a changing global climate on their existing and future operations. Investment decisions for long term projects with expected life-cycles of 20 years or more should consider how predicted changes in weather patterns, rainfall, wind and storm intensity, rising sea levels, and warming air and sea temperatures might affect their designs and planning. Table II summarises some of the climate change adaptation risks that industry and business should consider and manage.

For example, a new petrochemical plant with a design life of 50 years is planned to be built on a coastal plain with an average elevation of 0.4 m above sea level. Currently there are no plans to consider climate change effects in the design of the facility. However, best available science summarised by IPCC now indicates that average sea level rise of up to 1 metre is likely before the end of this century. More recent studies are suggesting higher probabilities of even larger rises. On that basis, the risks to the planned $5 bn development are significant. As sea levels rise (currently at 3 mm/yr and accelerating (IPCC, 2007a)), the likelihood of storm surges inundating the site increases considerably. The consequences of business and safety risks from flooding, and the possible disruptions to production, are significant, and could be catastrophic. The

Table II. Climate change adaptation risks for industry

Risk	Likelihood	Consequence	Mitigation measures
Rising sea levels and increased storm surges	High over next ten to 20 years Sea level already rising 3 mm/yr	Increased risk of inundation of low lying sites and structures, infrastructure damage, loss of production or capital	*Protect or relocate existing facilities select higher –elevation sites for new facilities* Examine vulnerability of transport corridors Strengthen existing infrastructure for increased storm loads Adjust health and safety practices in coastal and offshore operations
Declining water security	High over ten to 20 years Already a concern in many locations	Reduced availability and security of water Limitation on production and on expansion of existing facilities, limitations on new facilities, reduced growth, higher costs	*Develop a long-term water management strategy* Retrofit existing facilities to improve water efficiency Design and build new facilities for water efficiency Secure access to water supplies less vulnerable to the effects of climate change Move production to areas where water supplies are more plentiful Examine potential for competition and conflict with other water users at key facilities
Declining raw materials and process input security	High and rising over next few years	Greater difficulty in securing raw materials required for production	*Develop strategic plan to reduce dependence on raw materials sources that are vulnerable to climate change (e.g. forest and agricultural products)* Secure access to supplies less affected by climate change
Rising global average temperatures	High over next ten to 20 years	Declining efficiency of process cooling systems, higher costs	*Take rising atmospheric and ocean temperatures into account in all process engineering designs* Examine cooling measures which will not depend on increased fossil fuel energy consumption
More frequent and severe storms and weather anomalies	Moderate to high over next ten to 20 years	Increased insurance costs, higher flood risks, disruption of operations, higher costs	*Adapt design and operational practice to account for higher frequency of weather events* Strengthen and upgrade infrastructure and flood defences for key facilities Adapt heath and safety practices

likelihood of such events occurring, according to the IPCC (2007b), is high. Risk analysis would suggest that mitigation is required. One option is to raise the site elevation by 0.5 m by importing fill material, at a cost of over US$ 100 m. Other options include designing for future installation of raised protective sea wall and dewatering systems, or choosing another location altogther. Note that this additional project expense, which exists because of global GHG emissions, is not directly related to this facility's emissions, but is rather a direct expression of the social cost of carbon. This simple example illustrates how climate change adaptation for industry is a key financial and economic concern which should be included in project decision making now. Planning and designing for adaptation now will reduce the risks of future impacts, reduce project life-cycle costs, and enhance business competitiveness.

Conclusion

Managing GHG emissions and understanding the economics of achieving sustainability objectives will become increasingly important for business. Many companies are already establishing their own internal emissions reduction targets, and planning for a carbon-constrained and carbon-impacted future. Significant emissions reductions can be achieved at negative or low cost, in many cases actually reducing overall costs to operators, and improving profitability. How industry responds to these challenges will be an important factor in their future success. In both mitigation and adaptation, there is evidence that risks of inaction far outweigh the costs of well-considered, economically viable action using all of the tools, expertise and market mechanisms currently available to industry. Companies that wait to take action run increasing risks of higher costs, disrupted operations, and stakeholder scrutiny. Climate change carries with it a clear procrastination penalty for industry and the planet.

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