# THE COST IMPLICATIONS OF ENERGY EFFICIENCY MEASURES IN THE REDUCTION OF CARBON DIOXIDE EMISSIONS FROM EUROPEAN BUILDING STOCK

**prepared by**

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**for**

## EuroACE

## THE EUROPEAN ALLIANCE OF COMPANIES FOR ENERGY EFFICIENCY IN BUILDINGS

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# 1. FOREWORD

In May 1998, Caleb Management Services produced a report[1] for EuroACE which made an assessment of the potential for carbon dioxide reductions arising from energy savings within European building stock. The report assessed current energy usage across the various sectors of building application – namely domestic, commercial, public and industrial. From this assessment, the study was able to derive the potential savings that could be realised from technically feasible energy efficiency options. The total realisable savings amounted to 430 – 450 Mtons of $CO_2$, which equated to over 13% of the total European $CO_2$ emissions based on 1990 figures.

This observation served to focus attention on the importance of the building sector in any strategy to reduce emissions. However, at the same time, it highlighted the fact to DG Energy and others that the strategic significance of energy efficiency options could only be fully validated if an assessment of the cost effectiveness of these measures could be included. This, therefore, became the subject of a second study, the results of which are covered in this report.

As previously, the study has covered energy efficiency initiatives in all four sectors supplied by the building industry and has sought to identify any fundamental differences in the way in which costs are incurred within each sector. In doing so, it has been recognised that every situation is unique and that no ‘rule’ can be formulated for the prioritisation of buildings to be targeted.

The report tries particularly to put the role of energy efficiency measures in buildings in the context of other options to save CO2. It is noted that, to a large extent, all measures are complimentary as they contribute towards the common goal of reducing $CO_2$ emissions in line with Kyoto requirements and beyond.

It is hoped that the study will contribute to the wider discussion on climate change mitigation and serve to ensure that the excellent opportunities afforded by simple energy efficiency measures in builidings are not lost.

P. Ashford – Caleb Management Services December 1999

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[1] ‘Assessment of Potential for the Saving of Carbon Dioxide Emissions in European Building Stock’, Caleb (1998)

# 2. EXECUTIVE SUMMARY

The evaluation of the cost-effectiveness of the various measures for mitigating $CO_2$ emissions has proved difficult for many closely involved with the subject. In the first instance, the definition of cost can vary depending from which perspective the issue is viewed. Legitimate options include:

- Regulatory and Governmental costs (e.g. promotion etc.)
- Investment costs only
- Full life-time costing

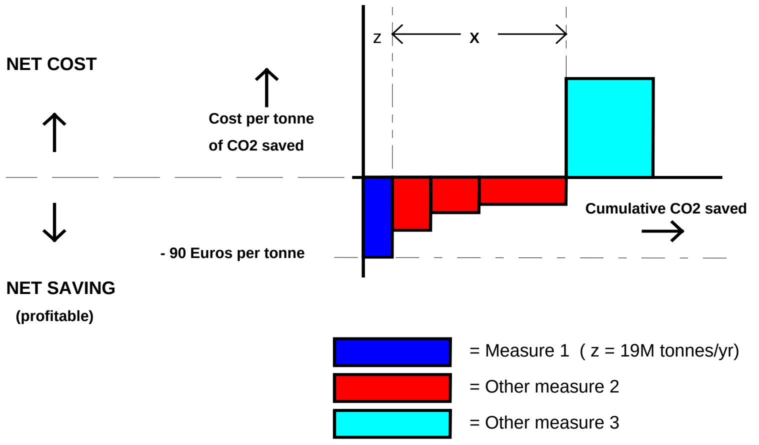
This report reviews the way in which the choice of measure affects the selection of cost-effective options and argues that it is important to look at the full life-time costing of a measure to identify its full benefit in reducing the burden of $CO_2$ emissions within the EU. The approach taken is to develop a net cost per tonne of $CO_2$ saved annually during the commitment period (2008-2012) using the following formula:

**Life-time cost = Initial investment cost - Σ [ Net Present Value of energy saving per year]**

The value of the savings is discounted using normal discounted cash-flow methodology to provide an appropriate comparative view. The discount chosen for the work was 8%, although this can be varied.

From the individual life-time costings so calculated, it is possible to put together a graph illustrating the potentials of various measures as shown in Figure ES-1 below:

**FIG. ES-1 : CARBON DIOXIDE SAVING STRATEGY DEVELOPMENT**



Such a model can then be used to identify the most cost-effective methods of reaching national targets. Measures involving energy saving such as CHP, some industrial initiatives and energy efficiency in buildings provide a particularly cost-effective route to reaching such targets since the value of the energy saved over the lifetime of the measure can be taken into full account. A review of all of the primary options available within the EU has allowed the development of Table ES-1 (overleaf) which assesses investment and lifetime costings:

| Option | Investment Cost per tonne of $CO_2$ saved annually (Euros/tonne) | Lifetime Cost/(Saving) per tonne of $CO_2$ saved annually (Euros/tonne) |
|---|---|---|
| | | |
| Wind Power | 350-450 | 200-300 |
| Hydro | 250-350 | 100-200 |
| Photovoltaic | 2000-3000 | 2000-3000 |
| Biomass | 300-350 | 300-350 |
| Geothermal | 900-1100 | 900-1100 |
| Solar (Thermal) | 1200-1400 | 1000-1200 |
| Vehicle Efficiencies | 60-300 | Dependent on Fuel Efficiency |
| Intermodal switching | Unquantified | Unquantified |
| Industrial CHP | 305-310 | 155-160 |
| Other Industrial Efficiencies | Unquantified | 5-45 |
| Commercial CHP | 250-275 | 10-20 |
| Small-scale CHP | 350-375 | 120-130 |
| Fuel Switching (Investment case) | 12-14 | 65-70 |
| Building Energy Efficiency (Retrofit) | 944 – 3002 | 206 – 1030[*] |
| Building Energy Efficiency (Refurb/New) | 282 – 884 | (247) – (869) |

***Table ES-1: Summary of Investment and Lifetime Costings for the Primary EU Options***

The prime conclusions from the study and report are therefore as follows:

- Energy efficiency initiatives in the building sector are amongst the most cost-effective measures available to policy-makers seeking to reduce carbon dioxide emissions
- Typical measures can create *FINANCIAL SAVINGS* per tonne of $CO_2$ saved when lifetime costed
- The initiatives which could stimulate such savings are based on existing and proven technology
- The method of implementing such initiatives is an important factor in the assessment of the cost-effectiveness of the measures. Major refurbishment initiatives are generally far more cost effective than piece-meal retrofitting
- Initiatives in the domestic sector are also highly dependent on investment costs and energy price with internal rates of return (IRRs) in excess of 20% possible.
- Cost-effectiveness in the commercial, public and industrial sectors are typically more attractive than the domestic sector
- If lifetime costing methodology is to be adopted on a widespread basis, an EU-wide standard method of calculation is required.
- This could be made equally applicable to other sectors outside of the building field (e.g. automotive and, if necessary, renewables)
- Considerable education will be necessary in the traditional ‘energy efficiency’ sector to move thinking from existing payback methodologies to lifetime costing.

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[*] Although the average lifetime cost is positive, several individual measures may generate savings (see table 4.4)

# 3. MEETING EUROPEAN $CO_2$ TARGETS AND CHALLENGES

The development of EU policy to respond to the threat of climate change has been a challenge which has engaged more than 50% of the departments within the European Commission. Although the inter-relationship between the various regulatory perspectives has been complex, two factors have emerged as critical in the development of appropriate policy:

(1) The speed at which any policy is required to have an effect
and
(2) The cost of the action necessary to implement the policy

As is so often the case in such circumstances, there is an inter-relationship between the cost of an action and its speed of implementation. Accordingly, if cost is to be minimised, policy options need to be prioritised with particular emphasis being placed on those options which are:

- Already available and proven
- Relatively low in investment cost
- Provide good cost effectiveness over their lifetime
- Can be applied sufficiently widely to have an overall impact at EU level in the necessary time-frame

In this report, these criteria are reviewed for energy efficiency measures in buildings, since such measures are perceived to provide some of the most attractive options available to policy-makers at this juncture.

## 3.1 Initial assessment of options

One of the key aspects of the Kyoto Protocol is that initial targets have been set over a relatively short time-frame (2008-2012). It is recognised by most regulators that this will be the first of several incremental targets and many view that a target of at least 50% emission reduction by 2050 will be required. Bearing in mind the growth in the world economy that is likely in the next 50 years, it is clear that fuel sources will need to change substantially from the traditional carbon-based options in this timeframe. Accordingly, renewable energy sources (hereafter referred to as 'renewables') rightly feature highly on most regulatory agendas. However, in the short-term, they are unlikely to provide a full answer because of the level of investment required (see 4.2). Accordingly, focus has rightly been addressed on other potential options[2] such as:

- Transport
- Combined Heat and Power
- Fuel switching and energy efficiency in power generation
- Industrial energy efficiency
- Energy efficiency in buildings (industrial, commercial, public sector & domestic)

Together with renewables, these five options can be assessed against each of the criteria set out above in order to provide an overview of the relative positioning of each alternative available to policy makers. This overview is depicted in Table 3.1. Although the table is qualitative, differences have been highlighted where appropriate. For example, domestic energy efficiency measures tend to be less cost-effective than commercial and industrial options because of the lower overall energy consumption involved.

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[2] 'Preparing for Implementation of the Kyoto Protocol' Commission communication to the Council and the Parliament (COM/99/23CEN) (1999)

| **Category** | **Sub-Category** | **Available /Proven** | **Low Investment** | **Good Cost – Effectiveness** | **Potential Impact** | |
|---|---|---|---|---|---|---|
| | | | | | **Short** | **Long** |
| **Renewables** | Wind | ✓ ✓ | ✓ ✓ | ✓ ✓ | ✓ | ✓ ✓ ✓ |
| | Hydro | ✓ ✓ ✓ | ✓ | ✓ ✓ * | ✓ | ✓ ✓ |
| | Solar | ✓ | ✓ ✓ | ✓ | ✓ | ✓ |
| | Nuclear | ✓ ✓ | ✓ | ✓ ✓ * | ✓ ✓ | ✓ |
| | Biomass | ✓ | ✓ ✓ | ✓ ✓ | ✓ | ✓ ✓ ✓ |
| **Transport** | Fuel Efficiency | ✓ ✓ | ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ | ✓ ✓ |
| | Less Usage | ✓ | ✓ ✓ ✓ | ✓ ✓ ✓ | ✓ | ✓ ✓ |
| | Alt. Fuels | ✓ | ✓ ✓ ✓ | ✓ ✓ | ✓ | ✓ ✓ |
| | Intermodal | ✓ | ✓ | ✓ ✓ * | ✓ | ✓ ✓ |
| **Fuel Switching & Generating Efficiency** | Gas | ✓ ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ | ✓ |
| | Other | ✓ ✓ | ✓ ✓ | ✓ ✓ | ✓ ✓ | ✓ ✓ |
| **CHP** | Industrial | ✓ ✓ | ✓ ✓ | ✓ ✓ * | ✓ ✓ | ✓ ✓ |
| | Commercial | ✓ ✓ | ✓ ✓ | ✓ ✓ * | ✓ ✓ | ✓ ✓ |
| | District Heat | ✓ ✓ | ✓ ✓ | ✓ ✓ * | ✓ ✓ | ✓ ✓ |
| **Industrial Efficiency** | Process | ✓ ✓ | ✓ ✓ | ✓ ✓ * | ✓ ✓ | ✓ ✓ ✓ |
| | Ancillary | ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ | ✓ |
| **Building Efficiency** | Industrial | ✓ ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ |
| | Commercial | ✓ ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ |
| | Public Sector | ✓ ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ |
| | Domestic | ✓ ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ |

* Cost-effectiveness depends on treatment of depreciation. Source: Caleb

✓ ✓ ✓ = Strong ✓ ✓ = Moderate ✓ = Weak

***Table 3.1: Qualitative Assessment of the $CO_2$ Saving Options within the EU***

## 3.2 Renewables

The renewable energy portfolio offers substantial long term opportunities for reducing the carbon intensity of power generation. However, the main drawback is that the speed at which these can be introduced will be insufficient in isolation to meet the reduction targets required by 2010. In simple terms, an 8% reduction in emissions by 2010 requires a ‘per capita’ reduction of around 35% (often called energy intensity) because of underlying GDP growth over the period. Even the most adventurous of investment programmes suggest that only around 12% of EU energy will be from renewable sources by 2010[3]. The potential annual $CO_2$ saving estimated through such a programme will be in the order of 402 Mtons by then. However, the estimated cost of such a programme is approximately ∈165 billion which represents an investment cost per tonne of $CO_2$ saved in 2010 of approximately ∈410. When corrected for avoided fuel costs this reduces to approximately ∈358 per tonne, although it is not clear whether this correction includes an adjustment for discounted cashflow. It should be noted that these figures already take into account an adjustment for the reducing investment cost of renewables as technologies mature between 1997 and 2010. The following table summarises the current EU assessment as set out in the Commission’s White Paper.

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[3] ‘White Paper for a Community Strategy and Action Plan, Energy for the Future : Renewable Sources of Energy’, COM(97)599 (1997)

### *Table 3.2 : Estimated Investment Costs/Benefits by Sector*

| *Type of Energy* | *Additional Capacity 1997-2010* | *Unit Cost 1997 (Euros)* | *Unit Cost 2010 (Euros)* | *Average Unit Cost (Euros)* | *Total Investment 1997-2010 (billion Euros)* | *Additional Annual Business 2010 (billion Euros)* | *Benefits of Annual Avoided Fuel Costs 2010 (billion Euros)* | *Total Benefit of Avoided Fuel Costs 1997-2010 (billion Euros)* | *$CO_2$ Reduction Mton/year In 2010* |
|---|---|---|---|---|---|---|---|---|---|
| 1. Wind | 36 GW | 1,000/kW | 700/kW | 800/kW | 28.8 | 4 | 1.43 | 10 | 72 |
| 2. Hydro | 13 GW | 1,200/kW | 1,000/kW | 1,100/kW | 14.3 | 2 | 0.91 | 6.4 | 48 |
| 3. Photovoltaics | 3 GWp | 5,000/kWp | 2,500/kWp | 3,000/kWp | 9 | 1.5 | 0.06 | 0.4 | 3 |
| 4. Biomass | 90 Mtoe | | | | 84 | 24.1 | - | - | 255 |
| 5. Geothermal (+ heat pumps) | 2.5 GW | 2,500/kW | 1,500/kW | 2,000/kW | 5 | 0.5 | - | - | 5 |
| 6. Solar Collectors | 94 Mio m$^2$ | 400/m$^2$ | 200/m$^2$ | 250/m$^2$ | 24 | 4.5 | 0.6 | 4.2 | 19 |
| **Total for EU market** | | | | | **165.1** | **36.6** | **3** | **21** | **402** |

Source: Energy for the Future : Renewable Sources of Energy (COM(97)599 final)

It can be seen from the comparative data shown in the table, that biomass represents a particularly large proportion of the potential $CO_2$ savings from renewables. Of course, the technology does not eliminate the emission of $CO_2$ in itself but any emissions are offset in full by an increased sink for $CO_2$ during the growth phase of ‘energy crops’. The most typical use of biomass incinerators will be as energy sources for combined heat and power plants. However, the cost-effectiveness of such options will be dependent on the local availability of fuel sources. At present, the growth of energy crops is not promoted across the EU in the same way as the growth of food crops. This has created a tension between farmers and the power generators which will require government intervention to alleviate.

Other options such as wind power also have genuine potential, although non-financial considerations such as the environmental impact of major wind farms sited in exposed locations have caused concern. Such concerns can be dealt with by placing wind farms off-shore. However, doing this adds additional cost burden to such projects and also impacts the efficiency of each wind turbine. At best, a wind turbine will only be able to operate at about 43% of its nominal capacity because of the variability of the wind[4]. This declared net capacity (DNC) may reduce further if the siting of the facility is not optimised.

## 3.3 Transport

One of the other major factors influencing the effectiveness of measures is the speed of turnover of stock. In the automotive sector, for example, it is expected that the bulk of vehicles would be turned over within a 15 year timeframe. This would allow any measures for reducing the unit emissions of vehicles to become totally effective within this period. A recent Voluntary Agreement[5] signed between the European Commission and the car manufacturers is aimed to reduce the average carbon dioxide emissions of passenger cars to 140 grams of $CO_2$ per km by 2008. This represents a 25% cut on current averages. Member State Environment Ministers are pushing for even stricter targets of 120 grams per km (30-40% improvement) by 2005 or 2010 recognising the importance of this option in the short-term[6]. However, the growth of vehicle ownership and use is expected to substantially offset any unit savings. As an example, motor traffic in the UK had grown by 8% in the five year period since 1990 when measured in vehicle kilometres[7]. The average size of engine is also increasing as people move to larger cars and off-road vehicles. The net effect is that $CO_2$ emissions from road transport in the EU have grown by nearly 36% in the ten year period 1985-1995[8]. Measures such as additional fuel taxation seem unlikely to limit usage unless truly viable alternative public transport is available and this re-introduces the issue of significant infra-structure investment. In any event, most commentators predict that grid-lock will be the most significant factor in switching society to the wider use of public transport. In this case, the cost in $CO_2$ emissions could be even heavier in the short-term as engines idle unavoidably.

Cost assessments in this sector are notoriously difficult. The cost of inter-modal switching not only depends on the capital cost of public transport infra-structure but also on the likely uptake of the new provisions by the public. In addition, there may be gains in travel time which could be costed. Even within the passenger car sector itself, there are a variety of issues to be considered. Reduced emissions from cars can arise from either better abatement technology or better fuel consumption. Where improvements in fuel consumption are involved, the resulting cost savings need also to be included in any assessment. As an indicator based on investment only (i.e. assuming abatement rather than greater fuel efficiency), the current average emissions per 1,000 km driven is approximately 0.18-0.25 tonnes. The new targets of 0.12 tonnes per 1000km would deliver savings of around 24 tonnes per vehicle during its lifetime (250,000 km) or, more relevantly, 1.6

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[4] ‘Planning for Wind Power’ by Nick Eyre and David Toke (SERA, 1998)

[5] Agreement signed with ACEA – the organisation representing the European car industry

[6] UK Climate Change Programme – Consultation Paper (1998)

[7] UK Department of Transport Statistics (1997)

[8] DGXI Press Release ‘Commission outlines measures to reduce carbon dioxide emissions from transport’ (Mar. 1998)

tonnes per annum. A variety of incremental costs can be assumed for a new vehicle and the table below illustrates the sensitivity:

| ***Incremental Cost (New Car)*** | ***Cost per tonne of $CO_2$ saved*** |
|---|---|
| (∈) | (∈/tonne) |
| 100 | 62.5 |
| 200 | 125.0 |
| 300 | 187.5 |
| 400 | 250.0 |
| 500 | 312.5 |

***Table 3.3 : Relationship between Investment Cost and Cost Effectiveness for Cars***

Fuel savings could provide substantial further cost benefits, although it should be noted that, in practice, the increase in average car engine size between 1986 and 1996 has broadly offset these gains in fuel effficiency.

## 3.4 Fuel Switching and Generation Efficiencies

At one level, fuel switching represents the fastest option for reduction in $CO_2$ emissions since, in principle, the reduction only relies on a change in buying decision. However, this absolute versatility can only be maintained until the installed capacity of a particular fuel source is reached. At this juncture, reinvestment is called for. Bearing in mind, however, that energy generation is a high investment area with relatively rapid changes in technology, significant shifts in overall fuel source reliance can be achieved in a 10-15 year period. The UK in particular has benefited from a dramatic switch from coal based energy to gas-based energy. The so-called ‘dash to gas’ has delivered substantial savings, allowing the UK to meet its year 2000 obligations with some ease. However, the adoption of such policies does have some limits if the economic landscape is not to be transformed unnecessarily quickly. The decimation of the UK coal industry has only been avoided by some latter softening of energy policy and it is now clear that the accelerated forcing of fuel switching could have some uncomfortable and possibly unacceptable social consequences.

With respect to efficiencies in power generation, these are often linked to original design criteria and cannot therefore be improved substantially until major reinvestment programmes are undertaken. It is generally believed that the electricity supply industry has optimised the efficiencies of its current installations.

The investment costs for new ‘state-of-the-art’ coal generation plant are in the region of ∈700-1150 per $kW_e$ of installed capacity. Gas powered plants are known to be considerably cheaper (est. ∈500 per $kW_e$ of installed capacity). Assuming a usable life of 20 years continuous operation at 90% capacity and 50% efficiency, each $kW_e$ of installed capacity will account for 15,768 kWh of fuel per year. A switch from coal to gas will therefore save 1.58 tonnes of $CO_2$ per year for each $KW_e$ of capacity. However, the increase in fuel cost will be ∈78.84 per annum assuming that gas is twice as expensive as coal per unit of energy. Thus the overall cost per tonne of $CO_2$ saved annually will equate to around ∈65-70 per tonne of $CO_2$ saved.

The table overleaf shows the split of energy sources by Member State as at 1995. This gives an indication of some of the fuel switching options which may be available to the countries in question.

***Table 3.4 : EU Electricity Production (Percent produced in 1995)***

| Member State | Thermal % | Nuclear % | Renewables % |
|---|---|---|---|
| Austria | 30 | 0 | 70 |
| Belgium | 42 | 57 | 1 |
| Denmark | 97 | 0 | 3 |
| Finland | 52 | 30 | 18 |
| France | 7 | 76 | 17 |
| Germany | 67 | 29 | 4 |
| Greece | 93 | 0 | 7 |
| Ireland | 94 | 0 | 6 |
| Italy | 78 | 0 | 22 |
| Luxembourg | 86 | 0 | 4 |
| Netherlands | 94.5 | 5 | 0.4 |
| Portugal | 65 | 0 | 35 |
| Spain | 48 | 34 | 18 |
| Sweden | 7 | 51 | 42 |
| United Kingdom | 73 | 25 | 2 |

## 3.5 Combined Heat and Power

The position of combined heat and power (CHP) also needs some consideration at this point. Some studies view this as an element of a fuel switching strategy. However, in many cases, the CHP solution is simply offering opportunities to improve the efficiency of energy conversion and, as such, can be considered as an energy efficiency measure. Bearing in mind that the introduction of CHP is often an integral part of an energy efficiency strategy, this report considers this option primarily in this category.

Only 6-7% of the current EU demand for electricity is supplied by CHP. The approach to CHP varies substantially between Member States, but it is estimated that an achievable Europe-wide target for cogeneration schemes would be 30% by 2010. The split between large-scale, industrial and small scale CHP also varies widely across Europe depending on the reliance on district heating.

There are several types of engine which can be used to generate electricity within a CHP unit. These include:

- Gas Turbine
- Combined Cycle
- Fuel Cells
- Steam Turbine
- Reciprocating Engine (diesel)
- Reciprocating Engine (gas)

Two of the more traditional options are the gas turbine and the diesel engine. However, there has been more significant recent growth in the use of the gas engine because of its slightly lower cost and better emissions performance. For the diesel engine and gas turbine options, the respective investment costs are shown in the graph below.

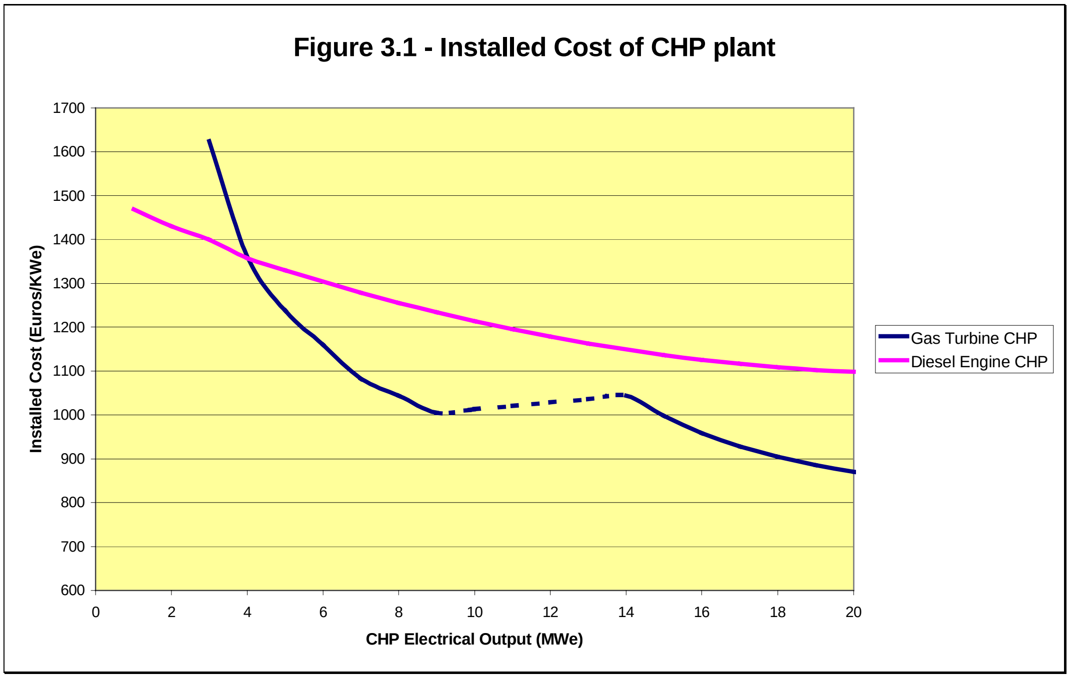

**Figure 3.1 - Installed Cost of CHP plant**

Source: DETR Good Practice Guide 200

It can be seen that the relative costs vary with both the selection of engine type and on the size of installation chosen. For small-scale CHP (i.e. units less than 0.5MWe), the unit costs are high and diesel generation is usually preferred. The Atlas database[9] notes that 'Price of the input fuels and of the electricity produced are both subject to large and unpredictable fluctuations, at international and national levels. This makes it difficult for investors requiring stability to select CHP as an investment scheme.'

It is anticipated that most CHP units will generate electricity with efficiencies of around 30%. Thermal efficiencies are typically around 45%. This compares with average current stand-alone efficiencies for electricity and thermal energy of 38% and 75% respectively. The ratio of electrical to thermal is of the order of 1:1.7. On the worst case assumption that the fuel used is coal, the net $CO_2$ saving equates to 485 kg of $CO_2$ per $MW_e$h of operation (assumes 0.31kg $CO_2$ per kWh for coal). On the further assumption that the utilisation rate is 95%, the saving over a typical 15 year contract period would amount to 30.28 ktons of $CO_2$ for a 0.5$MW_e$ unit – or just over 2,000 tonnes per year. Against an investment cost of ∈737,500, the average investment cost per tonne of $CO_2$ saved annually equates to **∈365/tonne**.

For larger units, the investment cost/benefit is more favourable with an 8$MW_e$ gas turbine system saving around 32.3 ktonnes of $CO_2$ per year at an installed cost of ∈8.32M. This implies an average cost per tonne of $CO_2$ saved annually of **∈258/tonne**.

It is, of course, clear that these investment costs on their own do not encourage selection of CHP. However, fuel savings counter the initial investment cost and offer a potentially cost effective package. The cost-effectiveness, however, depends heavily on the input fuel costs. Assuming a coal cost of ∈0.005/kWh, the annual savings for each option is as follows:

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[9] The Atlas Database is a DGXVII on-line facility which reviews emerging technologies in energy generation and use

| Capacity | Input Energy Saved Annually | Cost of Energy Saved per Annum | Total Saving at 8% Discount Rate | Net Cost per tonne of $CO_2$ saved annually |
|---|---|---|---|---|
| (MWe) | (MWh) | (∈/year) | (∈ '000) | (∈/tonne) |
| 0.5 | 6512 | 32,558 | 488.37 | 123.42 |
| 8 | 104,186 | 520,928 | 7,813.92 | 15.67 |

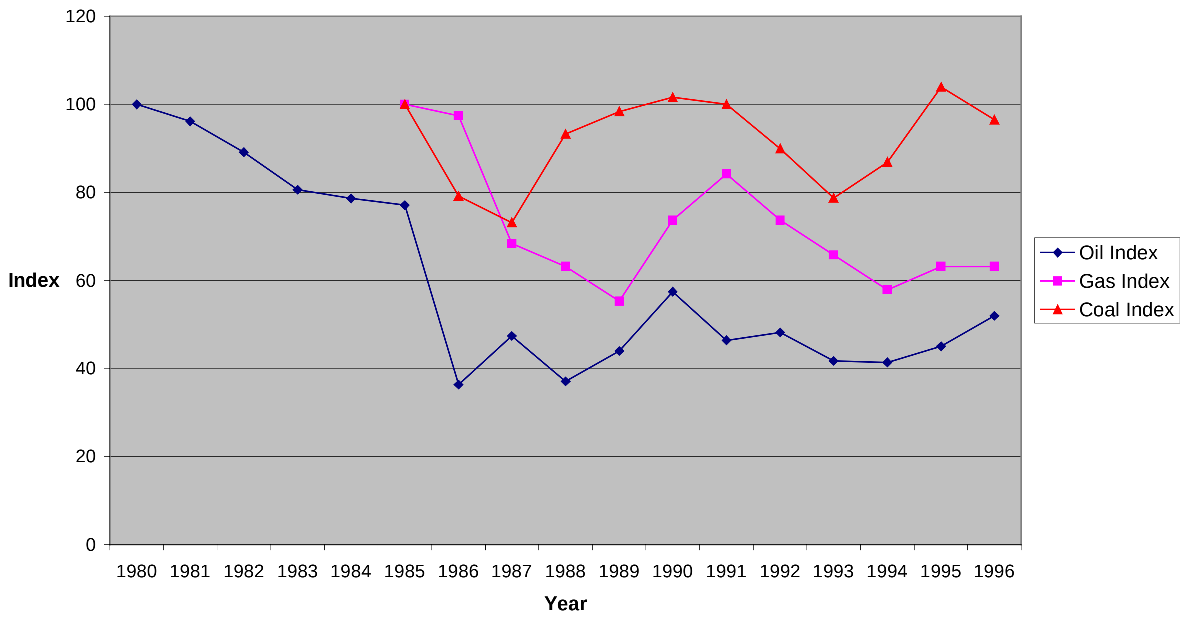
*Table 3.5: Impact of Energy Savings on the Cost Effectiveness of CHP*

For CHP systems below 20 $MW_{e,}$ it is unusual for there to be any supply of electricity back to the grid and hence this method of cost recovery is unavailable to all but the largest systems.

## 3.6 Industrial Efficiencies

The industrial process sector has one of the shorter response times. However, concerns over competitiveness and uneven cost burdens have tended to dampen political enthusiasm in some quarters. Where industrial energy taxation has been explored, it has been found in most countries to be too blunt an instrument to be truly effective, particularly when it is realised that most typical taxation levels only increase the price of fuel by around a third of the amount by which it has fallen over the last 15 years. The graph below illustrates the problem:

**Figure 3.2 : Price Decline in Fuel Sources 1980 - 1996**



It has been found, however, that threatened action in this area has stimulated strong Voluntary Agreements in a variety of industrial sectors. It is quite possible that these voluntary actions will deliver substantial contributions towards the 2008-2012 targets, particularly if renewable energy sources are promoted by additional exemptions.

The industrial sector is extremely diverse and has potential to save substantial further $CO_2$ emissions. A recent compilation of study data suggests that over 100 Mtonnes of emissions per year can be targeted cost-effectively. However, there is very little data on the cost criteria because of the variety of options available. The recent Commission document ‘ Preparing for Implementation of the Kyoto Protocol’ quotes figures of ∈5-45 per tonne of $CO_2$ saved. However, from the NTUA report quoted[10] as the source for this data it is unclear as to how this figure is defined (i.e. against annual $CO_2$ savings or lifetime $CO_2$ savings). The dominance of the PRIMES Ver. 2 Energy System Model in this work makes validation particularly difficult.

In summary, most industries have made substantial improvements in their respective energy intensities over the last 30 years. Progress in this respect has tended to show little correlation with the price of fuel. Voluntary targets have been set in several sectors for further reductions ahead of the 2008-2012 commitment period. The cost of meeting these targets is still unclear but anecdotal evidence suggests that there are still some highly cost-effective measures available. Nonetheless, it is likely that the average cost per tonne of $CO_2$ saved annually will increase with time as the ‘law of diminishing returns’ takes hold. The current estimate of ∈5-45 per tonne is likely to be a fair reflection of the lifetime costing scenario. However, as with other measures, the final figure will depend substantially on the method of implementation.

# 4. THE POTENTIAL ROLE OF ENERGY EFFICIENCY IN BUILDINGS

## 4.1 Speed of Potential Action

The building sector represents a spectrum of time spans and opportunities. The stock turnover in buildings is relatively long (minimum 50 years) although attention to new building standards can ensure that growth in domestic dwellings does not add to the current emissions burden on a pro-rata basis. The commercial and public sectors (often described as the ‘tertiary’ sector) provide larger opportunities for improvement in view of the greater potential for refurbishment programmes. As will be seen later, these have particular significance when cost issues are considered. Moving into the realm of building services and industrial energy efficiency, the installations tend to have shorter life-cycles and it is common for air conditioning systems and the like to be overhauled on a 10-15 year time frame. Accordingly, savings in these areas represent something that could well contribute to significant savings in the short to medium term.

## 4.2 Cost of Potential Action

As has already been seen, the cost of policy options is a subject that can exercise policy-makers indefinitely. There are numerous perspectives which can be used, such as:

- The cost in terms of government resources
- The cost in terms of absolute investment
- The scheduling of investment to spread intensity
- The lifetime cost of a measure taking into account any longer-term savings accruing

Whichever perspective is adopted, there is little argument that the assessment should be made per tonne of $CO_2$ saved annually in 2010 (or 2008-2012 if preferred). This is also consistent with the approach used by the Commission in most of its own assessments.

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[10] National Technical University of Athens, Capros and Mantzos (1999)

In reflecting the real societal cost, this report has taken the view that lifetime costing is the key element for any full assessment of options. However, it is recognised that some aspects of investment scheduling also need to be considered to make sure that the intensity of investment does not periodically exceed the resources available. The basis of lifetime costing is found in the following equation:

**Life-time cost = Initial investment cost - Σ [ Net Present Value of energy saving per year]**

The value of the cumulative energy saving is calculated over the full life of the measure. For thermal insulation this can be anything between 15 years and 50 years. However, to compensate for the cost of money, a discount rate is applied to future savings in accordance with normal discounted cash-flow techniques. This study has used a default rate of 8% which provides a conservative assessment of overall savings. Under these circumstances, the lifetime cost of an energy saving measure will almost inevitably be negative. In other words, there will be a financial **saving** per tonne of $CO_2$ saved in 2010. This saving arises because most energy efficiency measures will more than pay-back the investment cost over the lifetime of application. If this were not the case, few if any such investments would be made. It should be noted that the cost (or saving) per tonne of $CO_2$ saved has two independent components:

- The lifetime cost (or saving)
- The number of tonnes of $CO_2$ saved.

For example, it would be possible to envisage a situation where the cost (or saving) per tonne of $CO_2$ saved would be higher for a measure involving an energy source with lower $CO_2$ emissions per kWh of energy produced. Accordingly, the energy source being considered is an additional variable affecting the number of $CO_2$ tonnes saved. Table 4.1 below gives the average kg of $CO_2$ emissions per kWh for electricity generation across the Member States of the EU in 1995[11]:

***Table 4.1 Average $CO_2$ emissions for Electricity Generation across the Member States of the EU in 1995 (kg/kWh)***

| Member State | CO2 Emission Rate |
|---|---|
| | (kg/KWh) |
| **Austria** | 0.22 |
| **Belgium** | 0.29 |
| **Denmark** | 0.84 |
| **Finland** | 0.24 |
| **France** | 0.09 |
| **Germany** | 0.61 |
| **Greece** | 0.98 |
| **Ireland** | 0.70 |
| **Italy** | 0.59 |
| **Luxembourg** | 1.08 |
| **Netherlands** | 0.64 |
| **Portugal** | 0.64 |
| **Spain** | 0.48 |
| **Sweden** | 0.04 |
| **United Kingdom** | 0.64 |
| | Source: ORNL |

Since these are averages for electricity only, it is vital to get more specific information for individual carbon-based energy sources. Table 4.2 below illustrates these figures for the UK in the period 1992-1999:

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[11] 'Thermal Insulation and its Role in Carbon Dioxide Reduction' Caleb Management Services (1997)

| **Fuel Type** | **Kg $CO_2$ per kWh** | | |
|---|---|---|---|
| | *1992* | *1995* | *1999* |
| Gas | 0.21 | 0.21 | 0.21 |
| Oil | 0.30 | 0.30 | 0.30 |
| Coal | 0.31 | 0.31 | 0.31 |
| Electricity | 0.73 | 0.64 | 0.47 |

***Table 4.2 Typical $CO_2$ emissions by fuel type and the effects of fuel switching on electricity generation***

The fall of the electricity value between 1992 and 1999 is graphic illustration of the effect of fuel switching in the generation sector. This has continued downwards to a current level of 0.47 kg of $CO_2$ per kWh. Of course, the converse is also true. The reason why the Swedish targets for Greenhouse gas emissions increase on their 1990 figures is because of fuel switching from nuclear to carbon-based alternatives over the period in question. Efficiency gains in the energy generation sector can also reflect in lower emissions. It can be seen, therefore, that 'cost per tonne' assessments need to take full account of energy sourcing and regional factors if they are to provide appropriate comparative data.

Investment cost is also a parameter which requires some further definition in respect of energy saving measures. The investment cost will be incremental if the measure is taken as part of the normal replacement cycle (e.g. **new build** or **total refurbishment**). Accordingly, only that element of the cost related to the improvement in energy efficiency needs to be accounted in the saving. However, if the measure is initiated specifically to gain the energy saving benefit, the full cost of replacement (including labour) will need to be considered. This is known as **retrofitting** and can be a major cost element. Finally, there will be some measures which can be implemented by the building occupier themselves. Such do-it-yourself **(DIY)** measures tend to be the most cost-effective of all. The following figure illustrates the potential significance of this factor for the installation of alternative energy efficiency measures.

In summary, the following definitions are adopted for the purposes of this report:

- Retrofit - where a deliberate decision is taken to replace existing equipment and the costs incurred are therefore total replacement costs including all parts and labour.
- New/Refurb. - where the opportunity is taken to introduce upgraded equipment during a new build programme or major refurbishment. In such cases the costs allocated relate to the incremental costs of parts and labour over and above those required for more traditional installations
- D-I-Y - where the measure can be taken by the householder or normal company employee such that the installation costs are neglected for all practical purposes. In this case, only the cost or incremental cost of the parts is considered.

These principles are illustrated in Figure 4.1 below:

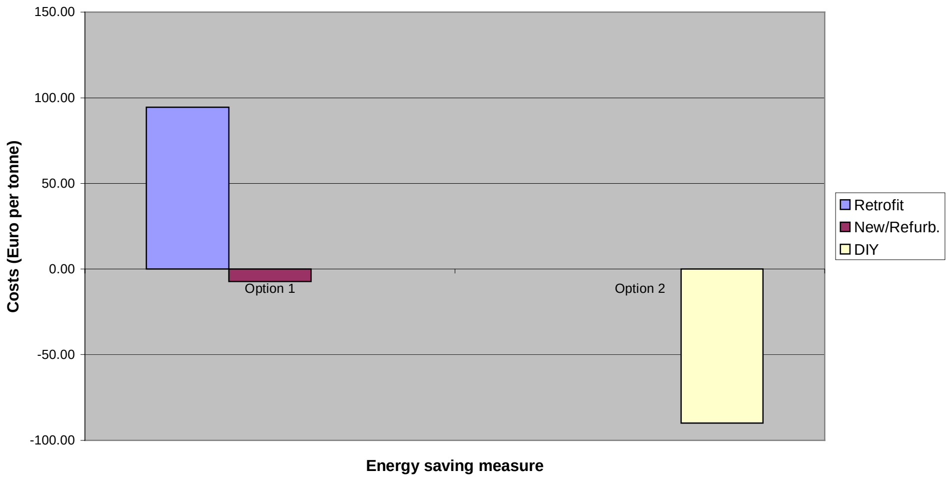

**Figure 4.1 : Summary of Costs per tonne of Carbon Doxide saved for two alternative Building Energy Efficiency Measures**

It can be seen that Option A can be converted from a level where there is a marginal saving per tone of $CO_2$ saved to one where there is a substantial cost, just by consideration of alternative routes of implementing the upgrade. This is an important observation for policy makers in assessing their best options.

A prime example of a DIY option is the replacement of traditional domestic electric light bulbs with compact fluorescent units. With the savings available per tonne of $CO_2$ saved, the immediate reaction would be to rush out and encourage every householder to replace all of their existing lamps. Of course, if supply could keep up with demand this would be a logical step. However, work conducted by Philips and others[12] and reflected in the 'Caleb I' report shows that the total energy saving achievable across the EU by this route would not amount to more than 19 M tonnes of $CO_2$ saving in 2010 (i.e. less than 7% of the required saving).

To evaluate the cumulative sources of saving which might be targeted by a policy-maker, some sort of ordering of options is clearly required. Figure 4.2 shown overleaf illustrates a methodology which is being used increasingly to assess relative options and their capability of contributing towards national and EU targets. The graph essentially plots 'cost per tonne of $CO_2$ saved' against 'cumulative annual $CO_2$ savings in 2010'. The potential measures are then placed in ascending order of cost per tonne of $CO_2$ saved. The net effect of the graph is that the box size and positioning illustrates the relative value of a particular measure. If lifetime costing is used as the basis of the y-axis, a full analysis of the cost of savings can be drawn from this one graph.

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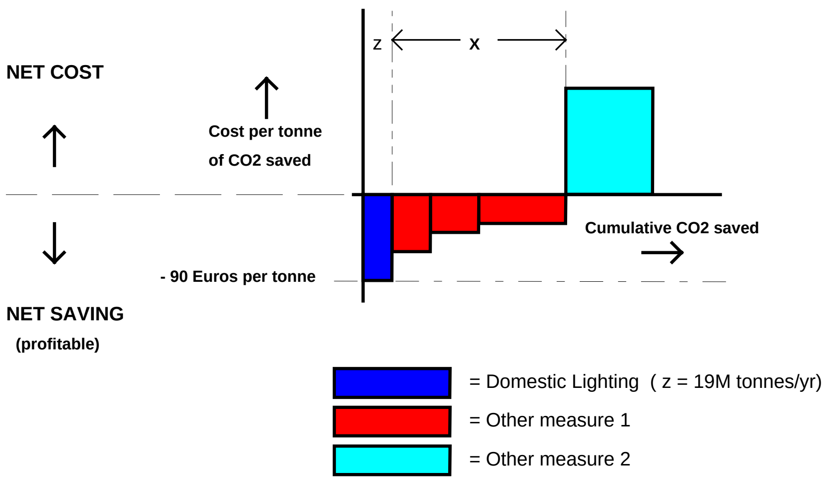
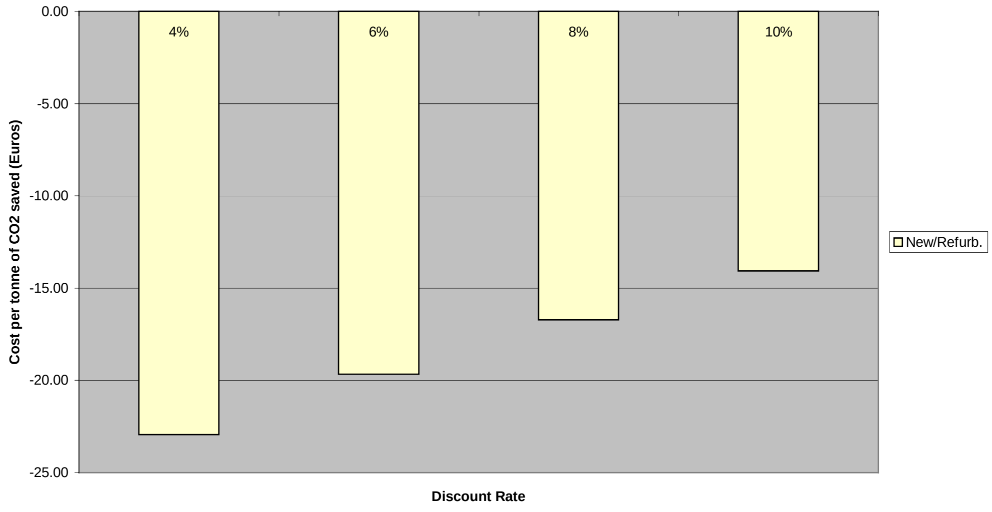
[12] Private communication from Philips (1998)

**FIG. 4.2 - CARBON DIOXIDE SAVING CONTRIBUTION FROM DOMESTIC LIGHTING**



In this particular illustration the domestic lighting example has been illustrated by the dark blue box. Its high value in the context of net savings is clearly evident, but then so is its relatively minor contribution to the overall potential savings target. Before leaving this initial look at the issues surrounding costing methods, it is important to dwell for a moment on the sensitivity of costing calculations to discount rates. The graph below illustrates the effect of various discount rates on the net saving per tonne of $CO_2$ saved for a typical building energy efficiency measure installed on a refurbishment or new-build basis:

**Figure 4.3 Sensitivity of Cost per Tonne of CO2 saved for a typical Building Energy Efficiency Measure**



## 4.3 Collective Application of Building Energy Efficiency Measures

Collective action has great value in ensuring that true marginal costing can be applied. The following example develops an overall cost per tonne of $CO_2$ saved for a collection of measures in a domestic dwelling. These include various thermal insulation, glazing and control improvements. The measures are assumed to have been installed during a major refurbishment thereby making them far less expensive to implement than would have been the case if they were retrofitted individually. To illustrate this in Table 4.3, the incremental cost [4] is listed alongside the full investment cost [2]. The savings arising from collective action are also incorporated as [3]. In each assessment, the fuel source has been assumed to be gas throughout. Accordingly, the $CO_2$ savings [1] are less significant than they would be under solid fuel, oil or electricity scenarios. This makes the savings 'worst-case' – albeit justified by the fact that gas is the most prevalent form of space heating now used in the domestic environment. The model used in calculating the respective impacts was that of the Dutch Domestic Dwelling featured in the previous Caleb report 'Thermal Insulation and its role on Carbon Dioxide Reduction' (1997)[11]. The bulk of the data on financial costs and savings has been drawn from work carried out by the Energy Saving Trust[13] and from private enquiries made by Caleb to a variety of suppliers and installers.

| Potential Measure | Annual $CO_2$ Saving Per dwelling (tonnes) [1] | Full Investment Cost per dwelling (Euros) [2] | Savings arising from collective action (Euros) [3] | Incremental Cost per dwelling (Euros) [4] |
|---|---|---|---|---|
| | | | | |
| | | | | |
| Measure 1 | 2-3 | 500 – 1050 | 0 | 500-1050 |
| Measure 2 | 1-2 | 5000 – 10000 | 4000-8000 | 1000-2000 |
| Measure 3 | 0.5-0.7 | 400 – 500 | 300 | 100-200 |
| Measure 4 | 0.4-0.6 | 200 – 250 | 0 | 200-250 |
| Measure 5 | 0.1-0.2 | 35 – 210 | 0-175 | 35 |
| | | | | |
| **TOTAL** | **4.0-6.5** | **6135-12010** | **4300-8475** | **1835- 3535** |
| | | | | |
| **Investment per tonne saved** | | **944- 3002** | | **282- 884** |

***Table 4.3 : Costs per annual tonne of $CO_2$ saved for a range of domestic energy efficiency measures***

These figures are, of course, calculated before any consideration is given to the energy savings that could also accrue. Against the same five measures, Table 4.4 overleaf provides an assessment of the additional impact of these energy savings. In this case, all costs are broken down into their cost per tonne of $CO_2$ saved annually. Column {1} provides information on the full investment cost and column {2} similarly expresses the incremental cost arising from collective action. Both columns are a direct re-presentation of the raw data given in columns [2] and [4] of Table 4.3.

Column {3} of Table 4.4 provides the first indication of the overall savings generated per tonne of $CO_2$ saved for the Full Investment (isolated retrofit) case. Column {4}, on the other hand, provides the more relevant savings achieved from collective action.

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[13] 'Energy efficiency and environmental benefits to 2010'; Energy Saving Trust (1997)

| Potential Measure | Full Investment Cost per tonne of $CO_2$ annually (Euro/tonne) {1} | Incremental Cost per tonne of $CO_2$ Annually saved (Euro/tonne) {2} | FI costs/(savings) net of energy* per tonne of $CO_2$ (Euro/tonne) {3} | Inc. costs/(savings) net of energy* per tonne of $CO_2$ (Euro/tonne) {4} |
|---|---|---|---|---|
| | | | | |
| Measure 1 | 167– 525 | 167 – 525 | (114)-(445) | (114)-(445) |
| Measure 2 | 2500 – 10000 | 500 – 2000 | 1916 – 3458 | (542)-(2084) |
| Measure 3 | 571 – 1000 | 143 – 400 | 220 - 300 | (129)-(380) |
| Measure 4 | 333 – 625 | 333 – 625 | (212)-(443) | (212) – (443) |
| Measure 5 | 175 – 2100 | 175 – 2100 | (1353) – 199 | (1353) – 199 |
| | | | | |
| **AVERAGE** | **944 – 3002** | **282 – 884** | **206 - 1030** | **(247) – (869)** |

* Energy costs assumed to be ∈0.01/kWh for gas, ∈0.1/kWh for domestic electricity

***Table 4.4 – Costs and (Savings) per tonne of $CO_2$ saved for a range of domestic measures***

It can be seen that with low unit levels of $CO_2$ saved by domestic energy efficiency measures, the calculation of cost per tonne of $CO_2$ saved annually becomes highly sensitive to investment costs and, in particular, assumed energy prices. Accordingly, high investment measures can often only be justified in the domestic sector if they are carried out as part of a wider refurbishment programme. The relatively low investment barriers in other areas can result in extremely high Internal Rates of Return (IRR)[14] where energy prices are significant. For example the lower investment cost value (∈167) in Measure 1 provides an IRR of 22.6% while the higher value (∈ 525) gives an IRR of 10.7%.

This assessment has focused on the domestic scenario since this is typically the worst case scenario for building energy efficiency investments. Commercial and public buildings usually provide much better returns because the energy demands are that much higher, particularly where air conditioning equipment is involved. The only aspect which may adversely affect the commercial, public case is where occupancy and/or utilisation rates are low.

In the industrial sector, it is typically more difficult to separate process related energy issues from building-specific items. In the case of office accommodation, the situation is much the same as for the commercial and public sectors. However, where process plant is present, the source of energy is often the waste heat of the process itself. This brings into focus the issue of ‘useful heat’ and the added question of whether waste heat is more efficiently recovered and recycled. Inevitably these debates are case-specific and beyond the scope of this report.

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[14] Internal Rate of Return is the discount rate which needs to be applied to the energy saved to make the Net Present Value equal to zero.

# 5. SUMMARY OF COST/BENEFIT COMPARISONS FOR ALL OPTIONS

From the analysis contained in this report, it has been possible to generate the following comparative cost information on the various options available to European regulators:

| Option | Investment Cost per tonne of $CO_2$ saved annually (Euro/tonne) | Lifetime Cost/(Saving) per tonne of $CO_2$ saved annually (Euro/tonne) |
|---|---|---|
| | | |
| Wind Power | 350-450 | 200-300 |
| Hydro | 250-350 | 100-200 |
| Photovoltaic | 2000-3000 | 2000-3000 |
| Biomass | 300-350 | 300-350 |
| Geothermal | 900-1100 | 900-1100 |
| Solar (Thermal) | 1200-1400 | 1000-1200 |
| Vehicle Efficiencies | 60-300 | Dependent on Fuel Efficiency |
| Intermodal switching | Unquantified | Unquantified |
| Industrial CHP | 305-310 | 155-160 |
| Other Industrial Efficiencies | Unquantified | 5-45 |
| Commercial CHP | 250-275 | 10-20 |
| Small-scale CHP | 350-375 | 120-130 |
| Fuel Switching (Investment case) | 12-14 | 65-70 |
| Building Energy Efficiency (Retro.) | 944 – 3002 | 206 – 1030 |
| Building Energy Efficiency (Refurb/New) | 282 – 884 | (247) – (869) |

It can be seen that Building Energy Efficiency initiatives represent some of the most attractive short and medium term options. More importantly, it is clear that the benefit gained by such an approach is complementary to the objectives of the other measures in that reductions on the demand side assist in meeting supply-side targets.

# 6. CONCLUSIONS

The prime conclusions from the study and report are as follows:

- Energy efficiency initiatives in the building sector are amongst the most cost-effective measures available to policy-makers seeking to reduce carbon dioxide emissions
- Typical measures can create *FINANCIAL SAVINGS* per tonne of $CO_2$ saved when properly lifetime costed
- The initiatives which could stimulate such savings are based on existing and proven technology
- The method of implementing such initiatives is an important factor in the assessment of the cost-effectiveness of the measures. Major refurbishment initiatives are generally far more cost effective than piece-meal retrofitting
- Initiatives in the domestic sector are also highly dependent on investment costs and energy price with internal rates of return (IRRs) in excess of 20% possible.
- Cost-effectiveness in the commercial, public and industrial sectors are typically more attractive than the domestic sector
- If lifetime costing methodology is to be adopted on a widespread basis, an EU-wide standard method of calculation is required.
- This could be made equally applicable to other sectors outside of the building field (e.g. automotive and, if necessary, renewables)
- Considerable education will be necessary in the traditional ‘energy efficiency’ sector to move thinking from existing payback methodologies to lifetime costing.

# 7. CONSOLIDATED REFERENCES

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