Environment 04

Economic Impact of Carbon Prices on Commercial Office Construction for Embodied Greenhouse Gas Emissions

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ABSTRACT

A life cycle study was undertaken to assess the economic impact arising from internalised embodied greenhouse gas emissions (GGE) costs for a commercial office building. A limited range of design and materials re-cycling strategies were investigated for their abatement potential. GGE quantities were determined by a hybrid process analysis where input-output data was supplemented with national average data to increase completeness, whereby all upstream emissions arising from material inputs to the point of extraction, as well as non-material inputs (e.g. goods and services) into the design and construction process are accounted for.

The hypothesis proposed abatement potential of 30%, as measured against the Benchmark Design (BM) would be economically viable in absence of the benefit of early-action credits. The hypothesis was disproved with 15% abatement shown at zero additional capital cost. A Stretch Technology (ST) scenario was investigated which showed 32% abatement potential however the associated marginal capital cost could not be determined. The theoretical value of abatement credits was determined at $19 to $1,280 /m2 NLA and is shown to present a significant economic and market transformation opportunity.

The results demonstrate that the cost-push inflation risk posed to commercial office construction is large where the price of embodied GGE is internalised in the economic system. Gross Construction Cost (GCC) increase per square meter is shown to be between 1.1% and 85.6% (with associated negative IRR impacts between -0.1 to -7%) depending on the GGE price level. An unsustainable cost impact is demonstrated at GGE prices greater than
AUD$66 per tonne CO2-e.

Internalised GGE studies have been largely limited to the operational cost impact arising from GGE of direct end-use rather than from the perspective of total embodied final demand. The results demonstrate the critical nature of embodied abatement strategies for commercial buildings, however it appears unlikely that the IPCC 60% global GGE abatement target can be achieved from property. An average kg CO2-e intensity per dollar of GCC is proposed for the three building models that may be applied to general scenario planning. The economic benefit shown for embodied credits is significant and worth pursuit with a suitable market mechanism.

GREENHOUSE GAS AND CLIMATE CHANGE CONNECTION

The IPCC synthesis report of 2001 (IPCC, 2001) provided the world with the strongest evidence to date linking human activities to global warming. The IPCC concluded, “even if we stopped all activity tomorrow, significant effects are already locked in as outcomes” (IPCC, 2001:17). The issue of greatest concern is the rate of acceleration in atmospheric GGE concentrations and the resultant speed of global temperature increase. A natural cycle is evident which can be linked to inter-glacial and glacial periods experienced over such significant geological time scales so as to allow natural adaption of the earth's biodiversity and animal species.

Australia is particularly exposed to the environmental as well as socio-economic consequences of climate change. A number of key economic sectors such as agriculture, property and tourism are directly and significantly impacted. CSIRO climate modelling suggests temperature increases in Australia by 2070 of between 1^{o}C to 6^{o}C and up to 20% less rainfall (AGO, 2002) in areas which are least prepared to cope or able to adapt quickly and which could contribute to a 50% loss of the Daintree World Heritage Area, which in itself, has the ability to drive a number of negative feedback loops.

Whilst temperature increases do not seem significant, it is the frequency and range of hotter events that is. Most directly, property will be affected by the increase in frequency of extremely hot days, (predicted to double) which presents immediate issues for the current building stock. The number of days where the temperature exceeds 34 ^{o}C, the design point for air-conditioning systems, may be exceeded by three times on average leading to a greater use of energy to drive systems (potentially accelerating GGE). The frequency of storm events is predicted to increase five fold with wind speed increases of 25% leading to a 650% increase in building related damage (IAG, 2003:6).

As the property sector generally designs on the basis of history rather than with a future perspective, it means that buildings being designed today are not being adequately equipped to cope with likely to very likely (IPCC define likely as 66-90% probability and likely as 90-99% probability) climate changes noted above which will result in significantly higher risk of loss (either economic or human) within their expected thirty to fifty-year life span. Queensland has been identified as presenting particularly high risk due to "rapid urbanization in low lying coastal areas where there are rapidly increasing population densities and the investment in the built environment will be exposed to greater coastal climatic extremes such as tropical cyclones and resulting inundation" (IPCC, 2001:p13, PIA, 2003).

A body of literature exists which contemplates the physical, social and economy-wide economic risks and likely direct effects of climate change on the built environment and proposes potential policy responses (PIA, 2002; Larsson; 2003; Lowe, 2003; IAG, 2003; CSIRO, 2002; AGO, 2002c). However, the majority of this work specifically focuses on the residential sector and none of this work deals with the microeconomic effects and risks associated with abatement and adaption strategies nor the scale of mitigation potential.

Constructed facilities are society's most important economic, social and environmental investment. When considered in terms of its economic significance (as measured as a proportion of GDP), the direct and indirect capital flows constitute on average about 40% of national GDP in OECD countries (Bon and 2000; CIB, 1999). It is estimated that approximately 50% of Australians own and rely on their wealth from property assets of some kind through superannuation and other direct investments (Jebb Holland , 2000:2). Direct employment in the construction sector accounts for 7% of total Australian employment, however up to 50% of total employment contributes indirectly to the sector each year (ABS, 2003).

The direct physical impacts facing property are discussed above, however it is the indirect impacts that present the sector with the most diverse and potentially insidious risks as they have the potential to erode the role the sector plays as a store of long-term wealth for society. Cost push inflation through carbon content of materials, sector productivity reduction through price increases, income loss from institutional property assets such as ecotourism, capital value loss or stranded assets through the inability to insure properties in certain climates or those which are exposed to certain risks are indirect and significant potential impacts for property (Munich Re, 2003).

There is consensus within the finance and insurance industries that the property sector is significantly at risk from climate change as noted above, but they have poor awareness and are among the least prepared to cope or adapt (CDP, 2004; CDP, 2003; AMP, 2003; Munich Re, 2003). Generally, the property sector view their exposure to climate as limited to the extent of direct energy inputs. It is only in the last two years that greenhouse emissions have been a topic of discussion at board level for some property companies (Investa, 2004; British Land, 2003; Mirvac, 2003; Hammerson, 2003; Johnson, 2004), an encouraging sign, but none have yet communicated their awareness as to the broader direct and indirect risks facing them, as noted above.

STABILISATION THEORY

The IPCC maintain about seven modelling scenarios that rely on varying socio-economic, emissions, demographic and technological assumptions (IPCC, 2001; WBCSD, 2004). Modelling suggests that by 2050 under a business as usual scenario, net additions could double, reaching 15-16 Gt per annum with an associated atmospheric concentration of about 1,000 ppm. A fundamental concern for this model is the belief that the run-away greenhouse effect is likely (probability of 60-90%) at a concentration level of 700 ppm (Pershing, 2003; IPCC, 2001) meaning, that nothing that we could do would arrest potentially catastrophic climate change.

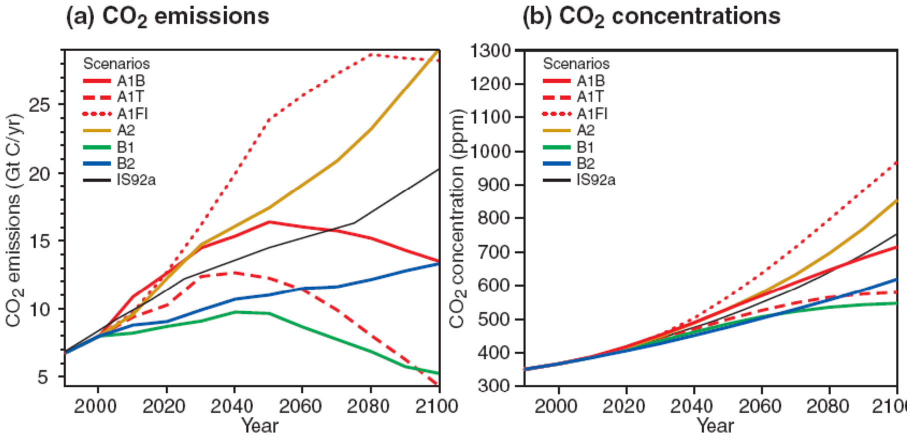


Figure 1. Primary IPCC models for CO2 emissions and concentration.
Source: IPCC, 2001:14.

It is generally held that a stabilisation concentration of 550 ppm by 2050 is desirable with a resultant temperature increase of between 0.6 to 2 degrees Celsius and could only be achievable with a 60% reduction in the greenhouse intensity of all human activities (with energy production and consumption central to that aim) (WBCSD, 2004; Thorning, 2003; IPCC, 2001). Figure 2.5 shows net annual emissions trajectories and resultant CO2-e concentrations determined by the IPCC for the seven main models.

For Australia to meet its share of the burden, the GGE reduction target is estimated at 60% from 2000 levels (AGC, 2004). Australia is currently at 107% of 1990 emissions levels based on the current range of policy instruments and abatement measures (AGO, 2003). In order to understand how property can respond to the challenge, it is useful to consider the structure of emissions from the Australian economy.

In 1999, total emissions from all energy sources were 337 572 Gg CO2-e or 337,572,000 tonnes of CO2-e of which direct construction accounted for only 3.1% while commercial buildings (all classes of building from 5-9) accounted for 13.8% or 46,536,000 tonnes. Manufacturing is the largest end-user accounting for just over 34% with transport second at 24%. When combined it can be seen that direct emissions from building use accounts for 32.4% of total emissions. Estimates suggest that a doubling of direct emissions for commercial buildings could be expected by 2010 (AGO, 1999), taking its absolute total to approximately 92,000,000 tonnes in absence of abatement strategies.

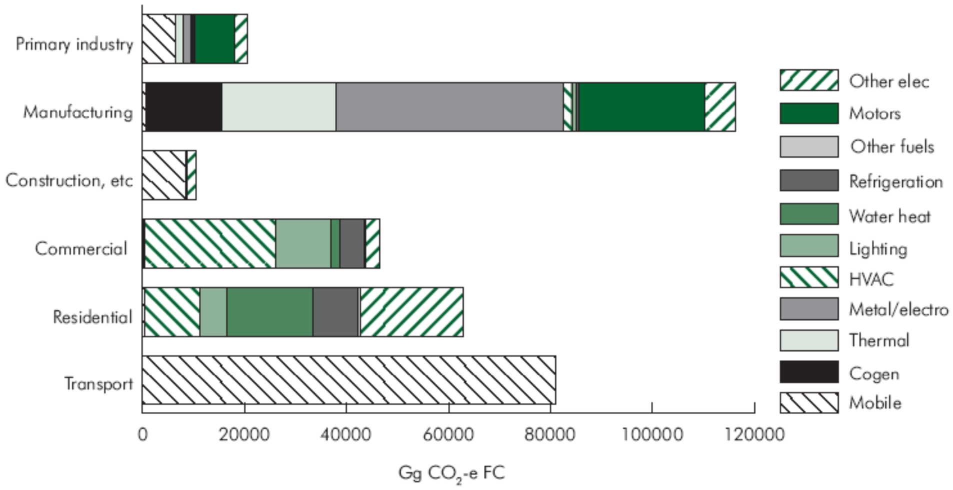


Figure 2. Sector emissions by end-use (all energy).
Source: AGO 2002b:131 figure 8.10.

Emissions are embodied into buildings indirectly through the materials, manufacturing and transport exchanges that service their capital formation. It is estimated that for OECD countries the materials inputs into the built environment could be as high as 70% of all emissions arising from these sectors (Faaij et.al. 2001;1). Assuming this holds generally correct for Australia, the embodied emissions attributable to the built environment and property could be equal to as much as 35% of total emissions. When added to direct emissions, a total emissions proportion of around 66% could be deduced. Common and Salma, (1992:10) found that when only direct inputs are considered, the construction was 15th of 25 sectors in terms of intensity but when assessed from the perspective of final demand was 3rd of 25 thus demonstrating the scale of indirect to direct emissions. Literature available seems to suggest an average total (direct plus indirect) of around 48% for most OECD countries, although this data is somewhat dated (Levine et al., 1995; Russell, 1998; CIB, 1999).

A significant body of work exists which demonstrates that a 25-30% reduction in the base building emissions footprint is viable and now regularly achieved (Mackley, 1998; Mackley 2002a; Bordass, 2000; Larson, 2000; BRITE, 2004). By way of example, the case study building achieved this level of reduction for base building services as measured against the prevailing New South Wales standard (as advised by the Sustainable Energy Development Authority). More recently, the author’s own experience with the Lend Lease built Bond building (30 Hickson Road) provides evidence that a 70% reduction (with an approximate 55-60 kg CO2-e/m2 NLA pa base building) against the NSW state average can be achieved within known economic constraints.

The main design strategies leading to this level of abatement include the elimination of over-specification in engineering margins and allowances for all building services and the use of what is called, realistic load estimates. This practice has been identified for some time as being an area of significant abatement opportunity (Lovins, 1992; CIBSE, 1998; CIBSE, 2000; Mackley 2002 a). It should be noted that by reducing over-specification, abatement is achieved both in operational and embodied terms. Significant technology strategies include the use of double glazed low-e external windows, free cooling cycles on mechanical services, high efficiency chillers, flat-screen technology, motion detection in non-permanently habitable spaces and energy star office equipment.

From an embodied perspective, the major design pathways for abatement also include elimination of design over specification of which structural engineering calculations present a substantial opportunity (Silman, 1977; CIBSE, 1998). Following this is the selection of alternative materials with lower emissions profiles; however, this must be done on an elemental assessment basis rather than at the level of the basic material. For example, a commonly held eco-design view is the selection of timber rather than aluminium for window sections, which can be appropriate for residential but when contemplated for a commercial building is not viable both in terms of functionality and durability. A better example of this substitution would be in terms of the use of timber flooring instead of terrazzo in public areas as both the mass and emissions per meter square of finished floor are lower for timber over a twenty year life cycle. The next strategy is the use of materials with a re-cycled content, which deliver the same functional outcome for a smaller emissions footprint.

The first three options above are desirable from the point of view that design intent does not need to be compromised in order to achieve emission abatement outcomes. The final strategy, alternative design approaches, is most useful at the earliest project stages where there is greatest flexibility, an example of which is to be found in the use of reinforced concrete slabs versus steel deck and topping slab which have fundamentally different embodied emissions profiles but which also require very different construction and design approaches.

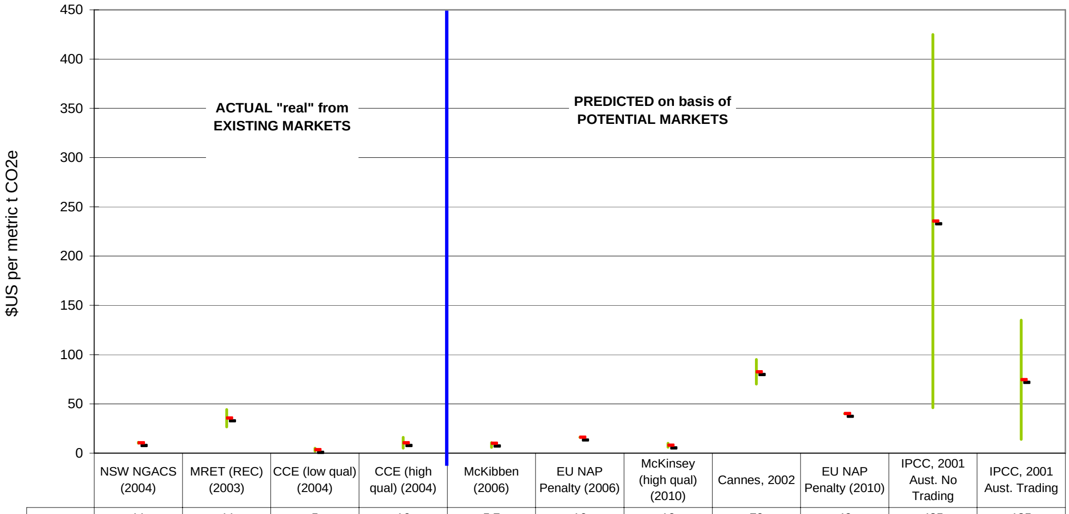
When considered together, it would seem that the 60-90% emissions goal of the WBCSD is a demanding challenge. The results of this work suggest that a 30-40% total emissions footprint reduction could be possible with operational abatement targets of 30-40% and embodied targets of 30-40%. As the property sector could be driving as much as 60% of national emissions, then achieving these goals would contribute to the overall substantial goal.

GREENHOUSE PRICING

The engaged community of economists and scientists argue that as climate change is essentially irreversible, it makes sense to avoid causing more of it than necessary but to have mechanisms that “provide incentives to reduce greenhouse gas emissions but avoid imposing unreasonably large costs” (McKibben, 2003:p10). The time scale within which the economy has to achieve the desired (or mandated) stabilisation level and the level itself are the major determinants of any equilibrium GGE cost or price.

A tradeable unit in carbon trading schemes is generally equal to one metric tonne of carbon dioxide equivalent (CO2-e) and is commonly valued in terms of US dollars. As discussed above, carbon dioxide is one of the greenhouse gases and the Kyoto Protocol provides an equivalency measure for all other greenhouse gases so as to provide a common instrument for trading. What is termed the Global Warming Potential (GWP) is a measurement of the impact that each different greenhouse gas has on global warming, relative to carbon dioxide and there are currently six greenhouse gases that are covered under the Kyoto Protocol.

The real markets shown for Australia are the NGACS and Mandatory Renewable Energy Target (MRET) schemes. It should be noted that the sorts of projects that can generate credits for the two Australian schemes vary. Under the NGACS scheme demand-side abatement, sequestration and on-site fuel swapping or generation projects can create credits and register these or they can be traded or banked. Only renewable energy projects are eligible to participate in the MRET scheme to create the tradable instrument a Renewable Energy Credit (REC). At these prices and at the scale of the scheme, it is clear that these mechanisms have not significantly contributed to Australia meeting its Kyoto target, let alone going toward achieving a 60% reduction from a 1990 baseline.



	NSW NGACS (2004)	MRET (REC) (2003)	CCE (low qual) (2004)	CCE (high qual) (2004)	McKibben (2006)	EU NAP Penalty (2006)	McKinsey (high qual) (2010)	Cannes, 2002	EU NAP Penalty (2010)	IPCC, 2001 Aust. No Trading	IPCC, 2001 Aust. Trading
High	11	44	5	16	5.7	16	10	70	40	425	135
Low	10	27	2	5	11	16	6	95	40	46	14
Average	10.5	35	3.5	10.5	10	16	8	82.5	40	235.5	74.5

Figure 3. Pricing Models for T CO2-e
NOTE: All prices are shown in US$ at an assumed exchange rate of 0.77.

Having regard for the discussion above, and the findings shown in figure 3, the prices used to support the economic impact assessment of this thesis are shown in table 2.2. As real life prices for GGE exist in Australia, these were used to define the lower range prices. The discussion above demonstrates that at its current level GGE pricing has not delivered or likely to deliver the necessary ecological abatement targets to meet the 2050 stabilisation target of 550 – 700 ppm. It is argued that the EU NAP penalty provides a rational mid-range, as it is a deemed market rate that will be available in 2010 and which reflects the stabilisation goal. The two IPCC trading/non-trading scenarios for Australia, define the higher end of the scale. The market convention is to quote GGE price in US dollars. An exchange rate of 71 cents per US dollar has been used as the basis for Australian dollar figures.

Table 1. Carbon prices adopted for the case-study.

Price Basis	Current Markets		EU NEP	IPCC Australian Models		
US$ / TCO$_2$-e	$ 11	$ 14	$ 46	$ 135	$ 201	$ 426
AUD$ / TCO$_2$-e	$ 15	$ 20	$ 66	$ 193	$ 287	$ 608

CASE STUDY DETAILS

The case study building is a high-rise premium A grade building of 44,300m2 net lettable space in CBD Sydney. The premium grade could mean this result is higher than those of comparative studies. The literature review failed to uncover any embodied GGE building studies. The system boundary is wider than those of prior studies, as it includes all upstream GGE arising from energy inputs to the point of extraction, as well as including non-material inputs (e.g. goods and services) into the design and construction process. GGE from operational energy consumption considers all end-uses (including tenant activities) upstream to fuel extraction. In addition, published studies have generally been restricted to the physical materials of construction and have ignored embodied GGE associated with preliminaries, profit, design, design-construction and project management which for CBD commercial office development can range between 20 to 40% of the net construction cost.

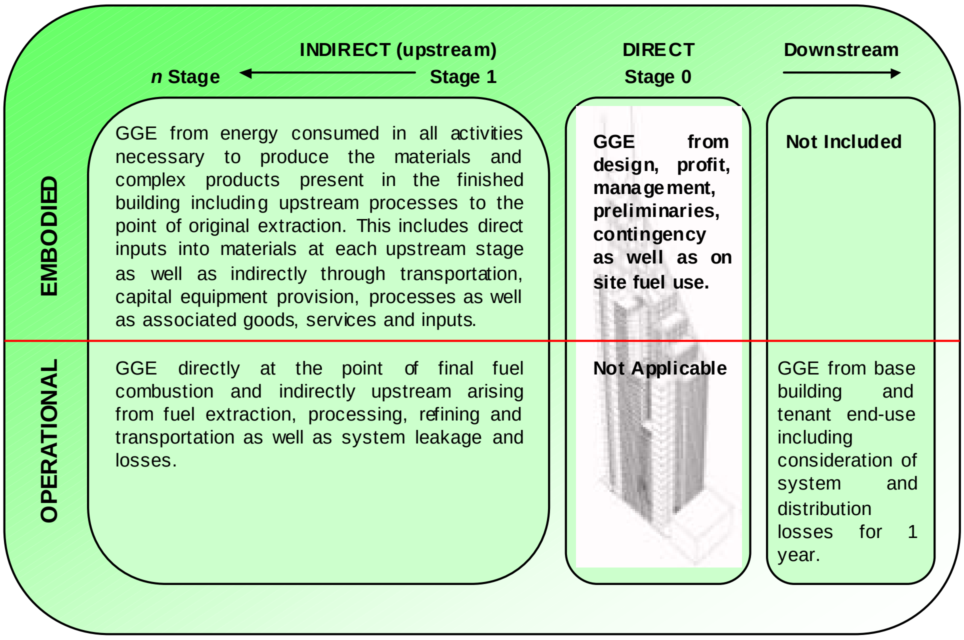


Figure 4. Study system boundary.

The major methodological corrections that this thesis makes include the following;

a) The case study is completed in GGE rather than energy terms and assesses resultant economic impact using current GGE market price data as well as projections from the IPCC.
b) Expands the embodied system boundary to include material inputs to the building, on-site construction as well as GGE related to the provision of design, profit, administration and other services and exchanges between parties to the development.
c) Attempts to resolve completeness by applying national average GGE intensities per dollar for unmeasured and service items (i.e. design, preliminaries, profit).
d) Derives operational GGE for both base building and tenant activities using the SEDA Australian Building Greenhouse Rating whole building methodology (and is based on whole building dynamic energy modelling).
e) Corrects normalisation basis to be consistent with industry standard (m2 of Net Lettable Area) as defined by the Property Council of Australia.
f) Uses ISO 14048/49 to bring consistency in application and replication in the future.
g) Uncertainty in the accuracy of embodied GGE coefficients is addressed through the use of three methods to derive a mean value Benchmark Model (BM).
h) Determination of abatement potential is determined through the modification of the case study building.
i) Net Lettable Area is adopted as the normalisation basis to provide consistency and comparability with industry conventions for economics and operational GGE.

A number of broad limitations apply to the findings of this study that include:

a) A single case study of this PCA grade does not have universal relevance within the Australian commercial office building stock.
b) Baseline years vary between key data sets and are likely to give rise to some uncertainties that have not been completely resolved. For example, the input-output tables used by CSIRO, Treloar and Lenzen are based on 1992-93 national input-output data, national

average GGE intensity per $GDP is 2002/03 data and case study pricing is relevant for 2003 with an escalation factor built in to 2005.

c) The heterogeneity assumptions that underpin input-output methodology prevail and have not been dealt with.
d) Difficulties with demolition re-cycling credits mean that analysis is exclusive of demolition and recycling GGE.
e) Reliance on published information of the percentage saving in GGE for recycling of primary metals is likely to have some variance, presenting some uncertainty to abatement values.
f) The developer's financing costs are excluded.
g) National average data limits the ability to assess mitigation contribution of an individual factory, proprietary specific process or product on the overall total. This work is generally an indication of the broad risk and opportunity associated with general direction.

STUDY SCENARIOS OR MODELS

The study goals is to quantify the total embodied GGE using a hybrid process analysis for a Benchmark (BM) case study building and then modify the design for a range of strategies that are currently known in Australia (Modified Benchmark – MO) and then again for strategies within current known technology (Stretch Design – ST). The design modifications were to be limited to materials substitutions, elimination of over-specification and substitutions of virgin for recycled materials. Using this method, the emissions' abatement arising from each model is then compared to the BM design for absolute and relative variance. Table 2 gives a summary of the model abatement and allocation procedures.

Table 2. Study scenarios.

Model	Scenario	Description of Allocation Method
1	Benchmark Design (BM)	Actual design with no modification or abatement features. Approx. 76% of material inputs process measured with GGE intensities (from hybrid IO extraction) and non-material inputs included bynational average kg GGE/$GCC. Cross check with findings of Lenzen, 1998.
2	National Average	Design as per BM but GGE derived using national average GGE/AUD$ applied to GCC only.
3	Modified Benchmark (MO)	Model 1 (BM) modified to reduce over-specification, modification of materials GGE for recycled content considered "viable".
4	Stretch Design (ST)	Model 3 (MO) modifed to change materials or substitute materials and increase recycling to levels known but not tested economicaly in Australia.
5	Modified National Av.	Model 2 but modified by the percentage variance found between Model 1 and 3.
6	Stretch National Av.	Model 2 but modified by the percentage variance found between Model 1 and 4.
7	Pure Input-Output	Benchmark Design absolute embodied energy multiplied by sector (other construction) embodied GGE per MJ from Treloar, 1998.

RESULTS

Model 1 BM results are shown in table 3, which show a CO2-e intensity of 5,258 kg CO2-e per m2 of NLA and an absolute total of 232,909 tonnes of CO2-e. The associated embodied energy was 65,000 MJ/m2 NLA, as compared to prior works of 40,000 MJ/m2 NLA. Model 2 is 23% lower than Model 1 and Model 7 is 48% higher. The mean value of the three Models is 5,697 kg CO2-e, some 8% higher than Model 1.

Table 3 - Absolute and Relative Results for BM Models.

Results for Benchmark Design (BM)	Model 1	Model 2	Model 7	Mean
kg CO2-e Per m2 NLA	**5,258**	**4,037**	**7,796**	**5,697**
Absolute Total kg CO2	232,909,708	178,856,452	345,496,216	252,420,792
Variance from Model 1	**0%**	**-23%**	**48%**	**8%**

Demolition data collected for the case study building suggested a GGE intensity in the order of 4,100 kg CO2-e/m2 NLA (net excluding preliminaries and non-material inputs) which provides a salient external reference. The mean GGE value of the element PR was found to be 1,022 kg CO2-e/m2 NLA. This suggests a total of 5,122 kg CO2-e/m2 NLA for the various buildings that existed on the site. The pre-existing buildings were of a different and generally lesser standard than the case study building.

Overall, the result confirms the expectations of the author but they are higher than that of prevailing industry-accepted norms. It is argued that based on the details of published studies that this difference is caused due to completeness (i.e. this study is more complete than others) and that results are in GGE rather than energy (MJ) terms. As such, it is essential to demonstrate a robust validation of Model 1, as this provides validity to the scale and economic impact propositions of the study hypothesis and conclusions.

An accepted alternative comparative measure can be found in the CO2-e intensity per dollar (kg CO2-e/$) of total demand or consumption as established by James (1980). There are three well-cited studies, which provide important contributions to establishing the CO2-e intensity per dollar of final demand and consumption, for the construction sector. They are; Common and Salma (1992), Lenzen (1998) and AGO (2002b).

Common and Salma, (1992) found a CO2-e intensity per dollar of final demand for Construction of 1.15 kg CO2-e/$ final demand in their 1992 study of embodied emissions (Common and Salma, 1992, Table 4, p12) which was based on 1985/6 input-output tables. The study accounted only for CO2 emissions as opposed to all Kyoto greenhouse gases and therefore results are understated. Lenzen (1998) found a CO2-e intensity of 1.2 kg CO2-e per dollar of total final demand (kg CO2-e/$AUD1993) (Lenzen, 1998, table 1, p501) for the construction sector. Lenzen's study was based on the 1992/3 Australian input-output tables and unlike Common and Salma, included all Kyoto greenhouse gases. In comparing his results to Common and Salma, Lenzen notes that his results were likely to be higher due to this issue.

Owing to the single point nature and other limitations of the case study it would be unreasonable to suggest absolute findings. As previously discussed, the approach taken to establish confidence levels for the Models was to establish a mean result from which to determination of 95% confidence levels. Once found, these form a more reasonable basis on which to complete economic modelling. Results of certainty testing are shown in Table 4.

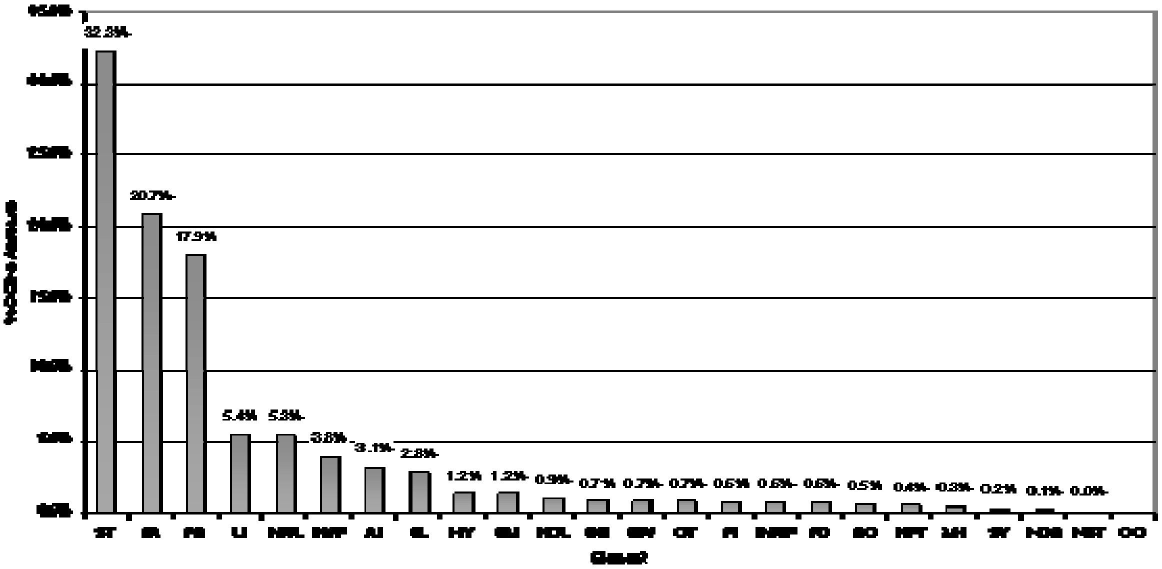
The standard deviation is calculated for the resultant mean value, however owing to the small sample size ***n*** = <30, an unbiased standard deviation is required which is represented as, S2. A 95% confidence estimate was calculated using a ***t***-distribution from S2, with 2 degrees of freedom. This gives range for emissions per dollar GCC of 0.75 to 1.45 kg CO2-e/$GCC and emissions per functional unit of 3,995 to 7,401 kg CO2-e/m2 NLA for the Benchmark Model (BM).

Table 4 – 95% Confidence for GGE per $GCC and NLA

BM Models ONLY	kg CO2-e/ $GCC	kg CO2-e/ m2 NLA
Mean	1.10	5,698
Standard Deviation	0.32	1,625
S2 Unbiased	0.31	1,505
95% Confidence Interval	0.35	1,703
Lower	0.75	3,995
Mean	1.10	5,698
Higher	1.45	7,401

The BM 95% confidence values are then adjusted by the absolute variance found for Model 3 and 4 relative to Model 1 (e.g. 15% and 32% respectively). These results are then used for the economic modelling impact assessment, for both capital cost and abatement value. This method is applied for the functional unit and dollar GCC Co2-e intensity.

The distribution of embodied GGE by building element shows a narrow spread with the top 5 elements accounting for 81.6% of total emissions and the top 10 elements comprising 93.7% of the total. Figure 5 highlights the impact of the inclusion of the element preliminaries (PR) in the consideration of total GGE for office construction and gives an indication of one of the reasons why the results of this study are higher than those of other works. It should be noted that this value includes for items such as escalation, contingencies, design, project and construction management as well as the traditional on-site preliminaries (e.g. tower crane, site facilities, temporary services and the like). This causes a value that is higher than what is traditionally considered as representative for this element.



The absolute value of GGE for the Models is between 178,856 tonnes (Model 2) and 345,496 tonnes (Model 1). The mean value is shown to embody 252,241 tonnes of CO2-e. The GGE intensity of the elements ranges from a high of 1,837 kg CO2-e per m2 NLA for structure (ST); to 3 kg CO2-e/m2 NLA for stair finishes (INST). There is a rapid reduction in the GGE intensity of the elements beyond preliminaries (PR) with 78% of the elements with emissions intensity of 5% or less. While not discounting the fact that the finishes and services elements of a building are replaced multiple times in a life cycle, it highlights the need to understand the nature and type of key abatement drivers for structure and façade.

Figure 6 shows the absolute total of all seven models. Model 7 is seen to be the highest, which was expected owing to a suspected double counting error. Model 1, 3 and 4 can be seen to be larger than Model 2,5 and 6. Absolute totals vary from 345,496 tonnes CO2-e for Model 7 to 126,169 tonnes CO2-e for Model 6. Models 1,3 and 4 should be considered together and Model 2,5 and 6 are the second family of models to be considered together due to the methodological approach taken.

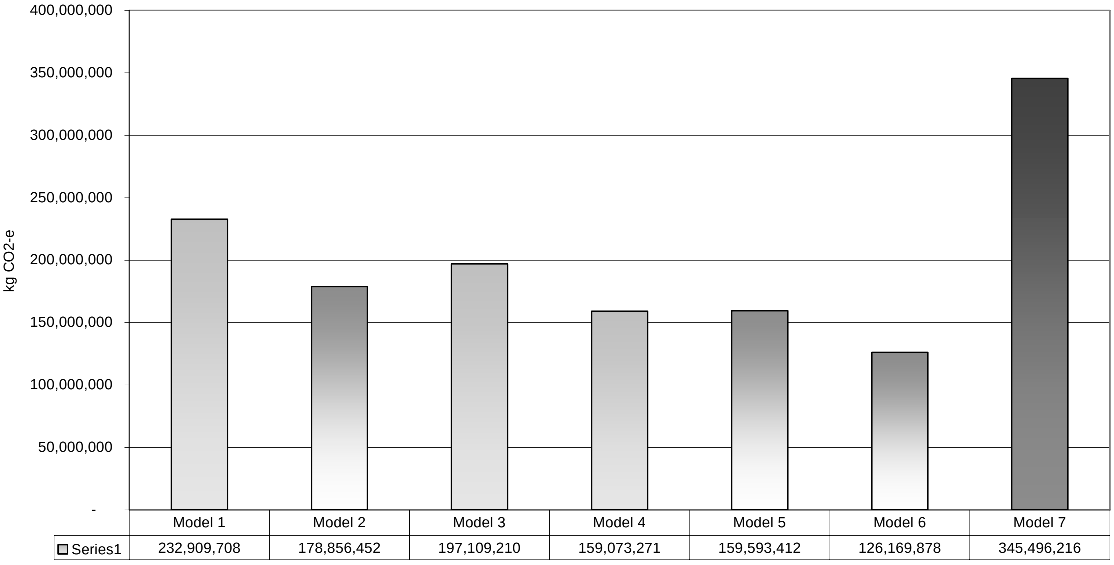


Figure 6 – Absolute Total GGE for Models 1-7

It is necessary to establish certainty levels for the BM family of models. Once complete, the BM values are varied in proportion to the findings of Model 3 and 4 in order to establish 95% confidence for each of the three Models BM, MO and ST. Table 5 shows the mean and 95% confidence values for BM, MO and ST on a m2 NLA basis. The figures shown in table 1 have carbon price levels applied in order to determine impact and abatement opportunity.

Table 5 – Overall Model Results

95% Confidence	BM	MO	ST
	kg CO2-e/m2 NLA		
High	7,401	6,291	5,033
Low	3,995	3,396	2,716
Mean	5,698	4,843	3,875

This shows that there is a 95% certainty that the total GGE intensity of office construction is between 3,995 kg CO2-e/m2 NLA and 7,401 kg CO2-e for the BM (typical construction in 2003). Within current known technologies, there is 95% certainty that GGE can be reduced to 3,396 kg CO2-e/m2 NLA and 6,291 kg CO2-e/m2 NLA. Theoretically, the intensity can be reduced to 3,875 kg CO2-e/m2 NLA and 5,033 kg CO2-e/m2 NLA, although it has been shown that there is additional abatement to reduce these figures further.

The small sample size causes the certainty range to be larger than is desirable. Additional samples are needed in order to tighten certainty levels. The results are for the mean and 95% confidence values for models BM, MO and ST. It can be seen that BM suggests a cost associated with embodied emissions of $60 to $111 per m2 NLA, at a GGE value of AUD$15 per tonne CO2-e, rising to $263 to $487 for the medium range price of $66 per tonne. At a carbon price of $608 per tonne, total GGE cost is higher than the capital costs for most types of commercial office buildings in Australia. Model MO and ST cost impact are 15% and 32% lower than BM, reflecting the abatement findings. Notwithstanding the reduction in GGE, the total cost increase per m2 NLA, where carbon prices are greater than $66 per tonne, are still significant (i.e. greater than 10%), compared to the current gross construction cost for office buildings in Sydney.

Economic Impact Assessment

The results of the economic impact assessment are shown in table 6 below.

Table 6 – Economic Modelling Results

		2003 $AUD/ T CO2-e					
	kg CO_2/ m_2 NLA	15	20	66	193	287	608
BM							
95% Lower Range	3995	$ 60	$ 80	$ 263	$ 771	$ 1,148	$ 2,428
Mean	5698	$ 85	$ 114	$ 375	$ 1,100	$ 1,638	$ 3,463
95% Upper Range	7401	$ 111	$ 148	$ 487	$ 1,429	$ 2,127	$ 4,498
MO							
95% Lower Range	3396	$ 51	$ 68	$ 223	$ 656	$ 976	$ 2,064
Mean	4843	$ 73	$ 97	$ 319	$ 935	$ 1,392	$ 2,944
95% Upper Range	6291	$ 94	$ 126	$ 414	$ 1,214	$ 1,808	$ 3,823
ST							
95% Lower Range	2716	$ 41	$ 54	$ 179	$ 524	$ 781	$ 1,651
Mean	3875	$ 58	$ 78	$ 255	$ 748	$ 1,114	$ 2,355
95% Upper Range	5033	$ 75	$ 101	$ 331	$ 972	$ 1,447	$ 3,059

These results demonstrate that the inflationary risk posed to the construction sector is large, where GGE pollution costs, are internalised. For the case study building, the total cost of GGE pollution for the mean Model BM value, where carbon price is AUD$15 per tonne, is in excess of $3,765,000. Irrespective of the study's limitations, a cost increase of this amount would be difficult to absorb without corrective action being taken.

Another way of analysing the results is in terms of a percentage cost increase per meter square of functional area. Table 4.22 shows the results in terms of percentage increase in GCC per m2 NLA. Prestige, of Premium A grade offices are very high quality buildings and represent the upper range of the rental market, as such, the results shown should be considered at the lower end of the cost increase scale. That is, as the GCC reduces, the percentage cost impact will increase (there may be a reduction in embodied emissions, but this has not been demonstrated). For example, in 2003, Rider Hunt suggested the average gross construction cost for CBD A grade office space in Sydney, as being in the order of $2,300 to $2,800/m2 NLA (Rider Hunt, 2003:6). Model BM shows a cost increase of 1.1$ to 2.1% for the low range carbon cost, and up to 85%, where carbon prices are $608 per tonne. At $66/tonne cost increase is shown between 5% and 9.3% per m2 NLA.

Table 7 – Relative Impact in % Cost Increase per m2 NLA for Mean BM Model

		2003 $AUD/ T CO_2-e					
Mean (BM) Result	kg CO_2/ m_2 NLA	15	20	66	193	287	608
95% Lower Range	3995	1.1%	1.5%	5.0%	14.7%	21.8%	46.2%
Mean	5698	1.6%	2.2%	7.1%	20.9%	31.2%	65.9%
95% Upper Range	7401	2.1%	2.8%	9.3%	27.2%	40.5%	85.6%

It should be reiterated that a carbon price beyond $20 per tonne, results in a significant cost-push inflation effect on the cost of office construction. The results shown in Table 7 and 8 can be considered in context with the operational cost impact, for the same GGE prices. The case study building was shown to have annual GGE from operational energy consumption, of 10,248 tonnes CO2-e (refer to Table 3.9). Where the carbon price is $AUD15/tonne, operational emissions costs amount to $153,720 per annum or $3.46/m2 NLA on a functional unit basis. This is equal to less than 0.05% in capital terms per m2 NLA. Even at the low range carbon prices, embodied inflation impact is over 20 times larger than the effect on operating costs.

A 1.1% cost increase per m2 NLA, represents approximately 10% of the Sydney average net rent cost (in 2003). In practical terms, if this cost were pushed through the economy, an inflationary effect of 10% would result in rental costs. As commercial office rent is extremely sensitive to price, it is unlikely that the increase could be passed through, and owners would need to absorb costs. A 1.1% cost increase negatively impacts the project IRR by approximately 0.1%; which would be considered a reasonably large burden on project economics.

In relative terms, abatement potential can be seen as being valued between, $19 and $1280 per m2 NLA for commercial office buildings. As discussed above, these figures are vastly larger than operating abatement, which was shown to be worth about $0.97/m2 NLA per annum. Even at the lowest levels, embodied abatement is ten times larger than operating abatement.

Table 8 – Absolute and Relative Abatement Value for Mean Model Values

	Value of Abatement in $AUD 2003					
Mean Value	**15**	**20**	**65**	**193**	**287**	**608**
Model MO	$ 567,947	$ 758,020	$ 2,490,636	$ 7,309,475	$ 10,882,996	$ 23,011,310
Model ST	$ 1,211,620	$ 1,617,109	$ 5,313,357	$ 15,593,547	$ 23,217,059	$ 49,090,796
Model MO	$ 13	$ 17	$ 56	$ 165	$ 246	$ 519
Model ST	$ 27	$ 37	$ 120	$ 352	$ 524	$ 1,108

CONCLUSIONS

While considered a small contributor to national emissions from the point of view of direct emissions, it has been demonstrated that in terms of final demand, the construction sector is responsible for driving over 50% of total emissions. The embodied GGE of office construction has been demonstrated as being much larger than operating and must be pursued as a whole of life approach to property sector abatement to effect a meaningful contribution to national abatement.

It has been demonstrated that a 32% reduction in the GGE intensity of office construction is possible where embodied and operating emissions are pursued jointly. In taking a combined approach, total abatement from construction by 2012, would be five times larger than that delivered just for operational policy instruments. Additional abatement opportunities have been identified, although they are not expected to be significant (e.g. less than 10%). The IPCC and ICG 60% abatement target does not appear possible from office construction within current market paradigms. A significant change in the economic environment is necessary to transform office construction to a low carbon basis. Transformation of this nature appears possible where carbon costs are internalised and priced in the range suggested by IPCC as necessary (i.e. beyond $AUD200 per tonne).

In the short term, if GGE pollution costs were fully internalised, it would have a large negative impact on office construction activity. The cost increase for office construction has been shown to be between 1.1% and >85% depending on the carbon price. This increase has been shown to have a negative IRR impact of 0.1% to 6% depending on the carbon price. It is suggested that an IRR impact of >0.3% could be considered unsustainable within current market principles.

Economic opportunities have been demonstrated as present for abatement strategies. While the marginal capital cost for Model ST could not be determined, the modelling and verification costs of abatement are suggested as being low compared to the credit value suggested. BP has shown that there is significant competitive advantage, (both in the areas of cost competitiveness and capacity development) for taking early emissions abatement action. It is suggested that builders and owners could adopt or test the strategies shown, to provide themselves a long-term competitive advantage. Competitive advantage is gained through cost efficiency as well as reducing the scale of inflationary risk.

The GGE intensity per dollar of GCC has been shown for the three models and suggested as a means of scenario planning to support the development of an abatement scheme. Moreover, it is suggested that building owners could apply these rates to investment decision-making within the context of responsible investment.

The major limitation of the study lies in its single point nature, which requires additional samples in order to reduce the spread of results. Moreover, it would be helpful to achieve performance bands (if they do exist) that are representative of the variety of office classes (e.g. Premium A, A, B and C), similar to the star rating bands established for the ABGR scheme.

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