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Developing an Integrated Assessment Model for the CMI Low Energy Building Design Tool: Final Report

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Abstract

The energy performance of buildings has become an increasingly important consideration for investors and governments alike. This paper describes a stochastic Integrated Assessment Model (IAM) created to understand the benefits and costs of a Low Energy Building (LEB) design tool developed by the Cambridge MIT Institute (CMI). As with many projects having high non-financial returns, the Low Energy Building design tool has the possibility to increase social welfare however may have difficulty finding financial backing in the private sector. This paper shows the expected financial and non-financial returns on investment of continuing such a LEB project as well as a simplified expected profit calculation. The results highlight the potential for market failure with regards to social welfare associated with such projects.

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Executive Summary

In this report we describe an Integrated Assessment Model (IAM) created to further our understanding of the benefits and costs of the Low Energy Building (LEB) design tool developed by the Cambridge MIT Institute (CMI). In line with our IAM framework, we consider financial benefits and costs as well as monetarised non-financial benefits attributable to the LEB project. The energy performance of buildings has become an increasingly important consideration for investors and governments alike highlighted by the EU directive 2002/91/EC. This directive acknowledging the long-term impacts of new buildings and aims directly at reducing the energy requirements of new and existing buildings with particular attention to heating, cooling and lighting as well as the requirement of energy performance certification.

The LEB design tool provides “a simple and fast way of exploring the performance of building designs - especially for the early-stage (first six hours) of the design process”. It is above all the simplicity and ease of use that sets this product aside from other building design tools capable of making similar, and potentially more accurate simulations. In its current state, the design tool is functional and can be accessed via the web. The existing tool covers large residential or commercial buildings and researchers are subjecting the model to ongoing validation. It would take some years to finalise the development and validation of the design tool and bring it to the market, and this would require a total budget, including the costs of marketing for the US market, of some tens of Million USD (Glicksman 2006).

The IAM assumes s-curves for the penetration of low-energy buildings both with and without the LEB project. With the aid of simple linear and exponential trends we also consider uncertain changes to all of the important model parameters, such as energy costs, carbon intensity of energy use, extra green building costs, and growth in the building market.

Since energy efficiency in buildings is a relatively young field in the academic literature, it remains difficult to get data that is well suited to the model. In order to overcome this we use expert opinion, estimation and historical data with error margins that reflect the limitations of our

knowledge. Having designed the IAM with uncertainty built in, we are also able to use sensitivity analysis to determine which of the parameters are most crucial so that extra effort can be spent to reduce the uncertainty in these areas. Where possible official data is used such as construction data published by the US and Chinese governments. We also use results from published reports, though limited in number and scope, when considering the cost and benefit estimations of low energy buildings as well as the penetration rate of low energy buildings or technologies such as the LEB design tool.

The IAM results show that a stand alone project in the US offers a high social return on investment despite our assumption of only a 27% mean expected probability of a successful launch of the product after incurring all development expenses. Mean total social net benefits in the US are $10 billion, with a range from $0 to $50 billion. The mean return on investment for the US is $470 per dollar spent, and using the world model that extrapolates from data for the US and China, the model gives a return on investment of $7000 per dollar invested. We foresee potential synergies and further increases in expected returns on investment were the LEB project to be brought in as part of new regulations to control the energy requirements of new buildings. In such a case we would suggest that the design tool could play an important role to assist builders/planners to meet new regulation cheaply and effectively. Using a very simplified business model we also make a first order approximation of potential profits for the project in the case that it is taken up by the private sector. Since the business model is based on willingness to pay and not on the sharing of calculated social costs and benefits, our estimates suggest that even with a low discount rate of 5%, the project would have a negative expected profit.

Introduction

MIT in conjunction with CMI has been developing a "design advisor" that is an on-line tool for architects and engineers to help in designing Low Energy Buildings (LEB), hence referred to as the LEB design tool. The tool provides "a simple and fast way of exploring the performance of building designs - especially for the early-stage (first six hours) of the design process". The tool responds to increasingly importance of buildings energy performance as highlighted by the EU directive 2002/91/EC. This directive acknowledging the long-term impacts of new buildings and aims directly at reducing the energy requirements of new and existing buildings with particular attention to heating, cooling and lighting as well as the requirement of energy performance certification.

It is above all the simplicity and ease of use that sets this product aside from other building design tools capable of making similar and potentially more accurate simulations. "Many existing design tools are time consuming to learn, too detailed (require CAD input), and promise high accuracy - resulting in slow feedback that is ill-suited for early stage design". The LEB design tool "allows the user to simulate and compare major design decisions - quickly and with little or no experience. Real-time calculations provide results typically within a minute's time, allowing the user to quickly explore the design space" (MIT Design Advisor Website). The design tool makes use of simplified formulae or "rapid algorithms" for instance for daylighting calculations. The use of model simulations can play an important role in reducing the "dependence of the building industry on precedent, as opposed to new research, as the deciding factor in the design of building systems". The emphasis of the LEB design tool is to facilitate design decisions at the early stage of "brainstorming" without the commitment of resources that a complete modelling of the building design would require (2004).

In its current state, the design tool is functional and can be accessed via the web. The existing model covers large residential or commercial buildings and researchers are subjecting the model to ongoing validation. Possible extensions to the model would be to allow for more varied building types such as residential housing, increased flexibility in the design of building features, further optimisation methods and a larger data base of materials and costs. It could take between 2 and 10 years to finalise the development and validation of the design tool and this could be expected to cost, including the costs of marketing for the US market, between 10 and 50 Million USD (Personal communication with Glicksman).

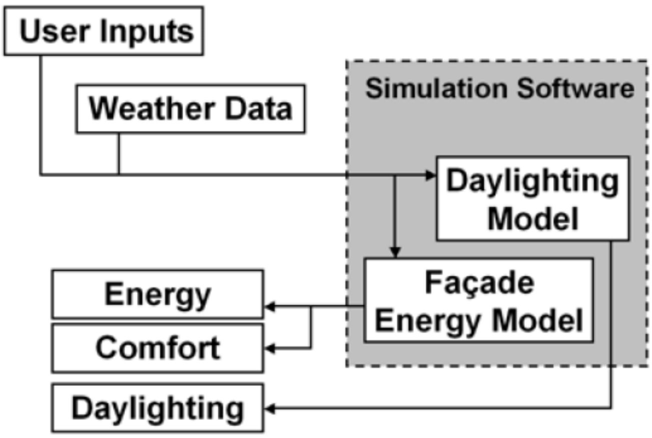


Figure 1 Organization of the Web Tool. Source: Lehar & Glicksman (2003)

Here we develop an Integrated Assessment Model (IAM) to further our understanding of the social costs and benefits of developing the Low Energy Building (LEB) design tool and introducing it to the market. In line with our IAM framework, we consider financial costs and benefits as well as monetarised non-financial benefits attributable to the LEB project.

Model Overview

The social cost-benefit calculation for the further development and marketing of the LEB design tool is implemented using a probabilistic integrated assessment modelling approach. We compare two different States of the World (SOW) in terms of penetration of energy efficient "green buildings", one with and one without the LEB design tool. In many ways the approach used is similar to the analysis of Cambridge MIT Institute's (CMI) silent aircraft project as presented in Morimoto and Hope (2005). However, due to the incremental nature of green building diffusion either with or without the LEB project we assume that the market penetration of a successful LEB project would follow a conventional s-curve (*BRE*, 2005). The current project also uses @risk from Palisade to perform the necessary Latin Hypercube Sampling, data compilation and sensitivity analysis reporting.

The model uses 1 year increments and includes 2 world regions with a multiplier to generate an approximate world total, with the US serving as the model's focus region. We consider the energy efficiency associated with new build only, without the possibility of retrofitting traditional buildings or the costs and benefits associated with refitting new green build at the end of the lifetime of the energy efficiency features.

Distributions are used as opposed to best guess inputs to better represent the uncertainties that exist in many, if not all, of the factors considered. These uncertainties can exist for a number of reasons including stochasticity, such as warmer or cooler years, limited knowledge about a parameter that could be improved through further searching or research, and policy decisions that we can not simulate apart from assuming, for instance, improvements in energy efficiency over time. By allowing for distributions to describe these uncertainties, we are also able to avoid the "[f]law of averages" whereby one might falsely assume that using mean expected inputs returns a mean expected output when the problem may be non-linear (Savage, 2000).

We explicitly model the costs of energy as a function of time and the resulting social costs including those related to the carbon content of energy. We also explicitly define the level to which social costs are endogenised in the price of energy, allowing for a comparison of financial and non-financial costs without double counting. In this report we consider “financial” costs and benefits as those that can be associated directly to the development of the LEB design tool including the development costs, extra costs to build the green buildings and the energy cost savings associated with them. The “non-financial” benefit on the other hand refer to productivity and health improvements from using green designs as well as the non-taxed externalities that are brought about by energy production.

Through modelling the relationships between all of the important variables and taking into account the uncertainties involved, we are able to calculate the net effects that the LEB project would have both in terms of costs and benefits arising from the increased building and development costs, reduced energy requirements from increased energy efficiency and productivity improvements achieved by improved natural lighting and ventilation. Alongside this more detailed social cost benefit analysis, we also develop a very simple first order approximation of the potential benefits that could be captured by the developers of the LEB project as a private sector business. The following table offers a brief summary of the cost and benefits of the LEB projected as they are calculated in the model.

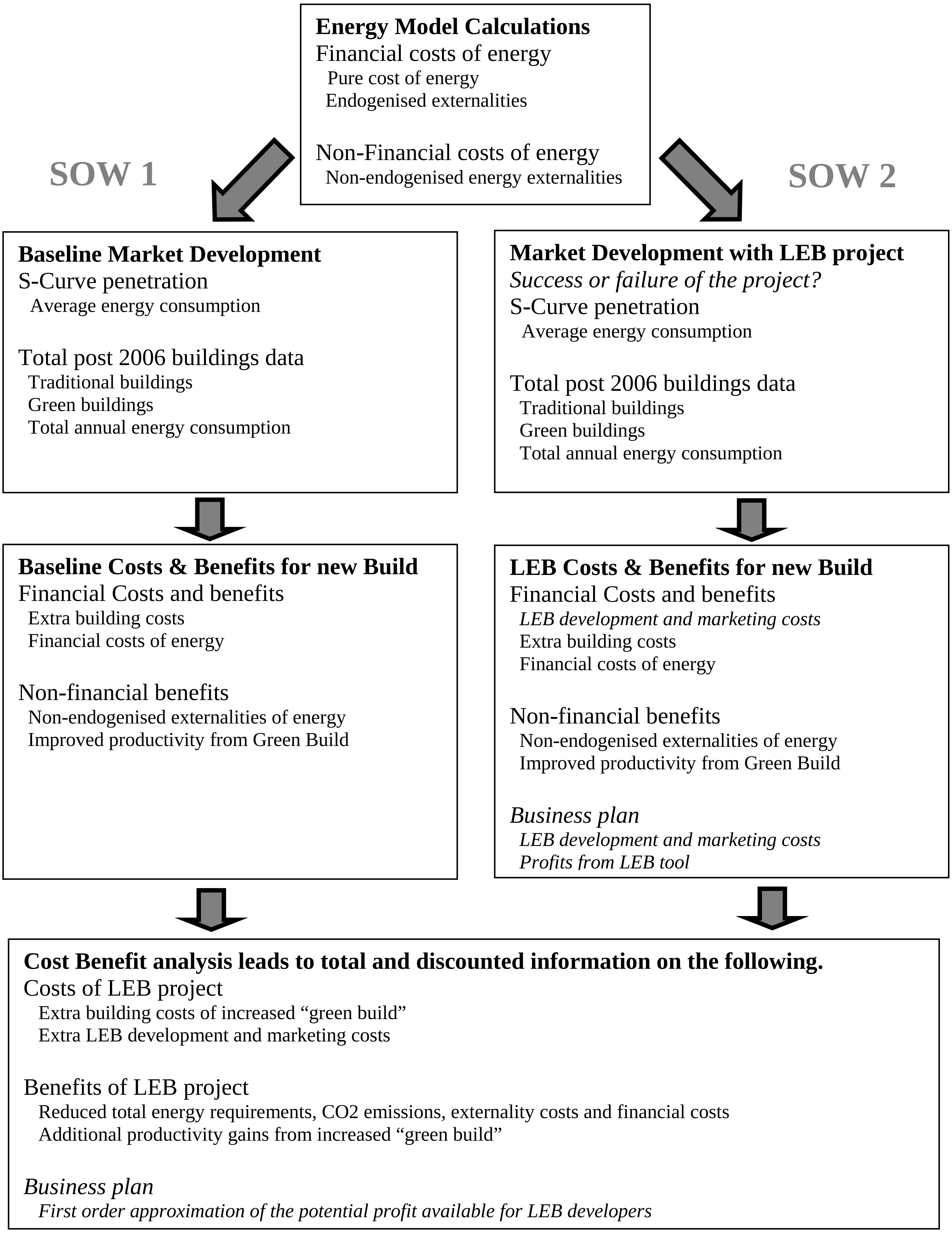
Table 1 Taxonomy of financial and non-financial costs and benefits calculated by the IAM

Costs	**Benefits**
1. Development and marketing costs of the LEB design tool 2. Added costs during the design and construction stage of new buildings	1. Pure cost of energy saved 2. Internalised externality cost of energy saved such as those coming with the existing SOx / NOx cap and trade scheme or the implementation of a carbon cap and trade or tax scheme. I.e. those taxes that follow the polluter pays principle 3. Non-internalised externalities avoided through reduced energy consumption 4. Productivity and health improvements

Green buildings are defined here as all new build that explicitly factors in low energy considerations into the design. Our description of green buildings differs from those used in other studies where energy aspects are considered alongside a number of other factors such as proximity to public transport, sourcing and toxicity of materials and so on (Kats 2003, SWA 2004). When calculating the costs and the benefits of the LEB project, we refer only to those costs and benefits directly associated with improved energy efficiency.

The following diagram is a stylised representation of our model and the calculations made for the two SOW's, the first being the baseline scenario and the second the scenario with a continued LEB project. We assume that the energy mix and cost of energy remains unchanged for the two SOW's, while the total energy use and cost/benefit results need to be calculated separately for the baseline and LEB states. Having calculated the outcomes in terms of costs and benefits for each SOW, the final box shows the calculation of relative costs and benefits between the two states including the NPV calculation itself.

Figure 2 Schematic representation of the model's NPV calculation



Through modelling both the baseline and LEB project's market capture of Green Buildings we are able to calculate the total energy used by all buildings built in the period post 2006 for the lifetime of the energy efficiency measures. However in making the jump from project development to increased energy efficiency in the building stock, there are a number of important uncertainties that need to be faced as described in Table 2.

Table 2 Some important uncertainties affecting the overall benefits of continuing the LEB project

1. Product Development Investment required? – There are uncertainties about the amount and cost of further work that would be required to bring the project to the market as well as the actual market development costs. This would be true for the US, the focus region, as well as the other regions that could be developed after a successful entry into the US market.
2. Development Success? – As with all project investments, it is possible that the project will fail due, for example to limitations of the design tool or competing design tools as well as problems in the market development strategy chosen by the developers. In such a case, the development costs would be incurred, however no benefits would be realised.
3. S-Curve Penetration Time? – We have assumed an S-Curve penetration of the existing market for new build mostly consisting of traditional buildings. We have calculated the shape of the S-Curve in terms of time taken to reach the S-Curve point of inflection, representing about one third of final penetration achieved. The time taken to reach this point of inflection as well as the maximum potential market share is uncertain.
4. Benefits of Green Buildings? – There is a growing body of literature researching the costs and benefits of green buildings, however there remains some conflicting evidence on just how big the costs and benefits are today, and what the future holds for green building costs and benefits.
5. Lifetime of Energy Efficiency Benefits? - Despite the eventual saturation of the market to the maximum level of penetration, the benefits of the extra green buildings in the building stock would continue to be obtained for many years. However, we remain uncertain of the mean lifetime of green building benefits.

Defining the LEB model

Throughout the model we use the simplest functional forms that have generally been based on uncertain initial conditions and a linear (or in some cases an exponential) trend as shown in the following equations.

The formulation for the linear and exponential trends used wherever a ‘trend’ has been indicated in the data is given below. Trends are stated as a fractional increase of base year levels and are described in the data as being either “linear” or “exponential”. For the purpose of simplification, for the remaining formulas we generally we refer to coefficient values at period ‘t’ and not in terms of its base year and trend function.

Linear Trend

$$Value_t^{linear} = Value_{t=0} \times (1 + t \times trend)$$

Exponential Trend

$$Value_t^{exponential} = Value_{t=0} \times (1 + trend)^t$$

When referring to parameters of regions other than the United States (the model’s focus region) we sometimes need to calculate them in different ways. To take into account the relationship between different regions, for example that increased energy costs in one region will be also seen in other regions, we usually calculate other regions relative to the focus region using a multiplier. Here the (uncertain) parameter for, say, China multiplies the parameter for the US (the focus region). In other situations, where differences in parameters are not going to be closely related, we use parameters that are non-correlated. Finally, in certain cases relating to time delays, the values need to be added and not multiplied.

The following table gives a brief overview of the model parameters used; a more detailed table with references to data sources used can be found in Annexe 1. The values in brackets represent the (minimum, mode, maximum) of the triangular distribution used throughout to describe the uncertain distribution of the parameters.

Table 3 Model parameter overview

	US – Focus region	China
Discount rate (d) This is the discount rate used for all cost and benefit calculations across all regions	(0.03, 0.04, 0.08) mean 0.05	
World Multiplier (m) This is the multiplier used to extrapolate from the cost and benefit data for the US and China to a world total.	(2,3,4) mean 3	

Energy Use

Effectiveness of green buildings (EffectivenessGreen) This represents the proportional energy savings made possible through “green building” design as compared to “traditional buildings”	(0.05, 0.25, 0.40) mean 0.28	Relative (.8,1.3,1.8) mean 1.3
Energy requirements, (BaseyearEnergy^{Traditional}) EJ/m^2/year Energy requirements of traditional buildings	(1.42, 1.58, 1.74) mean 1.58	Relative (1.5,2.5,3.5) mean 2.5
Energy requirements trend, (EnergyTrend^{Traditional}) proportion/year	(-.006, -.004, .002) mean -.0027	Relative (1, 1.25, 1.5) mean 1.25
Pure energy cost, (PureCostEnergy) BillionUS$(2006)/EJ Cost of energy before any taxes associated with externalities.	(8,9.5,11) mean 9.5	Relative (.5,1,1.5) mean 1
Pure energy cost trend, (PureCostEnergyTrend) proportion/year	(-.005,-.002,.01) mean 0.001	Relative (.5,1,1.5) mean 1
Non-Carbon externalities, (NonCarbonExtCost) BillionUS$(2006)/EJ Externality cost of energy for all areas except those relating to the carbon content of energy, such as global warming.	(2,5,8) mean 5.	Relative (.2, 1,1.8) mean 1
Non-Carbon externalities trend, (NonCarbonExtCostTrend) proportion/year	(-.002, 0, .002) mean 0	Relative (.5,1,1.5) mean 1
Carbon intensity, (CarbonEnergyIntensity)	(.045,0.055,.065) mean .055	Relative

Billion TCO2/EJ Amount of carbon emitted per energy unit produced		(1, 1.5, 2) mean 1.5
Carbon intensity trend, (CarbonEnergyIntensityTrend) proportion/year	(-.001,.0015,.003) mean .0015	Relative (.5,1,1.5) mean 1
Shadow cost of carbon, (CarbonShadowCost) US$(2006)/TCO2 Damages associated with every unit of CO2	(2,15,40) mean 19	
Shadow cost of carbon trend (CarbonShadowCostTrend) proportion/year	(.01,.025,.04) mean 0.025	
Internalisation of externalities (InternalisationRate) The proportion of externality damages that has been internalised into the price of energy through, for example, externality taxes.	(0, .05, .1) mean .05	(0,.025,0.05) mean 0.025
Internalisation of externalities trend (InternalisationRateTrend) proportion/year	(0, .005, .01), mean .005	Relative (0, 0.5, 1) mean 0.5

Market Size

New building annually, (BaseyearMarketSize) Billion m^2 Floor area of new build annually	(0.4,0.65,0.9) mean 0.65	Relative (1.7,2,2.3) mean 2
New building annually trend, (MarketSizeTrend) proportion/year	(0,.02,.04) mean of 0.02	(.05, .1, .12) mean .09
Lifetime of energy benefits of new build (BaseyearLifetime), Years This refers to the time period that the benefits of new green buildings would last. This tries to take into account the shorter lifetime of some of the physical attributes included in the extra building costs, as well as the longer lifetime of the larger structure.	(20,30,50) mean 33	Relative (.5,1,1.5) mean 1
Trend in lifetime of benefits, (LifetimeTrend) proportion/year	(-.001,0,.001) mean 0	Relative (.5,1,1.5) mean 1

Delay before entering market, (MarketEntry) Years The number of years before entering the US market from 2006, and the number of years for entering the China market after a successful development in the US.	(2,6,10), mean 6	Additive (2,6,10), mean 6
Delay for baseline entry, (t_{entry}), Years Number of years from the present before baseline penetration of green buildings (negative years implies that this has already begun).	(-10,-8,-6), mean -8	(-10,-5,0) mean -5
Maximum Penetration, (MaxPenetration), Maximum penetration of green buildings in the market. proportion	(.2, .5, 1) mean 0.57	Relative (.5,1,1.5) mean 1 N.B. maximum baseline penetration = 100%
Baseline Green Building penetration time ($t_{BaselineInflection}$), Years Baseline S-curve parameter, time taken to reach point of inflection of S-curve.	(15,25,50) mean 30	Relative (0.5,1.5,2.5) mean 1.5

LEB penetration time of remaining traditional build, ($t_{LEBInflection}$) Years LEB S-curve parameter, time taken to reach point of inflection of S-curve where considering the proportion of the potential increase in market remaining, between baseline green build and maximum penetration.	(20,40, 60) mean 55	Relative (.5, 1.5, 2.5) mean 1.5
Successful market development (MarketDevelopment) Probability of success when entering each market. We have assumed entry into second market only after a successful entry into the focus region.	(0.1,0.2,0.5) mean 0.27	Relative (0.3, 0.5, 0.7) mean 0.5

Cost Benefit

Added costs, (AddedCosts), US$2006/m^2 The added costs required to build green buildings as opposed to traditional buildings.	(20, 60, 100) mean 60	Relative (.25, 0.5, 1) mean 0.58
Added costs trend, (AddedCostsTrend) proportion/year	(-.005,0,.002) mean -.001	Relative (.5,1,1.5) mean 1
Market development cost, (DevelopmentCosts) Billion US$2006 Costs required to finalise product development and marketing for each of the regions successively. Although probably higher than minimum required investments, such a distribution would allow for the inclusion of a category of buildings including single-family houses and a variety of other specific building types inline with the General framework for the calculation of energy performance of buildings (article 3, Directive 22/91/EC).	(0.01,0.03,0.05) mean 0.03	Relative (.1, .5, .9) mean 0.5
Productivity Benefits, (ProductivityBenefits) US$/m^2 Benefits expected in terms of increased productivity per unit area of increased green building floor space.	(2,6,10) mean 6	Relative (.01, .1, .2) mean 0.103

Profit Calculation Only

Lifetime of project, (t_{MAX}), years Number of years from market entry that the project could continue.	(10,25,40) mean 25	Relative (.5,1,1.5) mean 1
Delay for competition, ($t_{CompetitionDelay}$), years Number of years after before competing software with similar attributes would form competition.	(1,8,15), mean 8	Relative (.5,1,1.5) mean 1
MarketLostToCompetition, (CompetitionLoss) The proportion of the LEB design tool market that would be lost to competing software solutions.	(.05, 0.5,0.95) mean 0.5	(.05, 0.5,0.95) mean 0.5
Baseline captured by LEB, (baselineCapture) The proportion of the baseline market for green	(0,0.1,0.4) mean 0.17	Relative (.5,1,1.5) mean 1

buildings that the LEB design tool would capture.		
Profit from LEB projects, (Profits) US$(2006)/m^2 Profits that could be extracted from the design tool per area of new green building using the design tool.	(0.05, 0.1,0.4) mean 0.18	Relative (0.1, 0.3, 0.5) mean 0.3
Trend in value extracted from LEB projects (ProfitsTrend) proportion/year	(-.005,-.002,.001) mean -.002	Relative (.5,1,1.5) mean 1

Energy costs (BillionUSD/EJ)

We distinguish energy costs as either financial costs paid by the consumer in their energy bill or non-financial externality costs. We also allow for an increasing level of externalities being endogenised through programs such as taxation for key pollutants.

$$CostEnergy_t^{Financial} = PureCostEnergy_t + InternalisationRate_t \times ExternalityCostEnergy_t$$

$$CostEnergy_t^{External} = (1 - InternalisationRate_t) \times ExternalityCostEnergy_t$$

Where

$$ExternalityCostEnergy_t = CarbonShadowCost_t \times CarbonEnergyIntensity_t + NonCarbonExtCost_t$$

Energy Requirements of New Build (EJ/Billion m^2)

Traditional buildings are assumed to improve according to a small linear energy efficiency trend, while green buildings are seen as having a step improvement in energy efficiency indicated by the coefficient of EffectivenessGreen.

$$Energy_t^{Traditional} = BaseyearEnergy^{Traditional} \times (1 + t \times EnergyTrend^{Traditional})$$

$$Energy_t^{Green} = Energy_t^{Traditional} \times (1 - EffectivenessGreen)$$

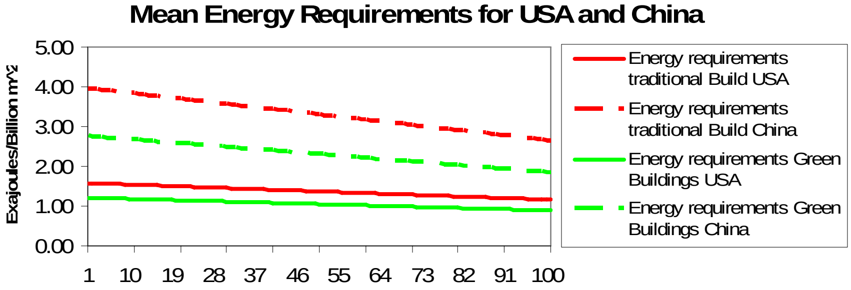


Figure 3 Energy intensity of green and traditional buildings in the US and China

Figure 3 illustrates the energy intensity of traditional and green buildings in the US and China over time assuming mean savings of roughly one third of the energy required in traditional buildings when using the LEB design tool. There is a general progression towards energy efficiency even in traditional build due to more general improvements in materials and quality of construction. Figure 3 shows the mean values only without the uncertain levels of the initial value and the linear growth component.

Market Size and Annual Energy Requirements

Baseline

Penetration occurs from year of entry of "green buildings" into the market t_{entry} which can of course occur before the base year of 2006. We have adopted the S-Curve form used by BRE in their scenario assessments of energy efficient technologies[1].

$$MarketCapture_t^{Baseline} = MaxPenetration \times \left(1 - e^{-k_{Baseline}(t - t_{entry})^2}\right)$$

We also calculate the k-value from the time given to reach the point of inflection.

$$k_{Baseline} = \frac{0.5}{t_{BaselineInflection}^{\ 2}}$$

The baseline annual Green and Traditional market size and total remaining Green and Traditional build for year 't' in billion m^2 can now be calculated. To calculate total green or traditional buildings, we need to sum all of the building previously built so long as the life time of energy efficiency benefits has not expired.

[1] More information about BRE and access to their publications is available through there website, www.bre.co.uk .

$$GreenMarketSize_t^{Baseline} = MarketCapture_t^{Baseline} \times MarketSize_t$$

$$TotalGreenBuildings_t^{Baseline} = \sum_{T=0}^{T=t} \left[\left(GreenMarketSize_T^{Baseline} \right) AND \left(t - T \leq Lifetime_T \right) \right]$$

$$TraditionalMarketSize_t^{Baseline} = \left(1 - MarketCapture_t^{Baseline} \right) \times MarketSize_t$$

$$TotalTraditionalBuildings_t^{Baseline} = \sum_{T=0}^{T=t} \left[\left(TraditionalMarketSize_T^{Baseline} \right) AND \left(t - T \leq Lifetime_T \right) \right]$$

The energy requirements of all new build can then be calculated simply as

$$EnergyNewBuild_t^{Baseline} = TraditionalMarketSize_t^{Baseline} \times Energy_t^{Traditional} + GreenMarketSize_t^{Baseline} \times Energy_t^{Green}$$

To calculate the total annual energy requirements, we must sum the energy requirements of all buildings built since 2006 so long as the lifetime of the benefits has not expired. For example, if new buildings from the year 2010 had a lifetime of energy efficiency benefits (such as triple glazed windows) of 30 years (Lifetime(2010)=30) we then need to factor in the energy requirements of buildings built in that year until the year 2040.

$$TotalEnergy_t^{Baseline} = \sum_{T=0}^{T=t} \left[\left(EnergyNewBuild_T^{Baseline} \right) AND \left(t - T \leq Lifetime_T \right) \right]$$

LEB Project

Here we calculate the extra market captured as a result of the LEB project where we have assumed that it can play a role in speeding up the entry into the market. We use a similar S-Curve that describes an improved penetration rate (reaching the same maximum level of penetration) that a successful LEB design tool could have. Hence, 0% refers to a baseline penetration rate, and 100% represents reaching the maximum penetration level, this occurring after the LEB successfully enters the market $t_{LEBEntry}$.

$$ExtraMarketCapture_t^{LEB} = \left(1 - e^{-k_{LEB} \left(t - t_{LEBEntry} \right)^2} \right) AND \left(MarketDevelopment = Success \right)$$

Where again we calculate the k value from the time given to reach the point of inflection.

$$k_{LEB} = \frac{0.5}{t_{LEBInflection}^{2}}$$

From this we can now calculate the total market capture of green buildings with the LEB project.

$$MarketCapture_t^{LEB} = \left(MaxPenetriation - MarketCapture_t^{Baseline} \right) \times ExtraMarketCapture_t^{LEB} + MarketCapture_t^{Baseline}$$

The baseline annual Green and Traditional market size and total remaining Green and Traditional build for year ‘t’ in billion m^2 is then

$$GreenMarketSize_t^{LEB} = MarketCapture_t^{LEB} \times MarketSize_t$$

$$TotalGreenBuildings_t^{LEB} = \sum_{T=0}^{T=t} \left[\left(GreenMarketSize_T^{LEB} \right) AND \left(t - T \le Lifetime_t \right) \right]$$

$$TraditionalMarketSize_t^{LEB} = \left(1 - MarketCapture_t^{LEB} \right) \times MarketSize_t$$

$$TotalTraditionalBuildings_t^{LEB} = \sum_{T=0}^{T=t} \left[\left(TraditionalMarketSize_T^{LEB} \right) AND \left(t - T \le Lifetime_t \right) \right]$$

The energy requirements of all new build can then be calculated simply as

$$EnergyNewBuild_t^{LEB} = TraditionalMarketSize_t^{LEB} \times Energy_t^{Traditional} + GreenMarketSize_t^{LEB} \times Energy_t^{Green}$$

Similar to the Baseline case, we can now calculate the total energy required for all post 2006 buildings that have not passed the lifetime of the energy efficiency benefits.

$$TotalEnergy_t^{LEB} = \sum_{T=0}^{T=t} \left[\left(EnergyNewBuild_T^{LEB} \right) AND \left(t - T \le Lifetime_T \right) \right]$$

Market penetration and energy use for the US

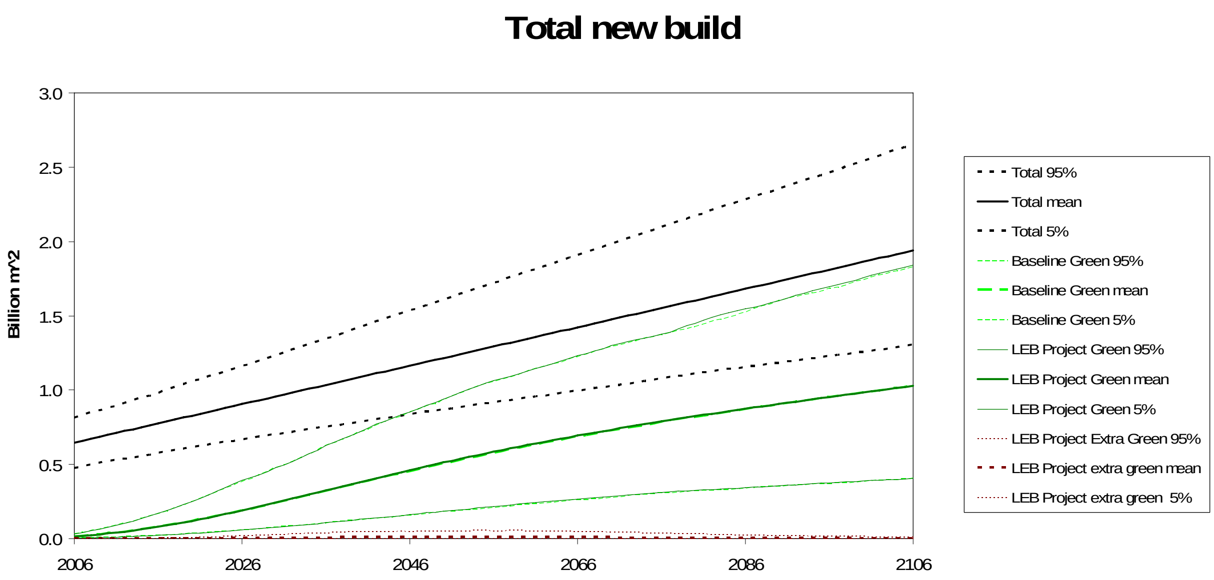


Figure 4 New build by date with and without the LEB project

Figure 4 shows that the expected difference in penetration of green buildings (the maroon dashed lines at the bottom of the graph) is likely to remain relatively small. This is due mainly to two factors. First that the probability of successful development of the LEB design tool is assumed to be much less than 100% and secondly that the LEB design tool will only be one of a variety of tools already in use or to be developed that have of aim to increase energy efficiency of buildings[2], which is reflected in the S-Curve parameter choice. Nevertheless, the LEB design tool is unique, especially in that it focuses on ease of use that would make it useful for early design stages and will also make it accessible to a greater number of people outside the dedicated world of green buildings.

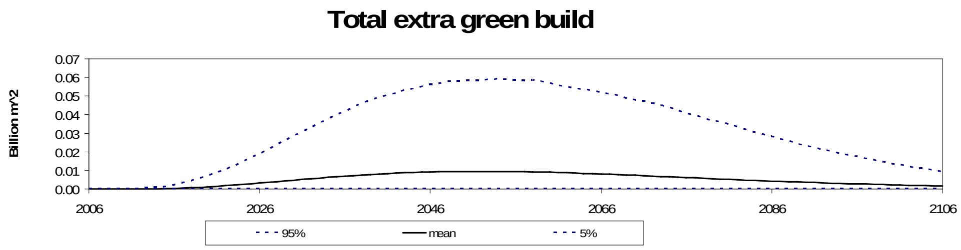


Figure 5 Total extra green build by date with the LEB project

A magnified representation of the total extra green build due to the LEB project is shown in Figure 5.

[2] Information on a number of similar projects and design tools can be found on the Greening the Building Life Cycle website, http://buildlca.rmit.edu.au/links.html .

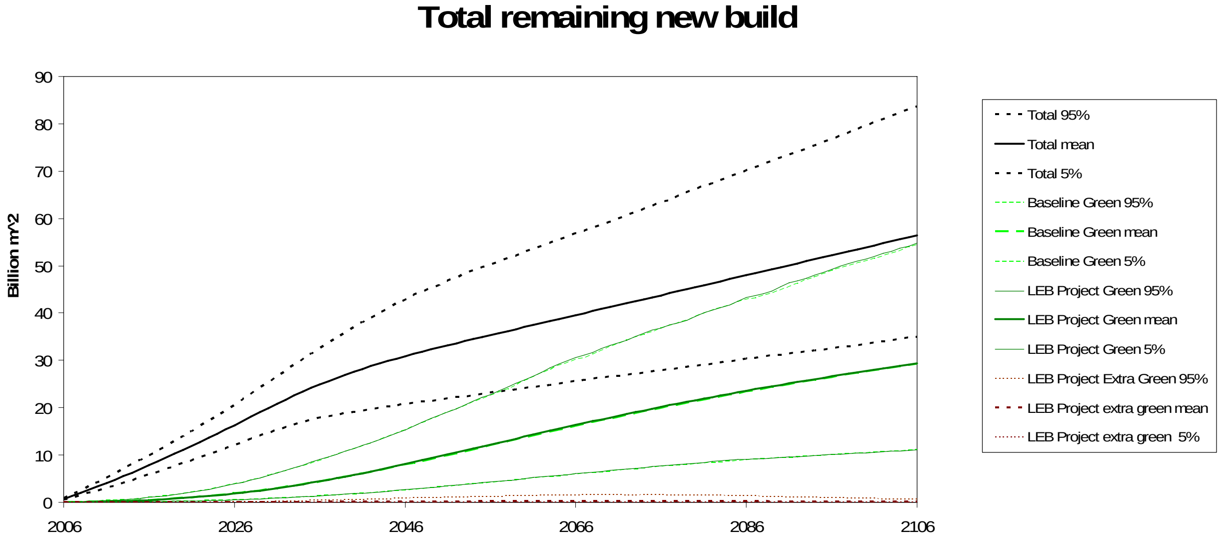


Figure 6 Total remaining new build by date with and without the LEB project

Figure 6 presents similar information to figure 4, however here we are not looking at annual new build, but instead the total remaining new build. For example green building built in the year 2026 will continue to have energy efficient benefits for many years to come right until the end of the life of the energy efficiency benefits. The kink in the total remaining new build is a result of our consideration of buildings only built post 2006. In the first part of the graphic, new buildings are being built but no "new" buildings have yet reached the end of their lifetime of energy efficiency benefits. In the second part of the graphic after the kink, the slope decreases since new buildings are being built while others are leaving the stock of the energy efficiency benefits of post 2006 build. This is because we consider the lifetime of the energy efficiency benefits, for example, from the installation of double glazed windows over their lifetime. However this does not make their contribution negligible. Far from it, quite simply the market size is so large and fragmented and the problem of energy efficiency is so large that even a small increase in efficiency can return important economic and social dividends.

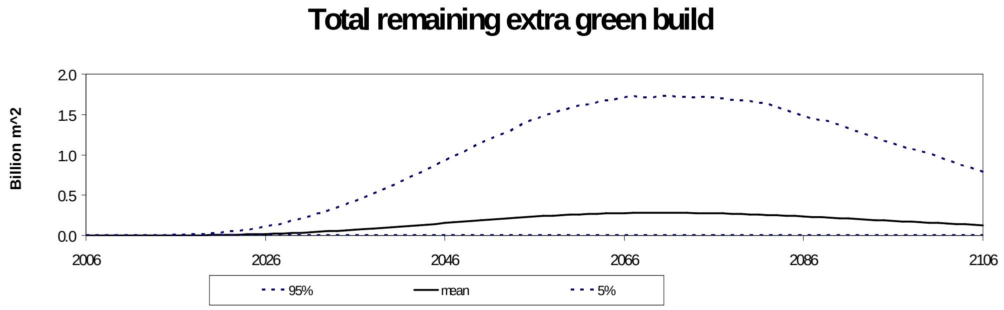


Figure 7 Total remaining extra green build by date with the LEB project

Figure 7 specifically looks at the extra green build associated with the development of the LEB design tool and is a magnified version of the LEB project extra green build of the diagram above.

Costs and Benefits

Baseline

Below we have the total costs calculation which is equal to the financial and non-financial energy costs multiplied by the total energy consumed in that year minus the productivity benefits calculated per unit of surface area of green build multiplied by the total green build for that year.

$$TotalCosts_t^{Baseline} = \left(CostEnergy_t^{Financial} + CostEnergy_t^{External}\right) \times TotalEnergy_t^{Baseline} + \left(Added\cos ts_t - productivityBenefits_t\right) \times TotalGreenBuildings_t^{Baseline}$$

LEB

$$TotalCosts_t^{LEB} = \left(CostEnergy_t^{Financial} + CostEnergy_t^{External}\right) \times TotalEnergy_t^{LEB} + DevelopmentCosts_t + \left(Added\cos ts_t - productivityBenefits_t\right) \times TotalGreenBuildings_t^{LEB}$$

The calculation for the LEB project is almost identical except that development costs must now also be included.

Social NPV Calculations

The Social Net Present Value of bringing the LEB design tool project to market can now simply be calculated as the difference between the costs with and without the LEB project discounted to the base year.

$$NPV(social) = \sum_{T=0}^{T=t_{MAX}} \left[TotalCosts_T^{Baseline} - TotalCosts_T^{LEB} \right] \times (1+d)^{-T}$$

Profit NPV Calculation

The Net Present Value for an institution, private or public, is modelled as a function of initial marketing and development costs plus the expected profit in the case of a successful market development. The profit factor is calculated as a product of the LEB market share (in billion m^2) and the expected profits per new green build. Profits are seen as the fee or software licence charged times a multiplier representing expected costs. We do not assume that the total social benefits are shared between the users of the design tool and the developers of the tool, but instead that the price charged is based on willingness to pay. This is in part because building developers and energy users (i.e. all of us) have shown that we do not make energy saving decisions easily even where we can expect a payback time on investment of less than a few years let alone for the more intangible benefits of reduced externalities or in the hope of improved productivity (HM Treasury, 2005). Instead we view the LEB design tool as an important support for building professionals and even individuals who would be prepared to pay for access to the support. This is similar to many tools for business such as the @risk software used to run our LEB model simulations: although it may offer considerable benefits to this and many other projects it must nevertheless be sold at a reasonable and competitive market price. This depends in part on willingness to pay and in the area of energy efficiency this should not be deemed to be too high.

On top of the extra new green build that the LEB project generates, we also add an element whereby the LEB project could profit from the baseline green build market share. In doing so we assume that the LEB design tool would take some of the market away from other similar, though often more complicated and more expensive alternatives. On the other hand we assume that a successful market development of the LEB design tool will encourage other software developers to build something with similar functionalities. For this we model a time after development from when “competitors” will take a share of the LEB design tool market. Finally we assume that at some point the project ceases to exist. Note however that this has only been used for the profit calculation, since it refers to the direct return on investment to the developers, whereas the remainder of the model considers total social benefits irrespective of the final developers.

$$LEBMarketSize_t = ExtraGreenBuild_t \times (1 - CompetitionLoss_t) + GreenBuild_t^{Baseline} \times BaselineCapture_t$$

$$Profits_t = LEBMarketSize_t \times ValueExtractedLEB_t - DevelopmentCosts_t$$

$$NPV(profit) = \sum_{T=0}^{T=t_{MAX}} profits_T \times (1+d)^{-T}$$

World Multiplier

The world total is calculated by extrapolating total world GDP from the US and China. We use this as a factor to multiply the model results from these regions in order to get an approximation for the world total.

$$m = \frac{GWP}{GNP_{USA} + GNP_{China}}$$

$$NPV_{World} = m \times (NPV_{USA} + NPV_{China})$$

In order to make this approximation based on only two regions as representative of the world's economy as possible, we use what we deemed the most important two economies from both the Annexe-1 (developed world) and non Annexe-1 (developing and emerging countries) regions. We also use a relatively wide distribution that coincides with our limited knowledge of what the true value of the parameter should be.

Data sources

Since energy efficiency in buildings is a relatively young field in the academic literature, it remains difficult to get data that is well suited to the model. To resolve this problem we use expert opinion, estimation and historical data with error margins that reflect the limitations of our knowledge and the stochasticity of the coefficient in question (for example when referring to projected growth rates). Having designed the model with uncertainty built in, we are also able to use sensitivity analysis to determine which of the parameters are most important and spend extra effort in those areas. Where possible official data is used such as construction data published by the US and Chinese governments. We also use the results from published reports, though limited in number and scope, when considering the cost and benefit estimations of low energy buildings as well as the penetration rate of low energy buildings or technologies such as the LEB design tool. There is also some data available on the ExternE website looking at the monetarised externality costs of energy both from carbon and non-carbon sources.

The best sources of information regarding the costs and benefits of low-energy buildings comes from the BRE Trust, the US General Services Administration (GSA) and Gregory Kats. BRE is an English based charitable company supporting research and education in all areas concerning the built environment. The three reports we use from BRE are *Domestic energy use and carbon emissions: scenarios to 2050* (2005), *Costing sustainability: How much does it cost to achieve BREEAM and EcoHomes ratings?* (2005) and *Putting a price on sustainability* (2005). Data from this source requires some modification to reflect the limited scope of our model whereby we include only energy efficiency aspects of green buildings and not the other non-energy related costs and benefits. The *GSA LEED Cost Study's final report* (2004) offers a similar analysis to the BRE reports for US based construction. But perhaps the most authoritative work found in the area of costs and benefits of green building can be attributed to Gregory H. Kats who summarises much of the available research in his publication *Green building costs and financial benefits* (2003).

For general energy and construction data, we use the US Energy Information Administration (EIA) forward projections to 2030 (http://www.eia.doe.gov/oiaf/aeo/index.html). From this data we are also able to get some detailed information on commercial construction annually as well as other derived coefficients such as energy intensity and carbon intensity. All data are converted into m^2 from square feet and into EJ from the various other energy units. Similarly for China we used the 2004 China Statistical Yearbook (http://www.stats.gov.cn/english/statisticaldata/yearlydata/yb2004-e/indexeh.htm) which provides some of the key data required for the model. As well as these sources we also use some approximations and best judgements including those of the authors as well as the LEB design tool program leader Prof. Glicksman.

The results of our data gathering can be found in Annexe 1, and includes the details and sources of the data for each coefficient. With respect to units, we use EJ for energy units, Billion USD(2006) for currency, Billion tonnes of CO2 for carbon and Billion m^2 of surface area for building data. For the cases where billions are divided by billions we use the simpler notation, e.g. US$(2006)/m^2. Concerning China, where there is some difficulty in finding data for certain parameters we use by default a distribution relative to the US of 0.5 to 1.5 with a mode and mean of 1.

Results

The model results are presented in two parts, first the results for the US where we have the higher quality of data inputs followed by some of the results from the World model that are found using data from the US and China with a multiplier to incorporate the rest of world.

US

To gain an overview of the model's results Table 4 shows discounted costs, benefits and at the bottom the expected profit calculation, and measures of energy and CO2 saved. Total mean social net benefits come to 9.4 Billion USD for an initial development cost of 23 Million USD. In other words, for every dollar spent developing the LEB design tool we expect a net social benefit of a little over 470 USD discounted to 2006.

Table 4 Costs and benefits of the LEB project in the US.

Discounted Totals Summary for US only

		5%	Mean	95%
Total development costs of LEB	Billion US$(2006)	-0.03	**-0.02**	-0.01
Pure energy cost savings from LEB project	Billion US$(2006)	0.00	**3.68**	20.93
Internalised externality savings from LEB project	Billion US$(2006)	0.00	**0.18**	0.98
Extra green building costs	Billion US$(2006)	-22.38	**-3.88**	0.00
Total financial benefits of LEB	**Billion US$(2006)**	-4.16	**-0.05**	3.66
Total prevented non-taxed externalities	Billion US$(2006)	0.00	**2.59**	14.36
Total productivity gains	Billion US$(2006)	0.00	**6.85**	40.04
Total non-financial benefits	Billion US$(2006)	0.00	**9.44**	56.30
Total social net benefits	**Billion US$(2006)**	**-0.03**	**9.39**	**54.80**
Total expected profits	**Billion US$(2006)**	**-0.03**	**-0.01**	**0.06**
Total Energy Saved	Exa Joules	0.00	**4.73**	27.69
Total CO2 Saved	Billion Tonnes CO2	0.00	**0.28**	1.61

These benefits come in part from the non-taxed externalities saved but the majority of the benefits come from the productivity improvements associated with green buildings and in particular those brought about by natural and controllable lighting and improved ventilation. In terms of purely financial costs and benefits, the results suggest that the energy cost savings are roughly cancelled out by the extra green building costs, however they are also sensitive to a number of other factors such as the discount rate and the parameter ranges for costs, benefits and energy reductions.

As can be seen when referring to the earlier graphs from Figure 3 to Figure 7, the continuation of the LEB project leads to an expected 0.3 Billion m^2 of extra green buildings floor space by the year 2070 with a 5% likelihood of the value being above 1.5 Billion m^2.

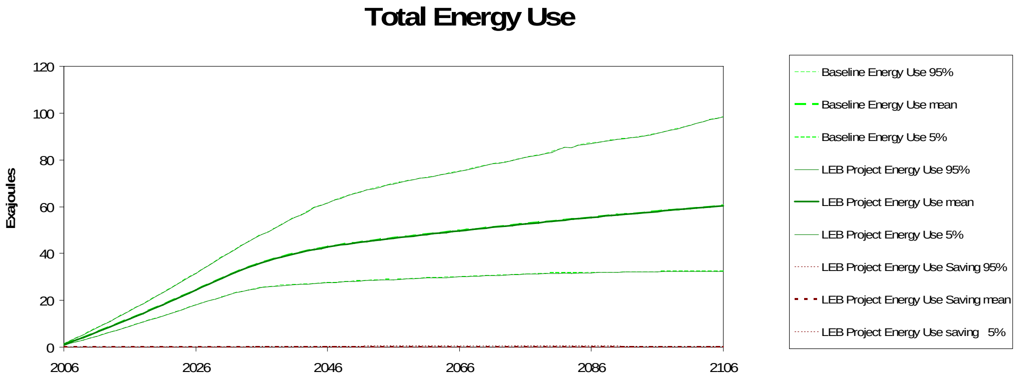


Figure 8 Energy use by date with and without the LEB project

In Figure 8 we see the energy use of post 2006 buildings with and without the LEB project. The difference between the two SOW's can be seen at the bottom of the diagram. The energy savings brought about by the increased penetration of green buildings with the LEB design tool may seem small compared to the overall energy requirements of the buildings represented here. However when considering the energy savings on its own as in Figure 9, the value is shown once again to be quite important.

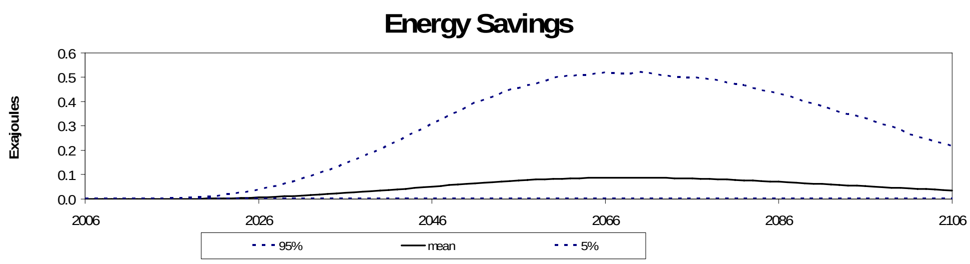


Figure 9 Energy savings by date with the LEB project

The total energy savings follow the similar path as the remaining extra green build, reaching a peak by about 2070 with a mean value of 0.1 exajoules, or 27 Billion kilowatt hours per year. At an average cost of, for example, 3c/kwh of primary energy, by 2060 this would represent an expected annual energy saving of close to a billion USD.

Costs and Benefits of the LEB Design Tool over time

Reducing the amount of energy required by buildings can bring with it important energy savings. The financial benefit that comes with reduced energy consumption is modelled here as two distinct benefits; the reduction in the pure energy cost as well as the internalised externality costs of energy represented by any form of environmental tax to account for energy externalities.

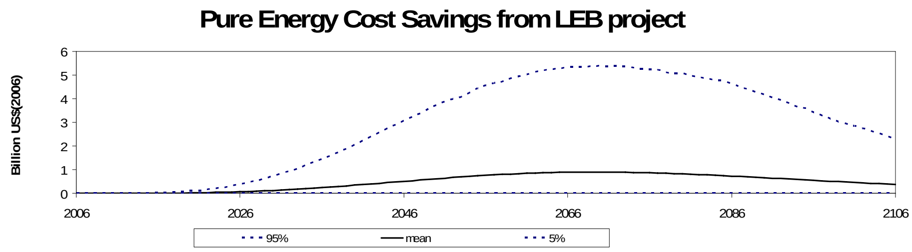


Figure 10 Pure energy cost savings by date with the LEB project.

Figure 10 presents the distribution of pure energy cost savings as a function of time while Figure 11 presents the internalised externality cost savings. As a result of our assumption that energy policies will include increasing levels of externality taxes, we find that the internalised externality cost savings peak at a later date than do the pure energy cost savings. The internalised externality cost savings remain far less important than the pure energy cost savings.

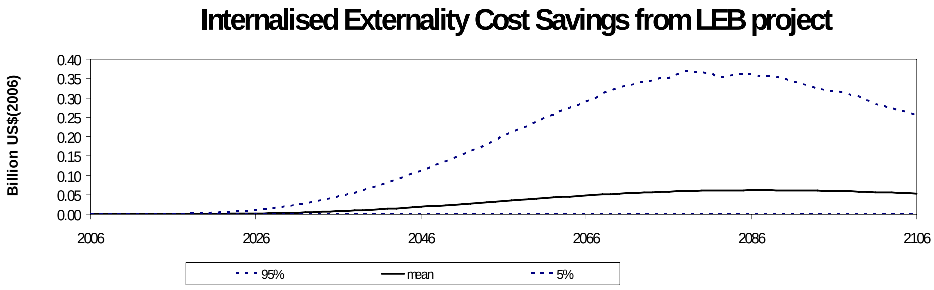


Figure 11 Internalised externalities cost savings by date with the LEB project.

We must also include the costs associated with developing and marketing the LEB design tool and the increased construction costs of building green buildings. Although the added development cost seems small compared to the extra green building costs, it remains relevant because it represents a near term cost and as such its value is hardly reduced by discounting. Furthermore, the development costs represent a risky investment as the success of the project in both the short and long term remains unsure, particularly if the project is to be funded with private finances.

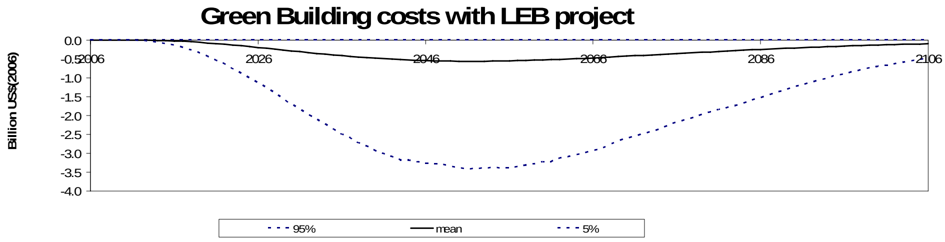


Figure 12 Added costs of building extra "green" buildings by date with the LEB project.

Adding these together we see in Figure 13 the progression of financial costs and benefits as a function of time. We can quite clearly see the smaller initial investments that are traded off for much larger future benefits; however when taking discounting into account, these two amounts roughly cancel each other out as was shown in Table 4.

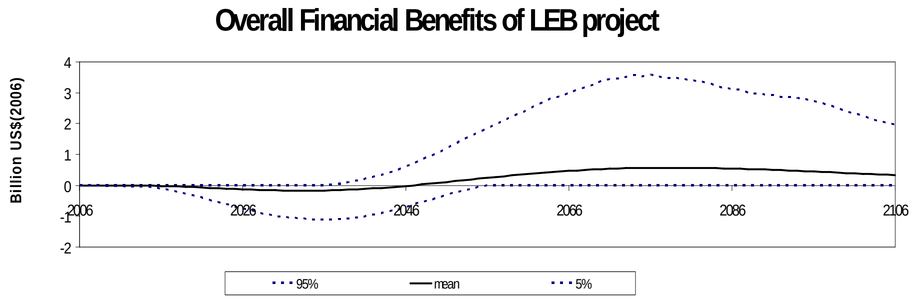


Figure 13 Overall financial benefits of the LEB project by date

Non-financial costs and benefits

Over and above these financial costs and benefits we have the non-financial costs and benefits that have an important effect on society and therefore need to be included in the social NPV calculation. These include the reduction in the externalities of energy production that energy efficient green buildings help to avoid (Figure 14) and the productivity improvements associated with green buildings (Figure 15).

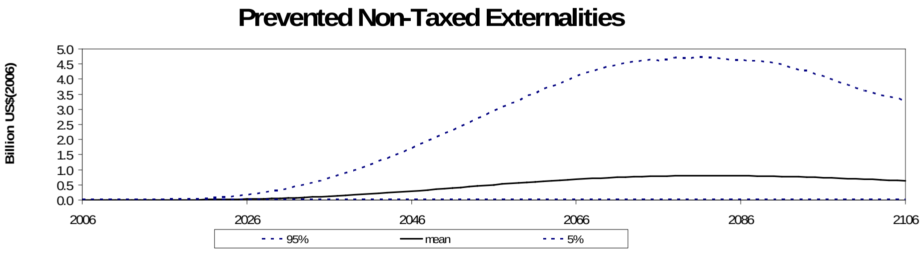


Figure 14 The prevented non-taxed externalities by date with the LEB project.

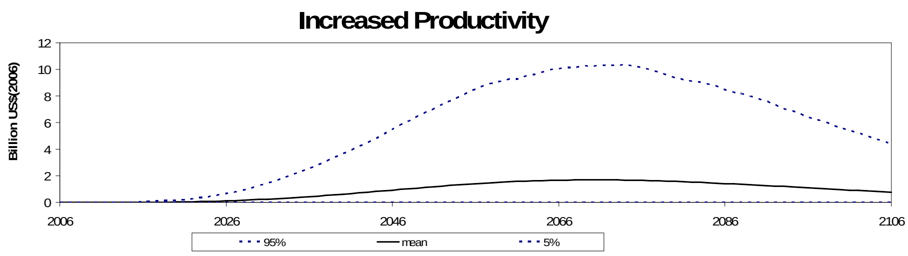


Figure 15 Increased productivity by date with the LEB project.

Now considering the financial and non-financial costs and benefits together in Figure 16, we see a similar picture to the financial costs and benefits, where we start out with negative costs and benefits that turn into positive costs and benefits in most cases as time progresses. The main difference here is that the long-term benefits now far outweigh the short-term costs

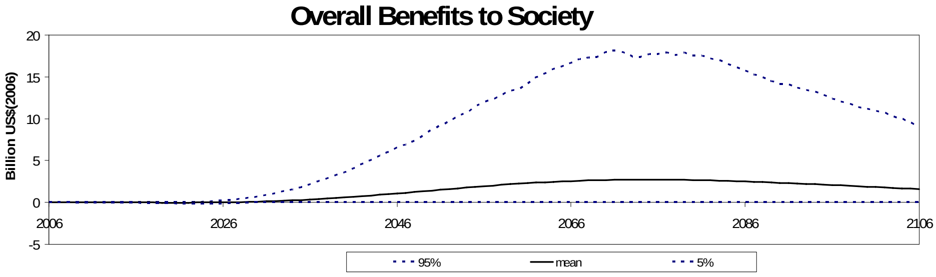


Figure 16 Non-discounted social net benefits to society as a function of time

Total Expected Profits

Using a very simple model to calculate the possible profit expectations of a private enterprise developing the LEB project, we also calculate expected cash flows. These start with an initial investment and then, if the development is successful, future cash inflows that can be used to recoup the initial investment. As described in the previous section, the profits depend not only on the actions of the LEB developers but also of the competition which has been represented in the model only very simply and thus is aimed to serve as a first approximation only. Although there is scope for future benefits to be made, these are shown to remain relatively small and spread out over time as compared to the initial development costs required. This leads to an expected negative profit calculation as shown in Table 4. Naturally, the profit calculations are sensitive to the probability of the project being a success, the size of the market it is able to capture, the amount that it is able to charge for access to the LEB design tool and the demand sensitivity to price. Further effort should be focused on increasing our understanding in these areas.

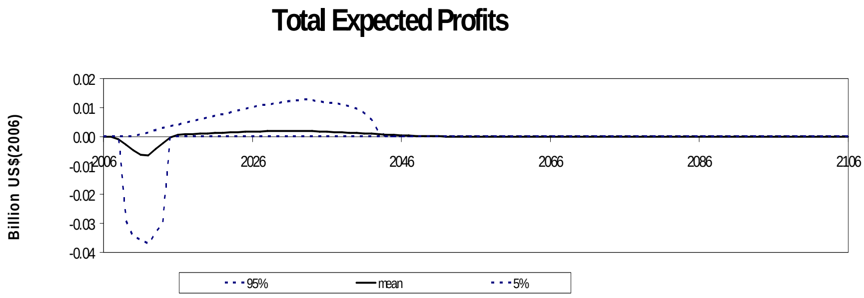


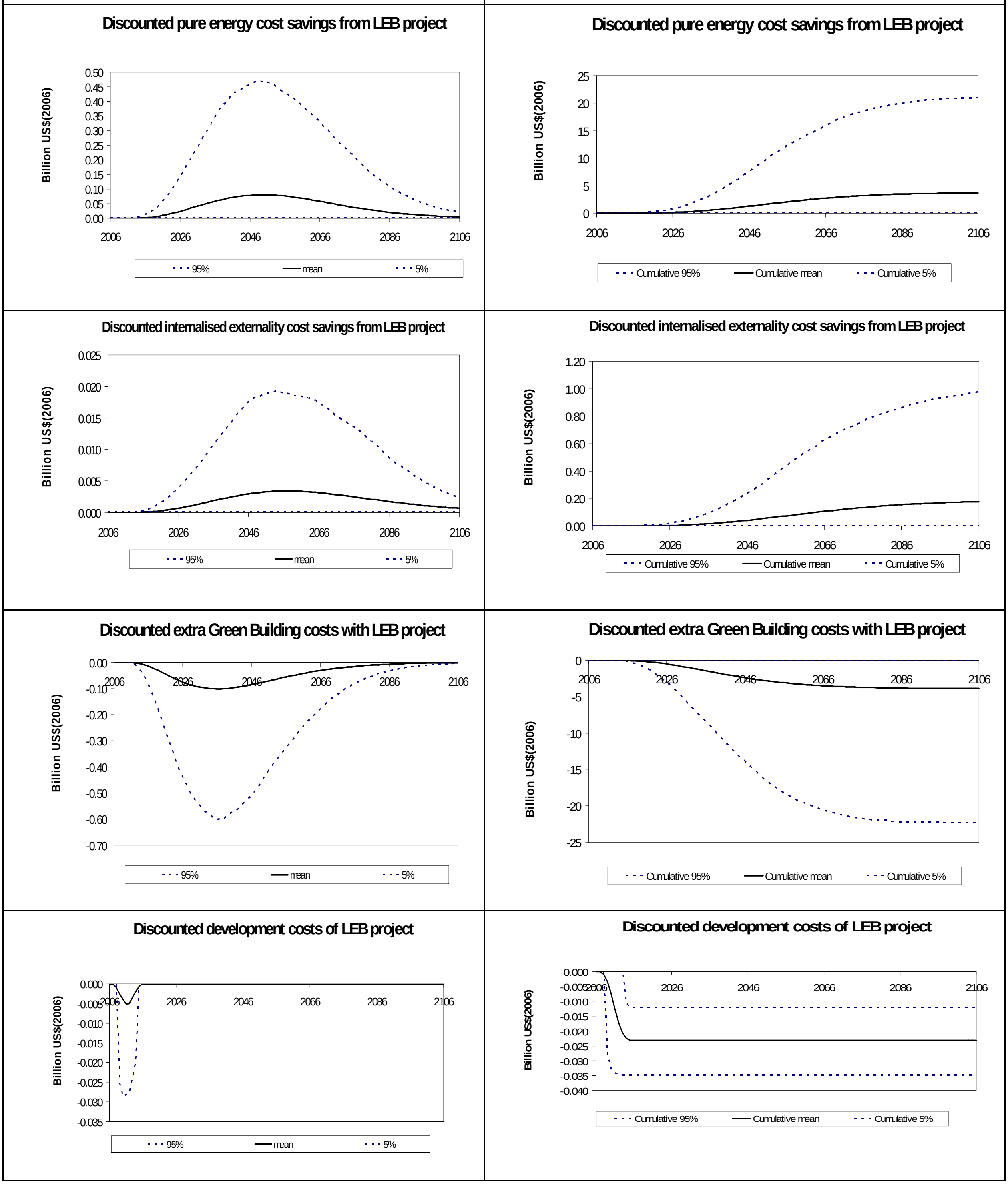
Figure 17 Total profits from the LEB project by date.

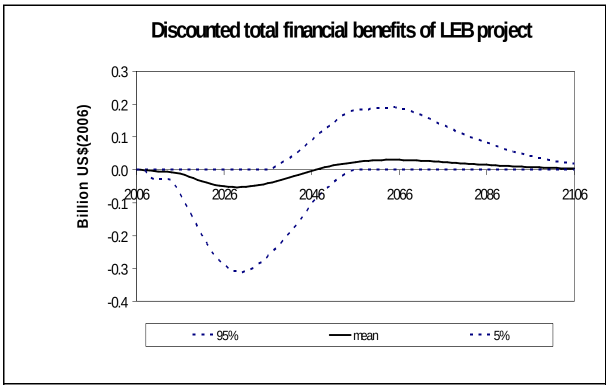
Discounted and Cumulative Results

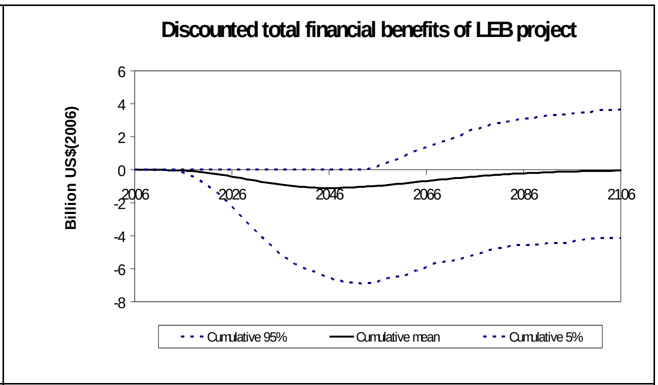
As well as calculating the costs and benefits as a function of time, we are interested in determining how they measure up when discounted to the present. In the following diagrams we show on the left hand side the discounted values as a function of time and on the right hand side cumulative discounted values also as a function of time. The graphics representing discounted and cumulative discounted total financial benefits are particularly interesting. If we first look at the non-discounted figure above for financial benefits, we see a reasonably small initial cost arising from the increased costs of building green offset by a much larger benefit in reduced energy needs in the future. However after discounting, as shown below, these later benefits are greatly reduced giving a final cumulative net financial benefit which is close to zero.

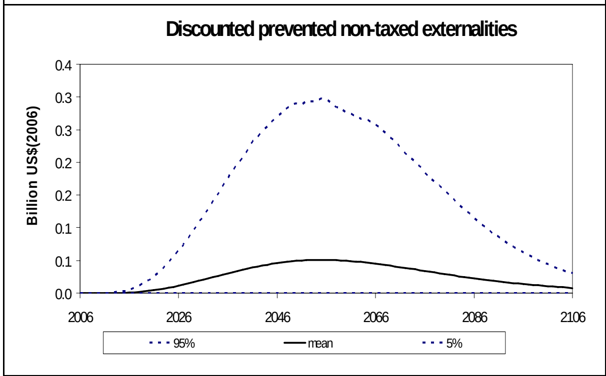
Figure 18 Discounted and cumulative discounted values for all of the cost and benefit factors of the LEB project as well as of the simple profit calculation.

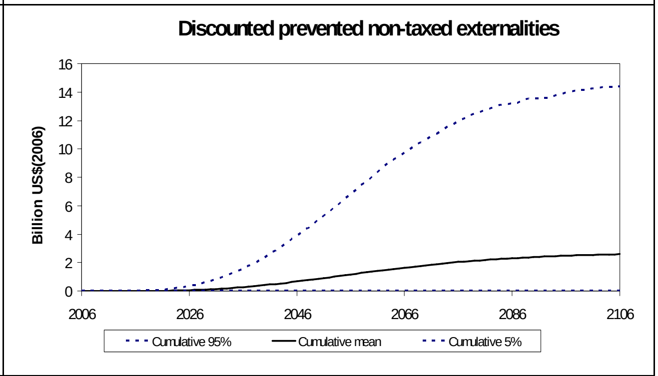
Discounted Values	**Cumulative Discounted values**

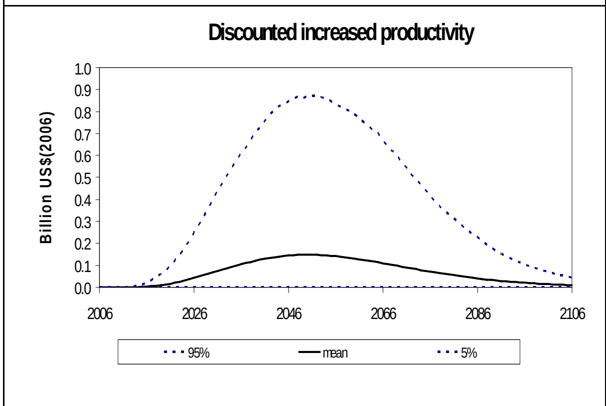


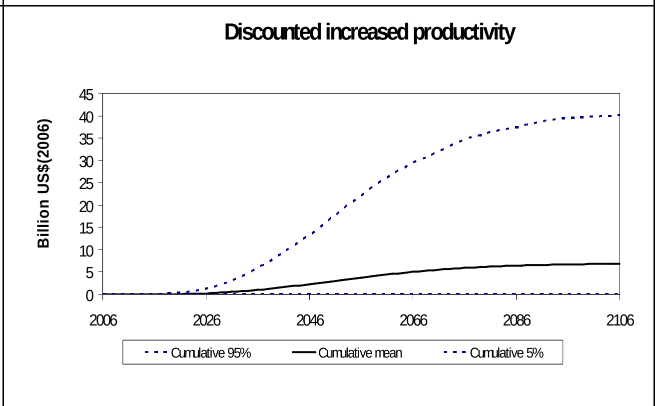

Discounted total financial benefits of LEB project
Billion US$(2006)
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
2006
2026
2046
2066
2086
2106
95%
mean
5%

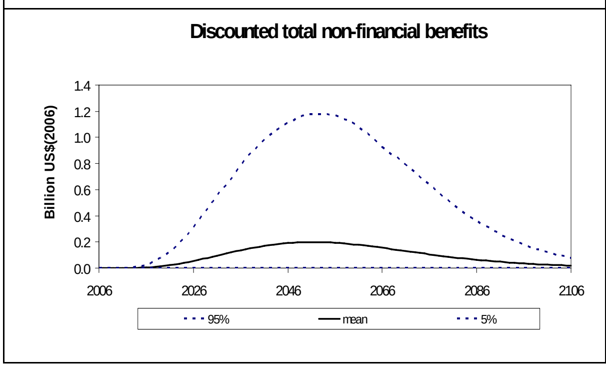

Discounted total financial benefits of LEB project
Billion US$(2006)
6
4
2
0
-2
-4
-6
-8
2006
2026
2046
2066
2086
2106
Cumulative 95%
Cumulative mean
Cumulative 5%

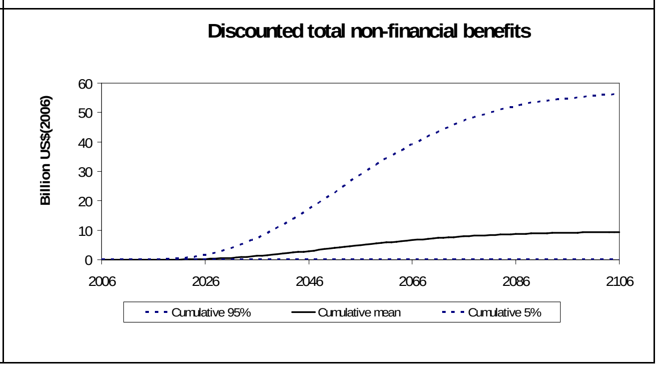

Discounted prevented non-taxed externalities
Billion US$(2006)
0.4
0.3
0.3
0.2
0.2
0.1
0.1
0.0
2006
2026
2046
2066
2086
2106
95%
mean
5%

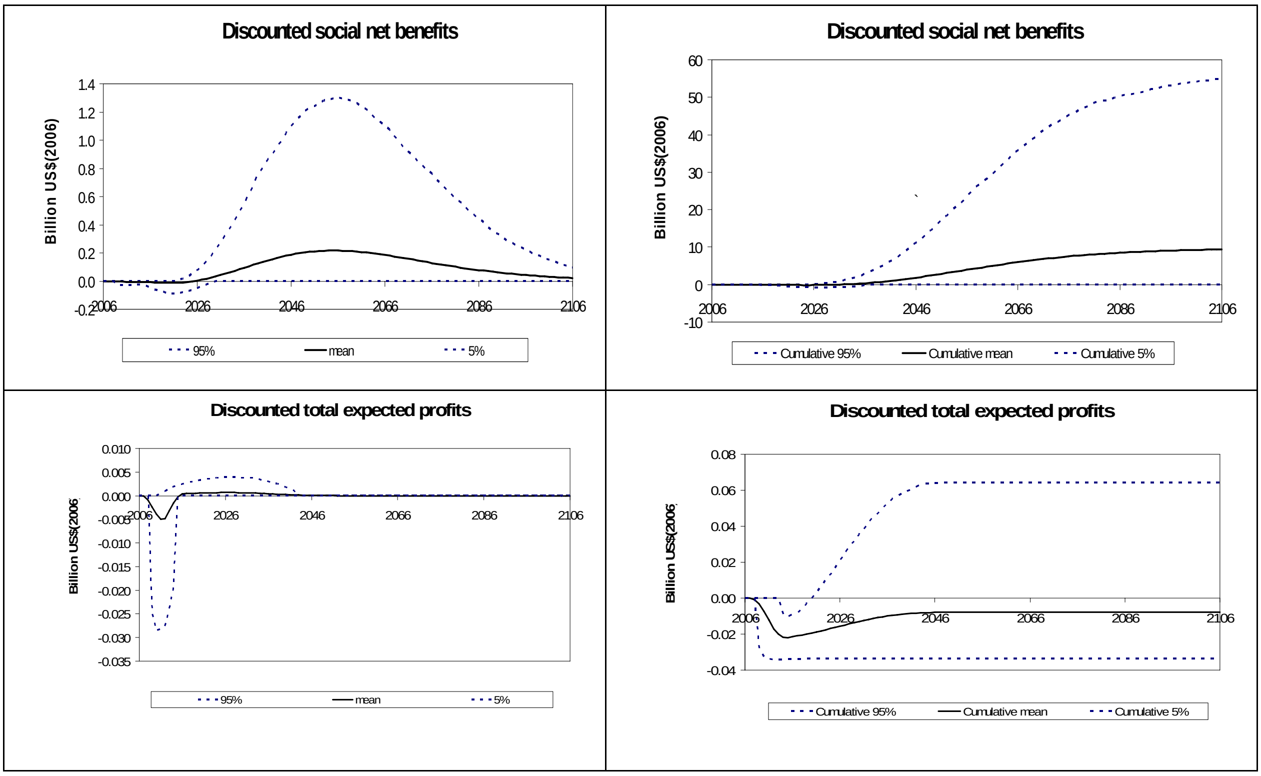

Discounted prevented non-taxed externalities
Billion US$(2006)
16
14
12
10
8
6
4
2
0
2006
2026
2046
2066
2086
2106
Cumulative 95%
Cumulative mean
Cumulative 5%


Discounted increased productivity
Billion US$(2006)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2006
2026
2046
2066
2086
2106
95%
mean
5%


Discounted increased productivity
Billion US$(2006)
45
40
35
30
25
20
15
10
5
0
2006
2026
2046
2066
2086
2106
Cumulative 95%
Cumulative mean
Cumulative 5%


Discounted total non-financial benefits
Billion US$(2006)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2006
2026
2046
2066
2086
2106
95%
mean
5%


Discounted total non-financial benefits
Billion US$(2006)
60
50
40
30
20
10
0
2006
2026
2046
2066
2086
2106
Cumulative 95%
Cumulative mean
Cumulative 5%



The above diagrams represent the distributions for the most important outputs, and clearly indicate the 5% and 95% bounds. However, for the sake of easy comparison, the mean values of the outputs are gathered together on a single graphic below. Figure 19 and Figure 20 present the discounted and cumulative discounted mean expected values of all of the financial and non-financial factors together. One interesting observation is that nearly all the costs and damages shown fall to zero over the coming 100 years, justifying the time period chosen for the model.

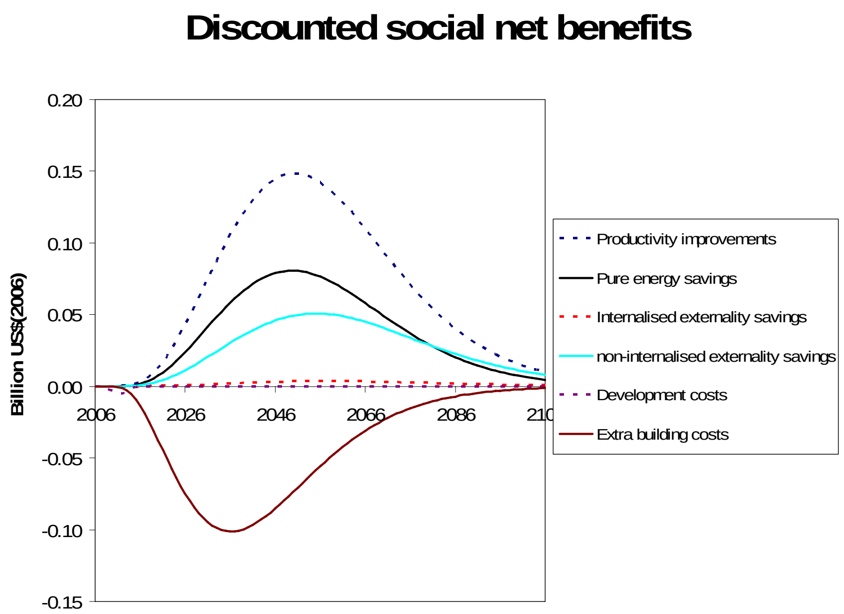


Figure 19 Mean discounted social costs and benefits of a continued LEB project by date and category.

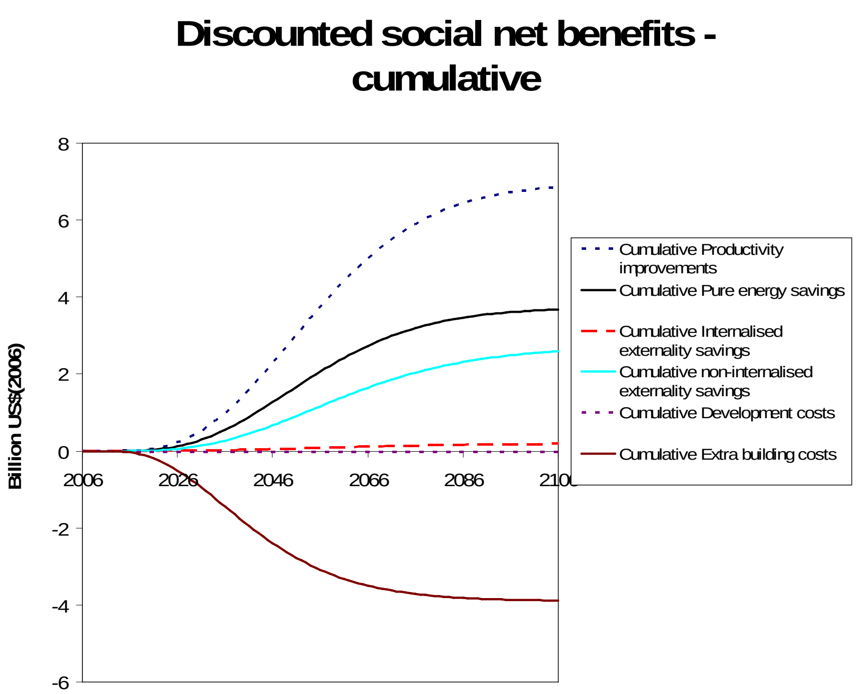


Figure 20 Mean cumulative discounted social costs and benefits of a continued LEB project by date and category.

The discounted and cumulative discounted diagrams show the relative importance of each of the factors in the NPV calculation. The slow take up of green buildings brought on by the S-Curve penetration and the sluggish manner that benefits respond to the increased building costs possibly helps to explain why the building industry and consumers in general have tended not to incorporate the benefits of energy efficiency into buildings when it may be reasonably cheap or even financially viable to do so. The initial investment to develop the project seems minimally important here too compared to the much larger costs and benefits at play, with net financial benefits being the relatively small difference between the much larger values of the extra building costs and energy saving benefits.

Sensitivity analysis

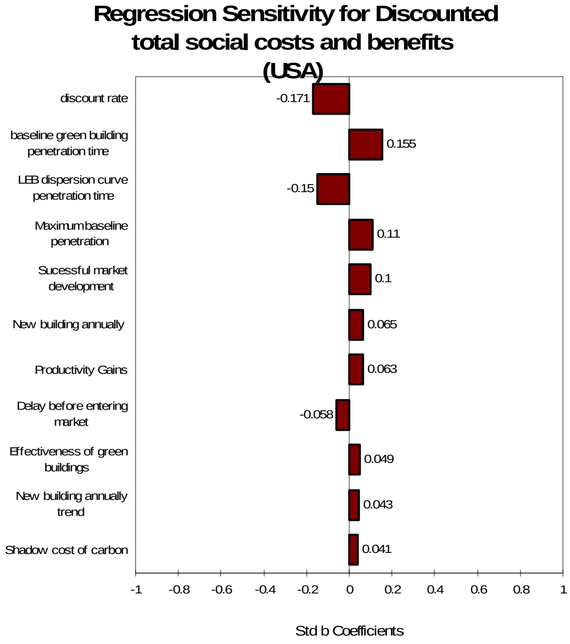


Figure 21 Major influences on the discounted total social costs and benefits

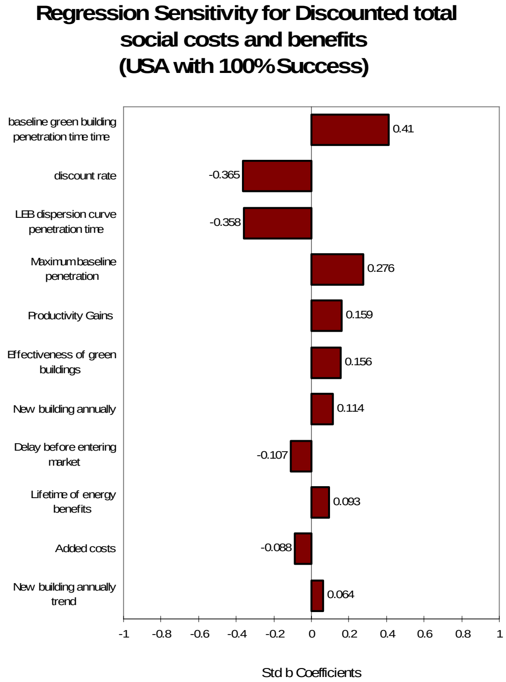


Figure 22 Major influences on the discounted total social costs and benefits, with a success rate of 100%.

The first sensitivity graphic,

Figure 21, shows the sensitivity of the total discounted social costs and benefits of a continued LEB project to the input values. As one would expect in a situation with upfront costs and delayed benefits, the discount rate is a very important factor with a negative coefficient such that high levels of discounting reduce the net social benefits. Next it is shown that a larger dispersion curve penetration time of baseline green buildings increases the benefits of the LEB project, while a larger dispersion curve penetration time of the LEB project serves to limit the overall benefits of the project shown by the negative sensitivity result. This arises as a result of modelling the LEB project's increased penetration as capturing the market difference between baseline penetration and maximum green building penetration. Here faster baseline penetration leaves less untapped market for the LEB project. However for these and the other parameters, the existence of a success/failure parameter waters down the results, hiding some of their influences. Therefore we have repeated the sensitivity analysis with a 100% successful market development to consider the importance of all other parameters as shown in Figure 22.

The sensitivity analysis with a 100% probability of success shows sensitivity results ordered in a similar manner, however, since the probability of success is 100% the sensitivity of all other coefficients is greatly increased. The main change being that the first two parameters have been switched so that the baseline dispersion time is shown to be more influential than the discount rate. We can see here that the sensitivity to the delay before entering market is small but negative, indicating the longer the project is delayed the smaller the expected return on investment. The lifetime of energy benefits, a data input that was difficult to quantify, has only a very small positive effect.

World

The world social NPV calculation is generated by taking the world's largest developed and developing countries, the US and China, and applying a suitable multiplier that extrapolates to expected world values. The results are qualitatively similar to the US, nevertheless there are a few important differences.

Table 4 Costs and benefits of the LEB project worldwide

Discounted Totals Summary World

		5%	Mean	95%
Total development costs of LEB	Billion US$(2006)	-0.06	**-0.03**	-0.01
Pure energy cost savings from LEB project	Billion US$(2006)	0.00	**100.07**	433.16
Internalised externality savings from LEB project	Billion US$(2006)	0.00	**3.61**	12.92
EXTRA green building costs	Billion US$(2006)	-140.54	**-28.64**	0.00
Total financial benefits of LEB	**Billion US$(2006)**	-3.64	**74.96**	317.86
Total prevented non-taxed externalities	Billion US$(2006)	0.00	**111.33**	418.75
Total Productivity Gains	Billion US$(2006)	0.00	**26.29**	143.93
Total non-financial benefits	Billion US$(2006)	0.00	**137.63**	551.44
Total social net benefits	**Billion US$(2006)**	**-0.11**	**212.59**	**874.84**
Total expected profits	**Billion US$(2006)**	**-0.11**	**-0.01**	**0.29**
Total Energy Saved	Exa Joules	0.00	**211.23**	1022.35
Total CO2 Saved	Billion Tonnes CO2	0.00	**18.24**	88.46

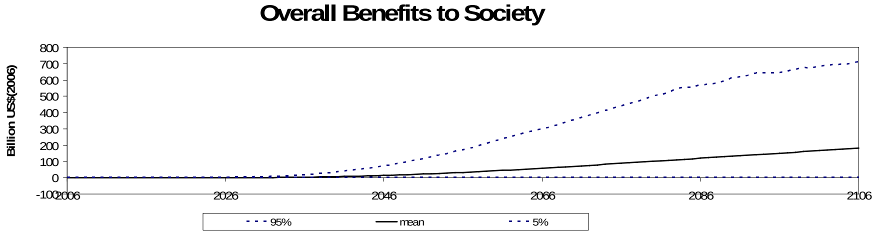


Figure 23 Non-discounted social net benefits to society as a function of time for the world.

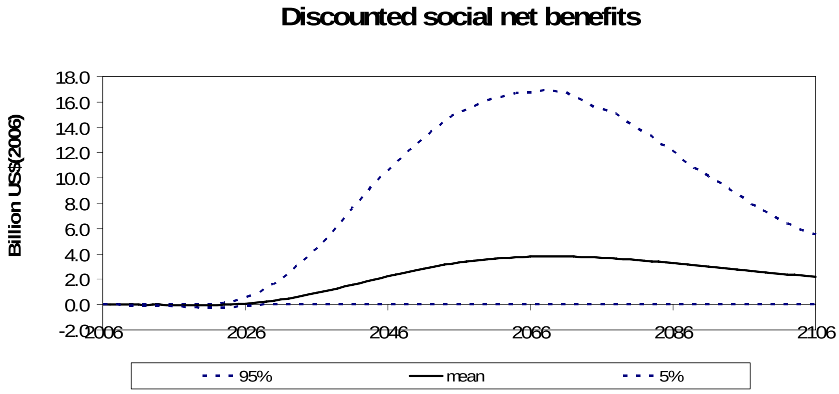


Figure 24 Discounted social net benefits to society as a function of time for the world.

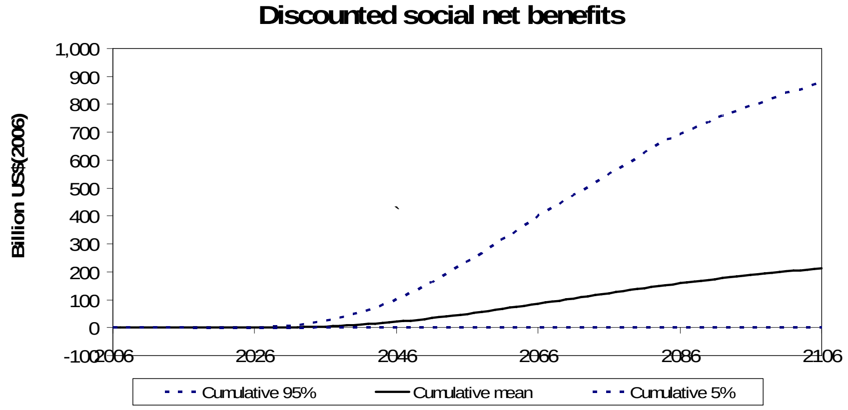


Figure 25 Cumulative social net benefits to society as a function of time for the world.

In the case of the world total, more of the benefits come in the form of non-internalised externalities of energy and less from the cumulative productivity improvements seen in the US. This fact alone explains some of the important qualitative differences between the US only and world total calculations and comes as a result of the assumptions made and coefficients chosen surrounding these aspects of costs and benefits. The delay before realising benefits is also increased in the case of the world analysis. Perhaps most striking is the difference in magnitudes when considering the fast growing emerging countries. Mean expected benefits of 200 billion are shown by the model to be likely, and 800 billion possible when considering world totals.

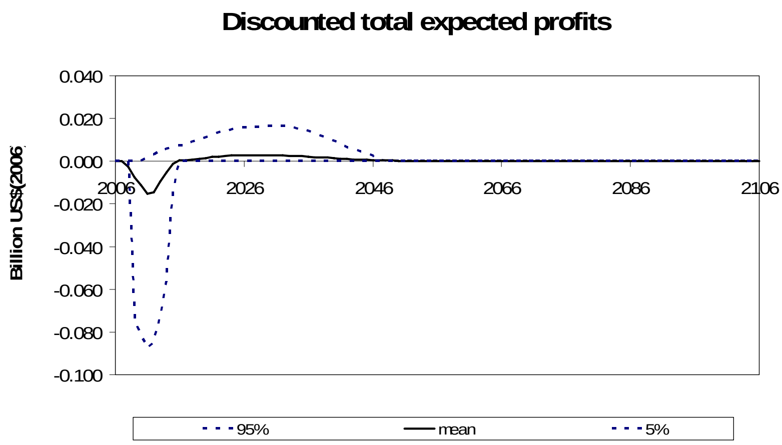


Figure 26 Discounted total discounted profits for the world by date.

Expected profits however remain negative as shown in Figure 27 even when using a low mean discount rate of 5% and this for the same reasons as suggested in the US analysis. Mainly that willingness to pay is not necessarily proportional to expected net social or even net financial benefits.

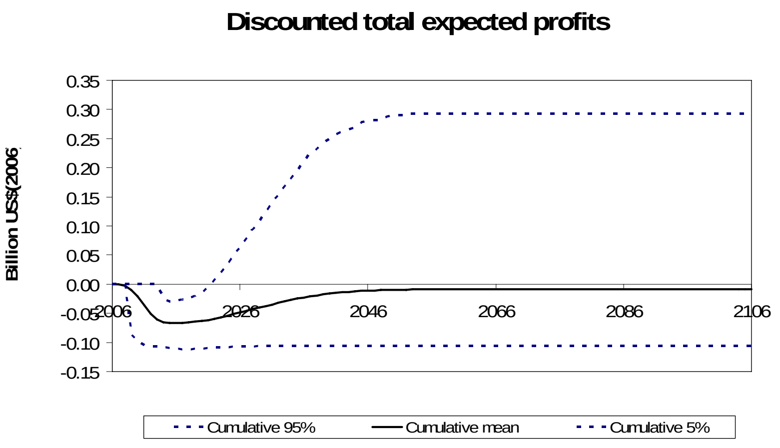


Figure 27 Cumulative discounted profits for the world by date.

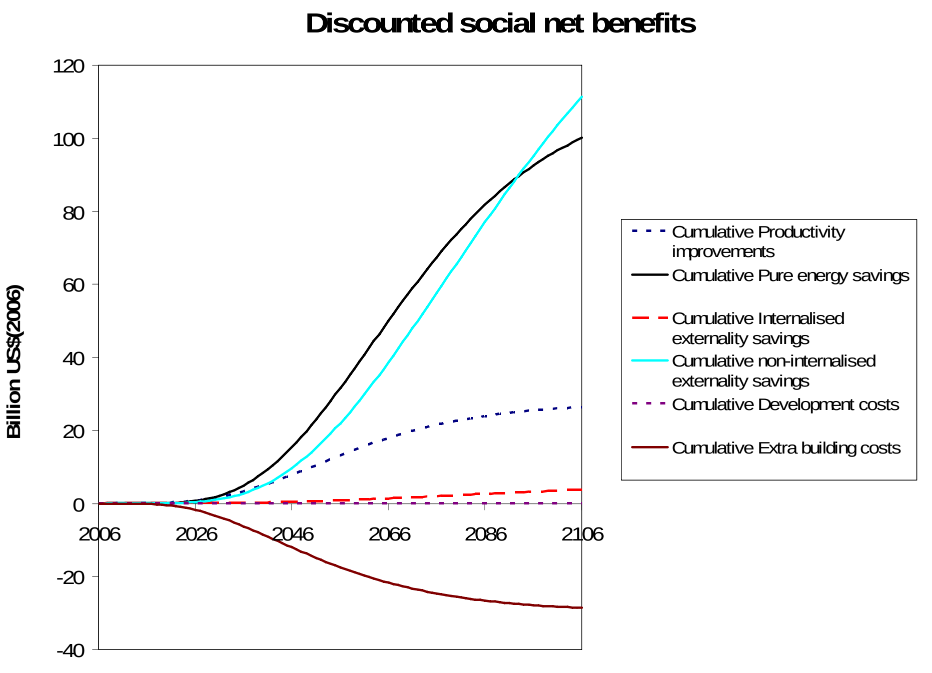


Figure 28 Mean cumulative discounted social costs and benefits of a continued LEB project by date and category for the world.

Figure 28 shows world cumulative discounted social costs and benefits that highlights the relative importance of each of the factors in the NPV calculation. We find a delay of 20 to 40 years until large scale changes take place, and while the cumulative extra building costs tends to slow down in about 60 years, the benefits for the world total continue to grow all the way through to the end of the 100 year time span. In contrast to Figure 20 that shows cumulative discounted social costs and benefits for the US, the world total shows a much larger potential for financial benefits from pure energy savings as well as non-financial benefits from non-internalised externality savings. Productivity improvements are comparatively less important for the world analysis, mainly because of the lower salaries in regions like China, however this is dependent on the parameter choices made.

For the sensitivity analysis we find the below results firstly with the possibility of failure after development and then with a 100% chance of success.

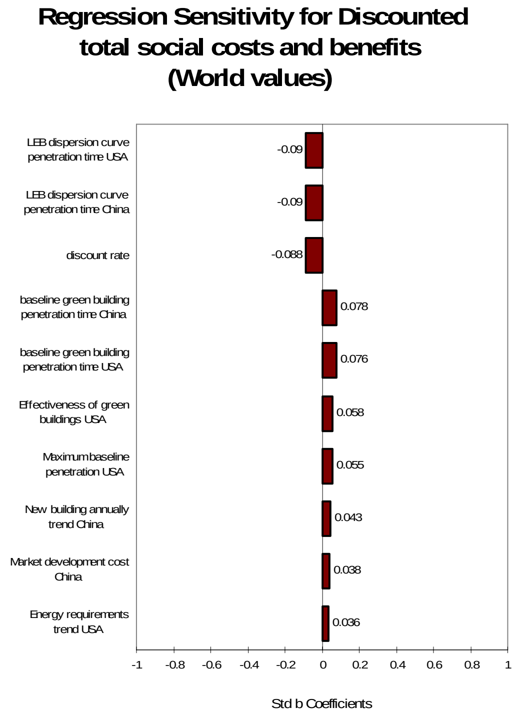


Figure 29 Major influences on the discounted total social costs and benefits

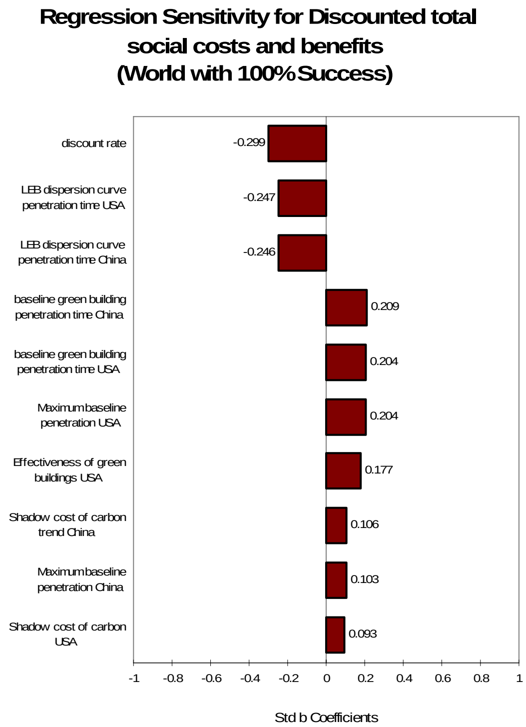


Figure 30 Major influences on the discounted total social costs and benefits, with a success rate of 100%.

The regression sensitivity analysis for the world total shows very similar characteristics to that of the US. The multiplier does not rate very highly in the sensitivity analysis for the world total. For the case of 100% probability of success, the regression sensitivity result for the multiplier is only 0.06. In general the magnitude of the sensitivities is lower for the world total, most probably due to the more heterogeneous nature of the world wide calculation.

Conclusion

The stand alone project in the US offers a high social return on investment and this with only an assumed 27% mean expected probability of success. The mean return on investment for the US is found to be $470 per dollar spent, and using the world model that extrapolates from data for the US and China, the model gives a return on investment of $7000 per dollar of investment. The latter value is much higher due to the higher potential benefits in the developing world and also because the development costs would be comparatively less for developing countries after a successful development in the United States.

Loftness (2004) summarised the benefits and costs of using policy instruments to drive up energy efficiency in buildings. She also cites Rosenfeld (2004) who calculated that the $3Million spent on the DOE programs for refrigerator standards & low-E windows reaped national benefits of $23000 and $2500 for every dollar spent. Hence it should not be surprising that low energy buildings policies or LEB type design tools also have results with similarly large returns on investment.

However the results described here are closely tied to the many assumptions made. These include not only the parameters chosen but also the way the model has been designed. The penetration rate used, for example, is an important ***assumption*** on our part and could easily be estimated by others to be greater or less as is true for the expected chance of a successful market development. In this report we have decided not to try a number of more optimistic outcomes since even with the more conservative levels chosen, the project is shown to give a very high return on investment. Our model has been developed for ease of use and it is quite a simple task for others to make use of the model using different assumptions of the parameter distributions. To increase accuracy, the model has also been designed to include another two regions, and with further data the model could easily be expanded to include results for all four regions and a modified multiplier to calculate world total benefits.

Furthermore, the level of costs/benefits that will be incorporated into new buildings is a consumer choice. For instance here we are calculating the costs of developing what would probably be a very energy efficient house but one that also has many other benefits such as controllable natural lighting and air circulation. These extra functionalities serve to increase the energy efficiency but also the productivity /comfort levels of the building and therefore overall benefits to the consumer. If however pure cost efficiency was the only motive, then it should be possible to decrease the costs of implementing low energy design into houses (by choosing only the “lowest hanging fruits”) with a smaller but more cost effective increase in energy efficiency.

When it comes to private sector development of the LEB design tool we find that it would be difficult to generate profits. One main reason is that many of the benefits of low energy design come in the form of non-financial benefits. Our very simple business model calculation suggests that on average a company trying to market the tool would make a loss. This suggests that the LEB design tool would fall into the category of projects that, although offering great benefits to society, would not be carried forward if left to market forces and thus represents an important market failure.

On the other hand, one could expect a much larger return on investment were new building policies and practices to be brought into play that worked hand in hand with the LEB design tool. The role of regulation being to insure that new levels of efficiency were to be met while that of the design tool being to ensure that designers and builders would have easy and affordable access to the information required to meet the targets. Under such circumstances, with a guaranteed receptive market for the design tool, and an affordable yet robust tool available to help implement stricter regulation, the overall return on investment would most probably be much higher. In such a situation the possibility of the LEB project financing coming from the private sector would also appear more likely.

Risk aversion plays an important role when considering how a continued LEB project should be funded. Companies should generally be more risk averse than government institutions in terms of expected future benefits while on the other hand, risk aversion to future large scale problems, such as energy shortage or potential damages associated with climate change, are more adequately dealt with by governments through their actions and policies. Hence the discount rate often used by governments, the social discount rate, is generally much lower than the rates used by individuals and companies.

In terms of risk aversion for the potential consumer of the LEB design tool, the LEB tool could help reduce important barriers to building green. Currently the decision to design green buildings faces an important measure of risk, or perceived risk. This comes from the possibility that building costs and green building consultation fees would increase overall expense without any guarantee of increased efficiency and value added from future tenants. A simple and accessible tool such as the LEB design tool could be particularly useful in reducing such (perceived) costs and risks therefore increasing the potential number of green buildings. This could have important social and economic advantages with limited downside risks since no large upfront costs are required and the project would certainly have the real option to be halted in case of poor performance or public acceptability. In general however our model suggests that the LEB project should definitely be continued and that, in the absence of private sector interest, funding for further development and initial deployment would need to be provided through government support.

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Annexe 1

Table 5 Explanation of the distribution choice for each parameter.

	Discription	**US – Focus region**	**China[3]**
Discount rate (d)	The discount rate has been used across the board, irrespective of region or type of value being calculated. Hence all net present values for costs, impacts and profit calculations are made using the same discount rate.	Discount rate of 5% used by Kats (2003). This is the rate stipulated by the California Energy Commission for lifecycle assessments, though is higher than the rate that government borrows funds (Which he claims is as little as 3.66%). Conversely this is lower than expected return on investment. (0.03, 0.04, 0.08) mean 0.05	
World Multiplier (m)	Since we are only using data for two regions, we need a method to calculate the effective costs and benefits for the remaining regions by way of a multiplier.	The GWP in 2005 was about 44 Trillion according to CIA fact book data. The US accounted for 12.5 Trillion and China 1.8, both representing substantial parts of the world's developed and developing countries respectively. Hence a multiplier of about 44/(12.5+1.8)=3.08 would seem reasonable with an appropriate error distribution. (2,3,4) mean 3	

Energy Use

Effectiveness of green buildings (EffectivenessGreen) %	This coefficient explains the efficiency improvement of "green" buildings over "traditional buildings" built during the same year. For instance a value of 25% suggests that green buildings will use 25% less energy per metre squared than a traditional building build in the same	The report by Gregory Kats (2003) claims that a review of 60 LEED certified buildings showed that Green Buildings are on average 28% more efficient (p4) not including energy produced from solar. The BRE report Costing Sustainability found values of between 3 and 17 % depending on the type of building (house, naturally	We have assumed that the design tool would generally be at least as effective in China since traditional buildings there are further away from what could be shown to be optimal. Hence we assume that relative to the US, efficiency in China will be

[3] Where no information has been given for the relative value of China except a range of (0.5,1,1.5) mean 1, this is simply our default distribution for where no further information on China could be found.

	year.	ventilated office, air conditioned office and health centre). It did not however account for re-evaluating the design from say, air-conditioned to naturally ventilated. We are including higher added costs to build green using the LEB design tool as it focuses on maximising energy efficiency and not simply passing some efficiency standards. With this increased cost should also come added benefits so we should also allow for a higher range. (0.05, 0.25, 0.40) mean 28%	Relative (.8,1.3,1.8) mean 1.3
Energy requirements ($BaseyearEnergy^{Traditional}$) EJ/m^2/year	This describes the energy required in EJ/m^2/year for all new buildings of traditional style. Using the effectiveness of green buildings above, we can calculate what the energy requirement of green build would be. We are using data for primary energy (as this includes any losses for electricity).	According to the US energy outlook data, Energy requirements including electricity losses averaged over households and offices is set to be in 2006 1.584 EJ/Billion m^2. Here we have used this value plus or minus 10%. (1.42, 1.58, 1.74) mean 1.58	It has been stated that Chinese buildings currently require up to 3 times more energy than comparative first world buildings (http://www.china.org.cn/english/BAT/111833.htm). There may also be lower thermal efficiency of the energy sector potentially further increasing primary energy use. Relative (1.5,2.5,3.5) mean 2.5 times US
Energy requirements trend ($EnergyTrend^{Traditional}$)	LINEAR trend denoting the annual percentage change in energy requirements per m^2 for new construction.	Energy intensity according to the same study is set to fall by .27% a year. (-.006, -.004, .002) mean -.0027	Due to the very low levels of efficiency of buildings we have assumed that energy intensity, in general, would also be reduced more quickly. Relative (1, 1.25, 1.5) mean 1.25

Pure energy cost (PureCostEnergy) BillionUS$(2006)/EJ	This is the pure cost of energy free from any environmental or other taxes such as NOx or Carbon taxes/paid permits.	Using the energy outlook data, the cost of primary energy is about 10$/EJ. Assuming an average 5% environmental tax this gives average energy cost at about 9.5$/GJ (8,9.5,11) mean 9.5	Relative (.5,1,1.5) mean 1
Pure energy cost trend (PureCostEnergyTrend)	LINEAR trend from 2006 to 2030.	The US energy outlook data suggests a slight decrease in costs of about .2% per year. However with recent scarcity problems, it would seem that a real possibility exists for costs to increase two fold in real terms over the next 100 years, giving an upper bound of the linear trend at 1%. (-.005,-.002,.01) mean 0.001	Relative (.5,1,1.5) mean 1
Non-Carbon externalities (NonCarbonExtCost) BillionUS$(2006)/EJ	Here we used the results of the ExternE study (subtracting the climate change aspects using data for the UK) and averaged the social costs per kWh for coal (53% of electricity in the US) and gas (13% of electricity and a major part of non electricity energy use). We used this average per energy unit which we assume to be a reasonable proxy for non-carbon externalities.	The ExternE data suggests that social costs are .025ECU/kwh (1995) for coal and 0.004 for gas. Note that in 1995, the exchange rate was approximately 1ECU to 1.25 USD. Compounding it (at 2%) and converting it to dollars then multiplying it by (total energy / final energy of or 1/0.75) to get a social cost/final energy in usd (2006) / GWh. The final approximate cost was found to be about 4.7$/GJ for all energy, which is about half total pure energy costs. Due to the uncertainties and simplifications made, we have used a wide distribution. (2,5,8) mean 5.	Here we have used similar values as for the US with large error margins. We have here two effects that counteract one another. Higher proportion of dirty coal increases health risks but lower wages reduces the costs of man-hours lost due to sickness. Relative (.2, 1,1.8) mean 1
Non-Carbon externalities	LINEAR trend included however we have no real information on this so a	(-.002, 0, .002) mean 0	Relative (.5,1,1.5) mean 1

trend (NonCarbonExtCostTrend)	zero mean trend was used.		
Carbon intensity (CarbonEnergyIntensity) Billion TCO2/EJ	This is the amount of carbon on average that comes from all primary energy burnt. Measurements done in Billion TCO2/EJ	Carbon intensity was found using the US Energy data to be 0.055 BillionTCO2 on average/EJ (EIA 2005). (.045,0.055,.065) mean .055	We have assumed here that the carbon intensity of energy is about 1.5 times that of the US due to their extensive use of coal. (http://www.unu.edu/unupress/unupbooks/uu17ee/uu17ee0h.htm Nakicenovic presents data for total energy up to 1990) Relative (1, 1.5, 2) mean 1.5
Carbon intensity trend (CarbonEnergyIntensityTrend)	LINEAR rate. This is the rate at which the amount of carbon per energy unit produced changes per year.	A slightly positive trend was found in the data over the next 30 years (EIA 2005). (-.001,.0015,.003) mean .0015	Relative (.5,1,1.5) mean 1
Shadow cost of carbon (CarbonShadowCost) US$(2006)/TCO2	This describes the social costs in dollars brought about by the emission of 1 tonne of CO2.	This is constant across the world as CO2 mixes thoroughly in the atmosphere. Hope’s evidence to the House of Lords gives a range of (7,45,130) in $ per tonne C. Divide by 44/12 to get $ per tonne CO2. (2,15,40) mean 19	
Shadow cost of carbon trend (CarbonShadowCostTrend)	EXPONENTIAL rate. This describes how the shadow cost changes as a function of time.	Hope’s evidence to the House of Lords gives a growth rate of 2.4% per year. (.01,.025,.04) mean 0.025	
Internalisation of externalities (InternalisationRate)	This is the part of total externalities that are currently being taxed. Hence this value does not affect the overall social net present value, but instead decides what part of the NPV calculation is in	This is a difficult value to define but should be based on the SO2, NOX and particulate taxes/trading scheme already in place in the US, as well as a small CO2 trading scheme under way. However, without further research into this area,	Unaware of any current efforts to internalise energy externalities, we assume a low initial internalisation of externalities.

	the form of financial benefits as opposed to non-financial. A detailed calculation could also include negative taxes such as subsidies that are given for coal.	we have assumed that something less than 10% is currently internalised. (0, .05, .1) mean .05	(0,.025,0.05) mean 0.025
Internalisation of externalities trend (InternalisationRateTrend)	LINEAR trend. This is the rate at which we can envisage externality costs to be brought into the financial world through some form of tax.	Although this is difficult to define, we have allowed for the full range that is anything from 0 to 100% of externalities could be internalised after 100 years (0, .005, .01), mean .005	We have assumed a slower level of internalisation of externalities with a mean value of half of that found in the US. Relative (0, 0.5, 1) mean 0.5

Market Size

New building annually (BaseyearMarketSize) Billion m^2	Since we are only looking at the effects of the LEB design tool for new buildings, we only consider the market from 2006 onwards. New Building Annually measures the total floor space of new build annually for commercial and residential purposes.	We have used the US energy data which includes residential and commercial buildings in square feet. Unfortunately it only has new build data for commercial buildings so we used the same proportion of new build to total build across both residential and commercial build. This gives us a value of about 0.67 billion m^2, however with an amount of uncertainty. (0.4,0.65,0.9) mean 0.65	The Chinese national Bureau of Statistics www.stats.gov.cn (2004) suggests that total new construction for China for the year of 2006 will be between 1.3 and 1.5 Billion m^2. this is approximately double that of the US Relative (1.7,2,2.3) mean 2
New building annually trend (MarketSizeTrend)	LINEAR TREND is used to describe to what extent the construction sector will grow or decline.	The US data suggests that there is an annual trend of 2% with their baseline scenario. Nevertheless we will include best and worst case scenarios. (0,.02,.04) mean of 0.02	China has shown to have 11.6% exponential increase in new build per year over the 18 years to 2003. We do not believe that such growth is sustainable over the coming 100 years so we have used a linear growth rate from year 2006 levels with an upper limit of 12%.

			(.05, .1, .12) mean .09
Lifetime of energy benefits of new build (BaseyearLifetime) Years	This coefficient is meant to give a weighted average of the benefits brought about by the use of a low energy design tool. This is difficult as the benefits are varied and complicated including actual building design, internal configuration, windows, blinds, air conditioning systems etc.	We have assumed that some benefits such as windows, blinds and air conditioners have a lifetime of 20 to 30 years while the building design and the low energy design itself will probably be valuable for 40 years to the lifetime of the building of perhaps 100 years. However new technology may reduce these benefits. (20,30,50) mean 33	Relative (.5,1,1.5) mean 1
Trend in lifetime of benefits (LifetimeTrend)	LINEAR TREND describing how the lifetime of benefits may change over time.	We were not able to establish whether building benefits would generally be extended or shortened. (-.001,0,.001) mean 0	Relative (.5,1,1.5) mean 1
Delay before entering market (MarketEntry) Years	Delay represents the number of years until the LEB design tool could be realistically marketed. Note that for non US regions, this is the number of years after a successful US entry that the other region follows.	These values are a slightly modified version of the estimates in Glicksman (2006). (2,6,10), mean 6 years	Here we have again used the same lead time, starting from the time of marketing of the LEB tool in the focus region. Additive (2,6,10), mean 6 years
Delay for baseline entry (t_{entry}) Years	This describes the beginning of "green" build in the baseline case that has occurred through schemes such as LEED or BREEAM type ratings.	According to Kats (2003 p5), by 2003 3% of projects had already applied for LEED certification and others had used LEED as a design tool without going through certification. LEED was first introduced in 2000. This suggests that baseline green buildings have already begun penetrating the market. In order to consider this	We have assumed that the Chinese market has already begun penetration of low energy buildings (relative to the efficiency of their traditional build) however there is no clear indication of by how much or whether this has really happened in a systematic manner. Without further

		factor we have used a negative baseline delay such that penetration by 2006 is slightly above this 3 % mark for all commercial / government buildings however the majority coming from the public sector. Since here we are considering both commercial and residential type buildings where commercial counts for les than half of total new build and the market has also penetrated the easiest area of building, commercial and not for profit organisations. We assume that there has also been a market for some energy efficient build before this time. (-10,-8,-6), mean -8	information we will assume a wide starting date (-10,-5,0) mean -5
Maximum Penetration (MaxPenetration)	Here we consider the maximum level of energy efficient buildings that we consider possible for the US and China. This depends on decisions of designers and procurers who wish to incorporate low energy into their building as well as step changes in policy towards buildings.	This is a very uncertain parameter as it requires understanding not only the market but also future possible political decisions. At best, one could imagine that new rules decree that such measures must be taken, at worst, perhaps a total of 20% of new build in the US by perhaps the end of the century would have energy efficiency in mind. (.2, .5, 1) mean 0.57	Relative (.5,1,1.5) mean 1 N.B. maximum baseline penetration = 100%
Baseline Green Building penetration time ($t_{BaselineInflection}$) Years	Since we are using S-Curve penetration, we must specify the slope of the S-curve. Here we have used a method that allows us to determine the point of inflection which occurs at a penetration of about 1/3 the maximum penetration.	Here we have assumed penetration times with a wide uncertainty to represent the lack of good data that we have for this coefficient. (15,25,50) mean 30 years to the inflection point.	We have assumed a slower baseline penetration however with the possibility of a faster baseline penetration. Relative (0.5,1.5,2.5) mean 1.5 times as much time required

LEB penetration time of remaining traditional build ($t_{LEBInflection}$) Years	This describes how useful the LEB tool would be to increase the penetration of buildings that would otherwise be built using traditional methods. Here too we have assumed an s-curve type penetration of the non-green build that falls below the maximum penetration threshold.	Here we have assumed that the LEB tool will reach the point of inflection (about 1/3 of the total difference between baseline and maximum penetration) will occur, on average 55 years from the start of green buildings. (20,40, 60) mean 55 years	We have assumed a slower baseline penetration by a factor of 2 Relative (.5, 1.5, 2.5) mean 1.5 times as much time required
Successful market development (MarketDevelopment)	Probability of success or failure after market development Note that for other regions, a successful US entry is required hence the overall success rate is multiplicative.	We have assumed a relatively low probability of success with a wide distribution. Following market research this range could be narrowed accordingly. (0.1,0.2,0.5) mean 0.27	Assuming success in the US, we have given a 50% mean success rate in China. Relative (0.3, 0.5, 0.7) mean 0.5

Cost Benefit

Added costs (AddedCosts) US$2006/m^2	Here we consider the extra costs incurred by the builder wanting to build a green building. Again here we refer only to the energy efficiency aspects of green buildings and consider only these costs.	BRE IP 4/05 for TYPICAL location for very good and excellent ratings gives average 2.6%. The LEED cost study came up with a similar 2.5 to 4% increase to get silver and some gold rated buildings. Kats (Green Building Costs and Financial Benefits) suggests about 30 to 50 $/m^2 (2004). However this is for overall Green Buildings and not simply energy efficiency suggesting that energy efficiency benefits could be cheaper. Kats also recognises that "the earlier green building gets incorporated into the design	We have assumed that efficiency measures here will come cheaper than in the US. Relative (.25, 0.5, 1) mean 0.58

		process, the lower the cost" (viii), which is the aim of the CMI project. On the other hand the energy efficiency improvements hoped for by the LEB design tool goes beyond the measures covered by the LEED. Hence it would be fair to assume that LEED energy efficiency costs are lower than that hoped for using the LEB design tool, however the effectiveness would also be lower. Glicksman (2006) suggests added costs of between 40 and 100 in $/m^2. (20, 60, 100) mean 60	
Added costs trend (AddedCostsTrend)	LINEAR TREND describing changes in added costs over time.	We have no information on this variable , so have allowed for an increase or decrease in costs over time. (-.005,0,.002) mean -.001	Relative (.5,1,1.5) mean 1
Market development cost (DevelopmentCosts) Billion US$2006	This is the cost required to complete the research and development part of the project and bring the project to market. Although probably higher than minimum required investments, such a distribution would allow for the inclusion of a category of buildings including single-family houses and a variety of other specific building types inline with the General framework for	Glicksman (2006) suggests a market development cost of between 10 and 50 million USD. (0.01,0.03,0.05) mean 0.03	We have assumed that entry to a second market would be relatively cheaper Relative (.1, .5, .9) mean 0.5

	the calculation of energy performance of buildings (article 3, Directive 22/91/EC).		
Productivity Benefits (ProductivityBenefits) US$/m^2	Productivity improvements are seen as a big driver towards green build especially since personnel costs are much higher than is the cost of using and maintaining buildings (by a factor of 10), however "the relationship between worker comfort/productivity and building design/operation is complicated" (Kats 2004 p54).	Kats has cited William Fisk who calculated overall US annual savings/productivity benefits of 43 to 235 Billion USD (2002). Dividing these benefits over all buildings of 24.8 Billion m^2 (2003), gives USD1.88/m^2 capitalising at 2%. (2,6,10) mean 6 $/m^2	Productivity gains per m^2 one would expect to be far lower in a country with much lower GDP per capita. US GDP/Capita is 42000, versus about 1250. That is about 35 times less using exchange rates, however with a higher density of workers per m^2, therefore we have used a wide range of values with mean at about 10% of the value of the US. Relative (.01, .1, .2) mean 0.103

Profit Calculation Only

Lifetime of project (t_{MAX}) years	This is the period over which we expect a successful market development to continue to run and make profits.	We have assumed a life time of project to vary between 10 and 40 years. (10,25,40) mean 25	Relative (.5,1,1.5) mean 1
Delay for competition ($t_{CompetitionDelay}$)	Here we specify a certain delay before competition comes and takes a certain percentage of the CMI design tool	These are best guesses and should be used as a guide only. (1,8,15), mean 8 years	Relative (.5,1,1.5) mean 1

years	market.		
MarketLostToCompetition (CompetitionLoss)	This represents the level to which the new competition will win some of the CMI generated market	These are best guesses and should be used as a guide only. (.05, 0.5,0.95) mean 0.5	(.05, 0.5,0.95) mean 0.5
Baseline captured by LEB (baselineCapture)	This represents the baseline green market that the LEB design tool project could hope to access after a successful market development.	These are best guesses and should be used as a guide only. (0,0.1,0.4) mean 17%	Relative (.5,1,1.5) mean 1
Profit from LEB projects (Profits) US$(2006)/m^2	This represents the profit that a developer could hope to retain after running costs for each m^2 of green development using the LEB design tool. We have assumed that this would be best represented by a cost per building than by a proportion of energy savings as one would expect from say a computer software that allows business to run more efficiently.	We have made a back of the envelope calculation which should serve as a very rough guide. If on average users purchase one copy of the software package/single access if web based for every 10’000m^2 of building for the cost of 1500USD, of which 1/3 is used to cover running costs, this would come to 0.15$/m^2 charged and 0.1$/m^2 profit. This would also be the equivalent of charging a one time house builder 75 USD to access the software via the internet for a 500m^2 house. Although to gain market access they may need to charge less or use a different business plan (for example free access with advertising), or perhaps could eventually charge more if the benefits of the tool were widely accepted and sought after. (0.05, 0.1,0.4) mean 0.18	We have assumed smaller profits on a m^2 basis. Relative (0.1, 0.3, 0.5) mean 0.3
Trend in value extracted	LINEAR trend in profits from LEB design tool.	We have assumed again that with time and the development of many competing software tools,	Relative (.5,1,1.5) mean 1

from LEB projects (ProfitsTrend)		expected unit profits should fall, with some possibility that profits may increase. (-.005,-.002,.001) mean -.002	