Applied Energy 133 (2014) 40–55

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Evaluating the energy performance of buildings within a value at risk framework with demonstration on UK offices

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HIGHLIGHTS

- Evaluation of value at risk to specific assets through an exploratory analysis of supporting systems.
- Demonstration on UK offices of feasibility to develop a Capital Market Line for building energy performance.
- A scalable methodology for shadow pricing a market correction when internalising climate change impacts into accounting.

ARTICLE INFO

Article history:
Received 21 March 2014
Received in revised form 14 July 2014
Accepted 20 July 2014

Keywords:
Asset pricing
Exploratory systems analysis
Energy performance
Building simulation
Feasibility studies

ABSTRACT

Facility quality is dependent on the performance of utility infrastructure and local weather conditions in addition to social context. Theoretically, improvements in facility quality such as energy performance should reduce marginal costs of consumption for occupiers so as to increase asset values. This research explores the relationship between expectations of building energy performance and the financial value of real estate. The United Kingdom was selected as a leading case, being a large economy that has enacted legislation committing the government to delivering ambitious emission reductions to mitigate climate change. Appropriate instruments are identified and applied to a diverse set of case study offices. A scalable method is employed for calculating value at risk from energy performance for buildings. This involves a novel approach to testing supporting system capacity through an exploratory analysis of 2050 end-states and demonstration on real world contemporary cases as a feasibility study. In doing so, the significance of systematic risks to building energy performance can be quantified. By comparing systematic excess returns for energy performance with rental value for a large sample a Capital Market Line for building energy management emerges, providing a means to shadow price the social impacts of climate change.

1. Introduction

The quality of a facility is highly dependent on the performance of utility infrastructure and local weather conditions in addition to its social context. In theory, improvements in facility quality such as energy performance should effectively reduce the marginal costs of consumption for occupiers and increase asset values [1]. Therefore, the ability to identify opportunities for creating such value through appropriately evaluating expectations of future energy performance should be of keen interest to property investors and asset managers. This research asked the question:

> "How can specific market risks arising from expectations for the energy performance of real estate be appropriately evaluated?"

This research addresses this question through designing a value-at-risk framework for appropriate capital budgeting with regard to building energy performance and carrying out a feasibility study on a small sample of case studies to demonstrate implementation. Although this study focuses on the micro-scale of specific assets, it is ultimately scalable to include any number of buildings and uses.

2. Climate change as a global externality

Tyndall is widely credited as the first scientist to rigorously identify the absorption of radiant heat by gases and vapours [2]. Indeed, these observations have since become common knowledge and the effects that vapours have on radiant forcing in the

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http://dx.doi.org/10.1016/j.apenergy.2014.07.074
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atmosphere has since been carefully scrutinised. Harvey explains the importance of considering not only the degree of radiant forcing, but also the duration that gases remain in the atmosphere. He describes how such estimation can cause difficulties as some vapours may remain in the Earth's atmosphere for a considerable length of time [3]. The current official perspective on this matter is presented in the Intergovernmental Panel for Climate Change (IPCC) Fifth Assessment Report [4].

Plausible climate projections included in the Intergovernmental Panel for Climate Change Fourth Assessment Report were based upon the application of the Special Report on Emissions Scenarios simulation ensembles of integrated climate and socio-economics models. The analyses of as many as 23 different climate models have been included in the report's cross-model comparisons. The reports states "*there is considerable confidence that climate models provide credible quantitative estimates of future climate change, particularly at continental scales and above*". The report provides a summary of projected global greenhouse gas emissions under these scenarios and corresponding resultant change in global surface temperature. The B1 scenario yielded a stabilisation in temperature change to a 2 °C increase from 1990 levels, with the least severe warming influence of any SRES scenario. The A2 scenario was found to have the most devastating warming effects on the climate, resulting in temperatures reaching over 3 °C by 2100 and probably continuing to rise [5].

Since the development of the SRES scenarios approximately 15 years ago there has been opportunity to evaluate the observed progress of development and make comparisons to them. It has become apparent that between 1999 and 2003 global society has developed most closely with an A1B SRES scenario, all others are now considered outliers [6]. In light of this it has become clear that, although the SRES scenarios benefit from detailed scrutiny, they are now largely obsolete and have lost decision-making utility.

New climate change scenarios have been developed for the IPCC Fifth Assessment Report which adopts an alternative and updated methodology superseding SRES. The SRES approach to scenario building explored the influence of pivotal uncertainties in socio-economic development on future climate change. In contrast to this the new scenarios make projections of Representative Concentration Pathways (RCP's) relating to various levels of combined mitigation and adaptation efforts resulting in alternative concentrations of greenhouse gases in the atmosphere. This means that the new scenarios are likely to retain consistency with a wide range of socio-economic futures. The Fifth Assessment Report provides four RCP's denoted by the level of radiative forcing in the year 2100: $2.6\,\mathrm{Wm^{-2}}$; $4.5\,\mathrm{Wm^{-2}}$; $6\,\mathrm{Wm^{-2}}$; and $8.5\,\mathrm{Wm^{-2}}$. Each scenario is considered plausible and illustrative, with no specific probability assigned to the likelihood of occurrence [4].

A comparison of radiative forcing between the SRES and RCP scenarios is made within the Fifth Assessment Report. It shows and $8.5\,\mathrm{Wm^{-2}}$ RCP scenario is similar to the trajectory of the SRES A1B scenario until 2050. However, these similarities are not sustained beyond the year 2050. The Fifth Assessment Report states how it is unlikely that mean global surface temperature will rise more than 1.5 °C between the present day and 2035 due to high levels of inertia in the atmospheric system. However, beyond 2035 there is the potential for large variation in the future climate depending on future concentrations of greenhouse gases. Therefore, immediate action to address climate change would have long lasting effects on the climate [4].

The reality of climate change poses great challenges to society. Greenhouse gas emissions have been an unknown and unmanaged externality of technological development for over a century. Stern asserts that climate change is "*the greatest and widest-ranging market failure ever seen*" requiring action that is "*global... long term...* (and) *ha*(s)*... the economics of risk and uncertainty at centre stage*" [7]. However, leading economists realise that Stern has arrived at the right conclusions from perhaps a significantly outlying economic position in regard to considerations of social equity [8,9].

3. Methodology

This research seeks to explore the relationship between expectations of building energy performance and the financial value of real estate assets. The context of the United Kingdom was selected as a leading case, being the largest economy to enact legislation that commits the government to delivering ambitious emission reductions to mitigate climate change impacts. Appropriate instruments are identified and applied to a diverse set of case studies. Through the analysis a scalable method for calculating value at risk from energy performance for specific case studies is determined.

3.1. Objectives

The valuation of risky assets requires the decision maker to evaluate expected returns over the duration of an investments life-cycle. Investments in property are a particularly challenging case where the underlying assets are in general highly illiquid, expensive, and commonly of unique quality [10]. Therefore, a credible and challenging expectation of plausible future development is a key consideration in evaluating long-term strategy. This research recognised that over the longer-term, the management of energy in the UK could be very different from anything that might be expected from current short-term trends and incremental change. Responses based upon such information could result in an over-investment in technologies that may become redundant or inappropriate over the course of time. Hence, there is a need to consider responses to energy challenges that are resilient to a broad outlook. Through evaluating a 40-year outlook a reasonable opportunity for significant system wide change is allowed for, including significant decarbonisation [11].

Objective 1: Develop plausible descriptions of expectations for the climate and energy systems towards 2050 for the UK.

To make the research outcomes most useful the study took a particular interest in commercial offices. This is because these assets are relatively expensive buildings providing services to high value industries that will grow regardless of energy prices [12]. Therefore, such buildings may be exposed to high levels of obsolescence within a competitive market. By focussing on such assets it is also more likely that the marginal costs of this research are very small compared with the capital value of the cases. It is the intention of this study that it is rooted in the real-world present day without requiring control of behavioural events. Real observations need to be analysed to demonstrate that such analysis can be carried out within a present state of circumstances.

Objective 2: Evaluate the expected energy performance of commercial property assets using an appropriate value at risk methodology towards 2050.

4. Describing expectations

This section provides a brief discussion of the field of 'futures studies' followed by an explanation of the approach taken for this research. Foresight provides a step-by-step guide to create descriptions of explorative scenarios and consider their implications, a procedure adopted by Parkinson et al. [13,14]. This study recognises the valuable insights of Parkinson et al.'s study, but also identified some clear deficiencies. To overcome this, the findings were translated for quantitative exploratory analysis.

4.1. Futures studies

4.1.1. Single factor studies

Many widely used methods for evaluating the performance of potential decisions employ forecasts of a single pervasive factor. Appraisals of the future value of decisions are then based upon these. For example, the Capital Asset Pricing Model and use of the Black–Scholes equation for pricing portfolios are both reliant on the assumption that future financial performance is contingent on observed variance in a single factor [15–17] Such studies tend to rely on extrapolations of historic trends [18,19]. Under relatively stable conditions and short timescales such forecasts can be reliable. Therefore, they can be potentially very useful as an aid to planning and decision-making [18–20]. In the short to mid-term system inertia may ensure that trends turn out as expected [21]. Börjesona et al. conclude that forecasts can be useful because they [18]:

- Make it possible to plan and adapt to situations that are *expected* to occur.
- Equip planners to deal with *foreseeable* challenges and take advantage of *foreseeable* opportunities.
- Make decision-makers aware of problems that are likely to arise under certain conditions.

4.1.2. Normative scenarios

An optimistic view is that individuals, businesses and/or societies have the capacity to shape their own future. That, once they have a vision of what they would like the future to be, the task is to see what it would take to achieve it [13,19]. These normative scenarios are inherently policy oriented and designed to identify the policy actions required [21]. Such a position features an underlying assumption that there is indeed one best solution. The job of the strategist becomes one of producing this or the closest possible thing to it [22]. Normative scenarios may be used for [18]:

- *Optimisation* – when the desirable future is not radically different from the present they can be used to determine how the prevailing system needs to be refined.
- *Transformation* – If the prevailing system is (considered to be) fundamentally flawed and part of the problem they can be used to determine the radical changes that are required.

4.1.3. Explorative scenarios

Explorative scenario planning is an established approach to decision making in an uncertain environment. It is considered a reasonable method of evaluating real options requiring a long-term perspective [22–24]. Modern methods of scenario planning emerged from the USA and France in the 1960s, in which three distinct 'schools' developed [25]:

- Intuitive Logics – Notably adopted with some success by Shell and General Electric.
- Probabilistic modified trend models – Trend Impact Analysis involves defining expert views on the probability of extrapolated historic trends being modified and adjusted. Cross Impact Analysis is another variant which adds extra complexity by attempting to evaluate event inter-dependencies.
- La Prospective – Initially set up to develop normative scenarios of the future orientated towards policy makers. This school influenced a number of national French economic plans. The work of 'La Prospective' was subsequently developed further by Godet based largely upon computer-based probabilistic models which analysed entire scenario morphologies, each with a defined probability.

Explorative scenarios, in contrast to forecasting and normative scenarios, are intended neither to determine a correct future or for probabilistic prediction. They are underpinned by the perspective that the future is unpredictable since it contains irreducible uncertainty. Such studies evaluate a broad range of plausible outcomes. Bell asserts that the foundations of explorative scenarios lie in the belief that a proposition is reasonable even if it cannot be entirely justified. The aim is to develop plausible descriptions of the environment rather than focusing on absolute certainty. By creating plausible scenarios the future becomes real, strengthening the basis for decision making and influencing choice and/or behaviour [26].

Of fundamental importance in the development of explorative scenarios is they are either appreciated for being interesting or are useful upon application. Wilson developed five underpinning criteria to evaluate this [27]:

- *Plausibility*: the selected scenario must fall within the limits of what might conceivably happen. Plausible scenarios should be possible, credible, and relevant.
- *Differentiation*: each scenario constructed should be sufficiently different for it not to be construed as variations of a base case.
- *Consistency*: the logical reasoning contained in a scenario must not have any in-built inconsistency that would undermine its credibility.
- *Decision-making utility*: each scenario should contribute sufficient insights into the future to bear on the decision focus selected.
- *Challenge*: the scenarios should challenge the organisation's conventional wisdom about the future.

Even today there is sufficient variety in the methods of scenario planning to allow for significant freedom in the techniques used [28,25].

4.1.4. UK climate projections towards 2050

The UK Climate Projections (UKCP) provides authoritative climate information designed to assist national adaptation plans for a changing climate. UKCP09 is the fifth generation of climate change information for the UK using an updated methodology based upon large climate model ensembles. They provide a continuous daily time series from 1950 to 2099 for a 25 km grid across the UK that is spatially coherent over land and sea [29]. The resulting projections describe probabilistic distributions showing the range of uncertainty in three IPCC SRES emission scenarios: high, SRES A1FI; medium, SRES A1B; and low, SRES B1 [30]. Eames et al. describe how future probabilistic design weather years can be translated from the UKCP09 data for use in building simulation [31].

4.1.5. Recent scenarios for the UK energy system towards 2050

Table 1 provides a summary of a number of significant projects that have been recently undertaken to support decision making specifically for the UK energy system towards 2050. This table shows little development of truly explorative, back-cast, quantitative scenarios for the whole energy system towards 2050 to date. Most recent quantitative future studies take a normative approach. A recent review of international low-carbon scenarios by Hughes and Strachan confirms the preponderance of a normative mindset amongst researchers in the field that is not strictly relevant to actors in society who may not feel that they can control largely external events [32].

4.2. Identifying the driving forces

In considering how uncertainty influences market expectations pivotal/critical uncertainties dominate. Parkinson et al.

Table 1
Summary of selected recent future studies focussing solely on market expectations for the UK energy system towards 2050.

Authors	Project	Methodology
[57]	Transition pathways for a low carbon electricity future	Normative, quantitative scenarios with 5-yr time series towards 2050
[56]	UK future energy scenarios – UK gas and electricity transmission	Explorative, quantitative scenarios with 5-yr time series towards 2050
[55]	UKERC energy 2050: making the transition to a secure and low-carbon energy system	Normative, quantitative cost-optimised scenarios with back-casting
[54]	Foresight, powering our lives: sustainable energy management and the built environment	Explorative, qualitative scenarios
[53]	40% house, background material B: foresight scenarios for the UK domestic sector	Explorative, quantitative, back-cast scenarios
[52]	UK 2050 energy plan: making our commitment a reality	Normative, quantitative scenario with back-casting
[51]	Building a low-carbon economy – the UK's contribution to tackling climate change	Normative, cost optimised quantitative scenarios with back-casting
[50]	Sustainable energy – without the hot air	Normative, quantitative scenarios matching supply and demand with back-casting
[36]	The carbon plan: delivering our low carbon future	Normative, quantitative scenarios with back-casting
[49]	Long-term energy network scenarios for great britain in 2050	Explorative, quantitative scenarios with 2000, 2025 and 2050 time-series
[14]	Exploring scenarios for the future of energy management in property	Explorative, qualitative scenario end-states in 2050

acknowledged that the future will be shaped by many driving forces. Some of these will have considerable influence (high impact), whereas others will only result in minor changes to the status quo (low impact). Furthermore, the characteristics of certain driving forces can be predicted with a high degree of certainty, whereas others are subject to considerable uncertainty. This study developed explorative scenarios for the energy management of UK property empirically through a combination of a widespread survey and stakeholder workshops. It identified axes of pivotal uncertainties shown in Fig. 1 [14].

In attempting to develop quantitative descriptions of the scenario axes developed empirically by Parkinson et al. it became clear that there were two fundamental problems:

- The axes did not differentiate between the international and national dimensions of the uncertainties identified.
- The axes titles require further refinement to allow for quantification.

The atmosphere is a common environmental sink. Its future development is contingent upon global aggregate economic activity and consequential greenhouse gas emissions. This is largely external to the response of any single nation [33]. Therefore, for the purpose of this study the future development of climate change is considered as an additional critical uncertainty, providing an additional factor in analysis. It considers two plausible extremes of development based upon the evidence provided in the IPCC Fifth Assessment Report [4]: continual development with no additional policies to mitigate climate change, known as 'baseline climate change'; and a considerable an abrupt effort to rapidly mitigate emissions towards an extreme of 'no climate change'.

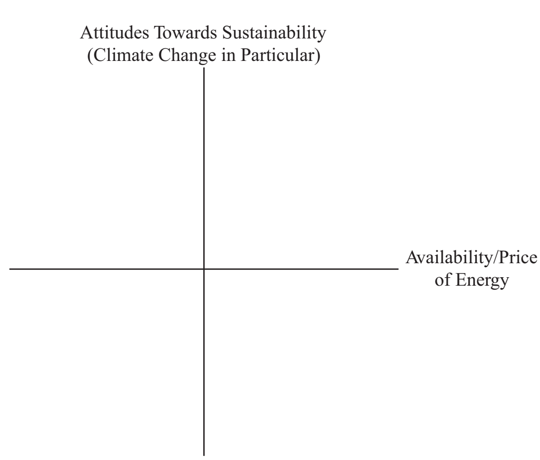


Fig. 1. The intersecting axes of uncertainty that defines four explorative scenarios developed empirically [14].

The UK's energy system could develop quite independently from that of the rest of the world, driven by institutions attempts to allocate resources so that the energy system efficiently and securely delivers a quality of service that satisfactorily meets resident demands [34]. In such a case, the development of service "price and availability" will be highly dependent on residents preferences for the services provided by the national energy system and the costs of investment [35]. The UK's policy on energy requires performance of the national energy system to be assessed in both values of energy and global warming potential. The Government's recently published Carbon Plan explicitly states the following objectives for national energy policy: "*achieving the first four carbon budgets*", requiring the use of units of greenhouse gas emissions; "*maintaining energy security*", requiring the use of units of power and energy; and "*minimising cost to consumers*", requiring the use of units of energy [36]. This plurality in performance measurement provides a clear indication of how to refine the critical uncertainty "*attitudes towards sustainability and climate change in particula*r" identified empirically shown in Fig. 1, for which an entire focus on an 'energy preference' or 'emissions preference' forms the two extremes [14].

Through developing this new understanding judgements were made to translate the axes of uncertainty to reflect these insights, yielding four quantifiable orthogonal scenarios for the energy performance of the built environment across two climate factors. A diagram describing the translation is shown in Fig. 2.

4.3. Scenario building

To initiate the building of a scenario framework this study first addressed the issue of setting an appropriate social discount rate that adequately reflected the UK context. The study then addressed expectations for the climate and energy systems independently, as two distinct systems treated with common social discounting of future consumption. For each of these systems, appropriate tools are identified that allow for the testing of supply constraints leading to the development of descriptions of explorative scenario for the energy system under both climate factors.

4.3.1. Social discount rate

To evaluate the scenarios consistently and appropriately it is necessary to impose a common social rate of time preference, or social discount rate, in evaluation. Such a decision has important

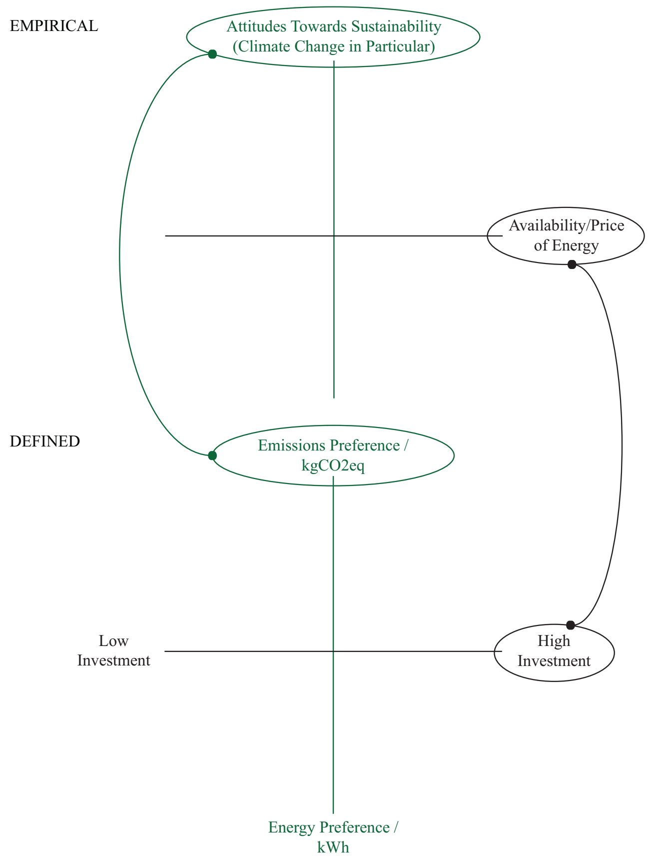


Fig. 2. Translation between the axes developed empirically and the result of using morphological analysis.

ethical considerations and is quite political in nature. Therefore, this study makes reference to empirical findings from HM Treasury, and Evans in particular, to specify elasticity of marginal utility with respect to consumption and pure rate of time preference for the UK (HM [37,38]. By employing Eq. (1) an annual social discount rate of 3.8% is considered appropriate to discount future consumption [39,34]. The input expectations are shown in Table 2.

Eq. (1): Determinants of long-term social discount rate.

$$S = \eta \cdot G(C_t) + \delta \tag{1}$$

where s = social rate of time preference, also known as social discount rate. η = elasticity of marginal utility with respect to consumption, indicative of how much weight should be given to the consumption of the poor relative to the rich. G = growth rate, which changes depending on future scenarios. δ = pure rate of time preference, indicative of our impatience to have goods now instead of in the future.

4.3.2. Expectations for the climate

The driver identification exercise described conditions for the climate that allow for two extreme expectations for the state of this common international system, 'No Climate Change' and 'Baseline Climate Change'. Both of these factors require descriptions of future climate conditions and an associated 'social cost of carbon' (SCC) which reflects the social cost of the damage made to the atmosphere through consumption of emission rights. Developing descriptions of the 'No Climate Change' factor is relatively straight-forward and requires only an extrapolation of present day conditions with a continual social cost of carbon of zero. However, developing a 'Baseline Climate Change' factor is more challenging and requires a review of recent advances in integrated assessment.

The modelling efforts of the Stanford Energy Modelling Forum (EMF-22) are considered state of the art in developing 'business as usual' baseline scenarios for use in integrated assessment for SCC estimation. They can be considered as preferable to the highly scrutinised IPCC SRES scenarios developed in 1997. The EMF-22 models are more recent, are internally consistent, peer-reviewed, published and publicly available [40,6,41]. The Intergovernmental Panel for Climate Change illustrate how the SRES A1B scenario is a reasonably close match to the highest emission RCP scenario presently considered plausible for projections of radiative forcing towards 2050. Therefore, the 'medium' set of UKCP09 weather files have been used as estimates for baseline future weather conditions, to be consistent with the IPCC's Fifth Assessment Report [4].

Table 2
Input parameters and calculation of social rate of time preference to discount future consumption in the UK.

Variable	Denotation	Expectation
Elasticity of marginal utility with respect to consumption	η	1.4
Growth rate	G	0.02
Pure rate of time preference	δ	0.01
Social rate of time preference	s	0.038

4.3.3. Expectations for the UK energy system

There were no accounting scenarios of the UK energy system that could be adopted as suitable descriptions for the axes of uncertainty developed. Therefore, it was necessary to explore the entire morphology of pathways, identifying the limits of technological knowledge and supply input expectations. In doing so, new descriptions were created that represent the most challenging plausibility's of the axes. This research identified the DECC 2050 Pathways Calculator as a suitable tool, available online as a Microsoft Excel workbook. The DECC 2050 Pathways Calculator is an open-source accounting framework for the UK energy system developed by the Department of Energy and Climate Change. It is capable of producing back-cast, quantitative pathways for a broad morphology of plausible futures towards 2050 in an internally consistent manner. One condition of the calculator is that it ensures no shortage of energy supply by deploying gas fired power stations to make up shortfalls and that excess energy surpluses are exported. [42].

The DECC 2050 Pathways Calculator is non-linear with a number of interdependencies and thus is challenging to solve for the various scenario conditions without running all significant iterations. The implication of this is that a simpler calculator was required with the ability to process in parallel so that a meaningful analysis could be made. This was achieved through rationalising variables and translating the calculator into a new format for rapid parallel processing.

Significant variables were selected on the basis of a differential sensitivity analysis, summarised in Tables 3–5. The analysis focussed specifically on energy sensitivities, rather than power or emissions. The differential sensitivity analysis split the supply and demand side variables so that they were analysed separately. A significant load was indicated by it representing more than 5% of the total supply or demand energy requirement. A significant intervention was indicated by a differential sensitivity of at least 8% when compared with other supply or demand interventions.

It was deemed critically important to consider the technologies or fuels used to serve significant supply or demand loads identified through the differential sensitivity analysis. When analysing such a complex system it is important to note that such variables may have significant impacts when analysing the system in combination. Therefore, a number of variables were translated into the rapid calculator even though they had no direct impact on energy

Table 3
Results summary of the differential sensitivity analysis for supply variables.

Intervention	Trajectory 1/TW h yr^{-1} (2050)	Trajectory 4/TW h yr^{-1} (2050)	Differential Sensitivity/TW h yr^{-1}	Notes
Nuclear power stations	0	1025	1025*	Significant differential sensitivity
CCS power stations	11	552	541*	Significant differential sensitivity
CCS power station fuel mix	NA	NA	NA	Significant differential sensitivity
Offshore wind	0	929	929*	Significant differential sensitivity
Onshore wind	0	132	132	
Wave	0	71		
Tidal Stream	0	68		
Tidal range	0	38.6		
Biomass power stations	5	168	163	
Solar panels for electricity	0	140	140	
Solar panels for hot water	0	116	116	
Geothermal electricity	0	35	35	
Hydroelectric power stations	5	13	8	
Small-scale wind	0	9	9	
Electricity imports	0	140	140	
Land dedicated to bio-energy	17	398	381*	Significant differential sensitivity
Livestock and their management	37	125	88	
Volume of waste and recycling	55	30	−25	
Marine algae	0	46	46	
Type of fuels from biomass	NA	NA	NA	Significant differential sensitivity
Bio-energy imports	0	266	266	

* Significant load and/or differential sensitivity.

Table 4
Results summary of the differential sensitivity analysis for demand variables.

Intervention	Trajectory 1/ TW h yr^{-1}(2050)	Trajectory 4/TW h yr^{-1} (2050)	Differential Sensitivity/ TW h yr^{-1}	Notes
Domestic passenger transport	NA	NA	NA	
Domestic transport behaviour	233*	175	−58	Significant load (Level 1 car and van tech, level 1 shift to zero emission transport)
Shift to zero emission transport	NA	NA	NA	Significant load
Choice of car and van technology	105	141	36	(Level 4 shift to zero emission transport)
Domestic freight	154*	65	−89	Significant load
International aviation	189*	131	−58	Significant load
International shipping	130*	29	−101	Significant load
Domestic space heating and hot water	NA	NA	NA	
Average temperature of homes	579*	261	−318*	Significant differential sensitivity and significant load
Home insulation	579*	467	−112	Significant load
Home heating electrification	NA	NA	NA	Significant load
Home heating that is not electric	NA	NA	NA	Significant load
Home lighting & appliances	111	49	−62	
Electrification of home cooking	NA	NA	NA	
Growth in industry	794*	251	−543*	Significant differential sensitivity and load
Energy intensity of industry	NA	NA	NA	Significant load
Commercial demand for heating and cooling	173*	82	−91	Significant load
Commercial heating electrification	NA	NA	NA	
Commercial heating that is not electric	NA	NA	NA	
Commercial lighting & appliances	101	58	−43	
Electrification of commercial cooking	NA	NA	NA	

* Significant load and/or differential sensitivity.

supply or demand when tested as an individual element of the energy system. In Tables 3–5 these 'technology/fuel' variables are shown as having a differential sensitivity that is 'not applicable' along with a note of a 'significant load'.

The resulting 14 parameters constituted the independent variables adopted by the rapid calculator, with others untested. The parameter 'types of fuels from biomass' was cost-optimised, as it was expected that such activity would be price sensitive with the potential for exporting surpluses. A summary of the independent variables (parameters) is provided in Table 6, along with a description of each trajectory consistent with the DECC 2050 Pathways Calculator.

The rapid calculator was checked for consistency through running sweeps of each parameter and checked for validity by comparing the outputs of 16 test cases with the DECC Calculator. The comparison between the outputs from the test cases is summarised in Table 7. It will be noted from this table that differences in absolute net present value for investment in the entire energy system are in the range of $-£1.7 \times 10^5$ and $-£1.9 \times 10^5$ excepting one outlier. Differences in emissions from the entire energy system in 2050 are in the range of 20 $MTCO_2eqyr^{-1}$ and -2.16×10^{-2} $MTCO_2eqyr^{-1}$ between the results of the two models. The large disparity between absolute net present values estimated by the two models was almost entirely due to difficulties in replicating the DECC 2050 Pathways Calculator method of loan repayments. An alternative, reasonable methodology was applied consistently for the rapid calculator, shown in Eq. (2). Differences in calculation of underlying capital and operational expenditure between the two equivalents were proportionally similar to the emissions calculations.

Table 5
Results summary of the differential sensitivity analysis for other variables.

Intervention	Trajectory 1/TW h yr^{-1}(2050)	Trajectory 4/TW h yr^{-1} (2050)	Differential Sensitivity/TW h yr^{-1}	Notes
Geosequestration	NA	NA	NA	
Storage, demand shifting & interconnection	NA	NA	NA	Significant load
Indigenous fossil-fuel production	NA	NA	NA	NA

Table 6
Summary of trajectories for each independent variable of the rapid calculator.

(Code) parameter	Trajectory 1	Trajectory 2	Trajectory 3	Trajectory 4
(A) Nuclear power stations	No new nuclear power installed; estimated closure of final plant in 2035	~13 3 GW power stations delivering ~280 TW h yr^{-1}	~30 3 GW power stations delivering ~630 TW h yr^{-1}	~50 3 GW power stations delivering ~1030 TW h yr^{-1}
(B) CCS power stations	Demonstration plants only; no roll-out of CCS	~240 TW h yr^{-1} from 25 to 40 CCS power stations; comparable to current gas & coal generation	~340 TW h yr^{-1} from 35 to 60 CCS power stations; comparable to total current demand	~510 TW h yr^{-1} from 50 to 90 CCS power stations; build rate of gas plants in the 1990s
(C) CCS power station fuel mix	100% coal/biomass, 0% gas/biogas CCS after demonstration plants	66% coal/biomass, 33% gas/biogas CCS after demonstration plants	33% coal/biomass, 66% gas/biogas CCS after demonstration plants	0% coal/biomass, 100% gas/biogas CCS after demonstration plants
(D) Offshore wind	~1400 turbines in 2025, reducing to zero as decommissioned sites are not replanted	~10,000 turbines in 2050, delivering ~180 TW h yr^{-1}	~17,000 turbines in 2050, delivering ~310 TW h yr^{-1}	~40,000 turbines in 2050, delivering ~430 TW h yr^{-1}
(E) Land dedicated to bio-energy	Energy crops and food production similar to today	5% of land used for energy crops	10% of land used for energy crops	17% of land used for energy crops
(F) Shift to zero emission transport	By 2050, 20% plug in hybrid electric cars; 2.5% zero emission cars	By 2050, 54% plug-in hybrid vehicles; 11% zero emission vehicles, all buses hybrids	By 2050, 32% plug-in hybrid vehicles; 48% zero emission vehicles; 22% buses electric	By 2050 100% zero emission vehicles; all passenger trains electrified; 50% bus electrified
(G) Average temperature of homes	Average room temperature increases to 20 °C (a 2.5 °C increase on 2007)	Average room temperature increases to 18 °C (a 0.5 °C increase on 2007)	Average room temperature decreases to 17 °C (a 0.5 °C decrease on 2007)	Average room temperature decreases to 16 °C (a 1.5 °C decrease on 2007)
(H) Home heating electrification	The proportion of domestic heat supplied using electricity is 0–10%, as today	The proportion of new domestic heating systems using electricity is 20%	The proportion of new domestic heating systems supplied using electricity is 30–60%	The proportion of new domestic heating systems supplied using electricity is 80–100%
(I) Home heating that is not electric	The dominant non-electric heat source is gas or gas CHP (biogas if available)	The dominant non-electric heat source is coal or coal CHP (biomass if available)	The dominant non-electric heat source is waste heat from power stations	A mixture of gas/biogas; coal/biomass; and heat from power stations
(J) Growth in industry	UK industry output more than doubles by 2050	UK industry grows in line with current trends	UK industry output falls 30–40% by 2050	NA
(K) Energy intensity of industry	No electrification of processes, little improvement in energy intensity	Some processes electrified; moderate improvements in process emissions and energy demand	High electrification; CCS captures 48% of emissions; process emissions reduced	NA
(L) Commercial heating electrification	The proportion of non-domestic heat supplied using electricity is 0–10%, as today	The proportion of non-domestic heat supplied using electricity is 20%	The proportion of non-domestic heat supplied using electricity is 30–60	The proportion of non-domestic heat supplied using electricity is 80–100%
(M) Commercial heating that is not electric	The dominant non-electric heat source is gas or gas CHP (biogas if available)	The dominant non-electric heat source is coal or coal CHP (biomass if available)	The dominant non-electric heat source is heat from power stations	A mixture of gas/biogas, coal/biomass, and heat from power stations
(N) Storage, demand shifting & interconnection	Today's 3.5 GW storage & 4 GW interconnection with Europe for balancing	4 GW storage & 10 GW interconnection with Europe for balancing	7 GW storage with 2 more pumped storage, 15 GW interconnection & some demand shifting	20 GW storage with large lagoons, 30 GW interconnection & substantial demand shifting

Eq. (2): Calculation of loan repayments.

$$-pmt = pv \cdot \frac{rate(1+rate)^{nper}}{(1+rate)^{nper}-1} \quad (2)$$

where $-pmt$ = payment made each year over the life of the annuity. pv = present value of capital expenditure. $rate$ = the interest rate for that period. $nper$ = the total number of payment periods in the annuity.

Table 8 provides an overview of the parameter trajectories selected from exploring the scenario morphology to represent each UK energy system scenario family. By looking across the scenarios and identifying common trends one can make high level sweeping evaluations of strategy resilience.

The emission intensities of delivered energy sources under each UK energy scenario family have been extracted from the DECC 2050 Pathways Calculator. These intensities were derived from data describing flows of hydrocarbon production and consumption throughout the energy system, as well as bio-energy shares under each scenario [43]. The results are shown in Table 9 and illustrate how the emission intensity of gas is likely to remain largely unaffected. The emission intensity of grid supplied electricity could change significantly, to a relatively negligible intensity under three of the scenario families by 2030.

Wholesale prices for gas and electricity were extracted from the DECC 2050 Pathways Calculator for each scenario family. These prices reflect the combined capital, operating and fuel expenditure that contribute towards the provision of each delivered energy source discounted at an annual social discount rate of 3.8%. Unadjusted estimates are suitable for use in the 'No Climate Change' scenario family [43]. The wholesale prices were adjusted by the social cost of carbon for the 'Baseline Climate Change' scenario family [33]. Please refer to Appendices A and B for a full description of these values.

5. Evaluation of value at risk with demonstration on case study UK offices

This section describes the process of evaluating the implications of the scenarios for UK real estate. It focuses specifically on commercial offices, as assets of particularly high capital value.

Table 7
Summary comparison of rapid calculator and DECC 2050 Pathways calculator output.

Parameter														Total amortised cost (£NPV)			Absolute 2050 emissions ($MTCO_2eqyr^{-1}$)		
A	B	C	D	E	F	G	H	I	J	K	L	M	N	DECC	Rapid	Difference	DECC	Rapid	Difference
1	1	3	2	1	2	2	4	4	3	2	2	2	4	$6.9e^{6}$	$7.1e^{6}$	$-1.8e^{5}$	$4.4e^{2}$	$4.4e^{2}$	0.4
1	2	2	3	1	1	4	2	2	3	1	3	4	3	$7.3e^{6}$	$7.4e^{6}$	$-1.8e^{5}$	$4.5e^{2}$	$4.5e^{2}$	$2.2e^{-2}$
1	3	1	3	2	1	2	4	1	2	1	1	2	1	$6.9e^{6}$	$7.1e^{6}$	$-1.9e^{5}$	$4.4e^{2}$	$4.4e^{2}$	0.1
1	4	3	2	1	3	4	3	4	2	3	4	3	3	$7.5e^{6}$	$7.7e^{6}$	$-1.8e^{5}$	$3.2e^{2}$	$3.2e^{2}$	$-4.7e^{-2}$
2	1	4	2	1	3	4	2	4	3	1	2	1	2	$7.2e^{6}$	$7.4e^{6}$	$-1.8e^{5}$	$4e^{2}$	$4e^{2}$	0.2
2	2	4	1	1	1	4	3	1	1	2	1	2	1	$6.9e^{6}$	$7e^{6}$	$-1.8e^{5}$	$5e^{2}$	$5e^{2}$	0.4
2	3	4	4	2	2	1	2	3	3	1	3	3	1	$7.5e^{6}$	$7.6e^{6}$	$-1.8e^{5}$	$4.2e^{2}$	$4.2e^{2}$	0.1
2	4	2	3	3	4	4	3	3	2	2	4	2	4	$7.4e^{6}$	$7.6e^{6}$	$-1.9e^{5}$	$2.7e^{2}$	$2.7e^{2}$	1.3
3	3	3	3	3	1	3	4	2	1	1	1	2	3	$7.1e^{6}$	7.2e6	$-1.2e^{5}$	$4.8e^{2}$	$4.6e^{2}$	20
3	2	1	2	1	1	4	3	1	2	3	3	1	3	$7e^{6}$	7.1e6	$-1.9e^{5}$	$4e^{2}$	$4e^{2}$	0.1
3	3	3	1	4	1	2	2	3	2	3	1	4	4	$7.2e^{6}$	7.4e6	$-1.8e^{5}$	$3.9e^{2}$	$3.9e^{2}$	1.5
3	4	1	2	3	1	4	1	2	3	1	2	2	1	$7.2e^{6}$	7.3e6	$-1.9e^{5}$	$4.7e^{2}$	$4.6e^{2}$	0.5
4	1	4	1	2	2	2	2	4	1	2	4	3	4	$7.2e^{6}$	7.4e6	$-1.8e^{5}$	$4.6e^{2}$	$4.5e^{2}$	0.2
4	2	3	4	3	4	2	3	4	2	2	2	4	1	$7.7e^{6}$	7.9e6	$-1.9e^{5}$	$3.6e^{2}$	$3.6e^{2}$	1
4	3	3	1	3	2	2	3	3	3	3	2	2	3	$6.9e^{6}$	7.1e6	$-1.8e^{5}$	$2.8e^{2}$	$2.7e^{2}$	0.6
4	4	2	2	2	4	4	1	1	2	2	4	3	3	$7.1e^{6}$	7.3e6	$-1.8e^{5}$	$3.4e^{2}$	$2.4e^{2}$	0.5

Table 8
Trajectory comparison across the four UK energy scenario families.

Parameter	Low investment in emissions	High investment in emissions	Low investment in energy	High investment in energy
Nuclear power stations	1	4	4	1
CCS power stations	1	1	1	4
CCS power station fuel mix	1	2	1	4
Offshore wind	1	4	1	4
Land dedicated to bio-energy	1	4	1	4
Shift to zero emission transport	1	4	1	4
Average temperature of homes	1	4	1	4
Home heating electrification	1	3	1	2
Home heating that is not electric	1	3	1	2
Growth in industry	1	3	1	3
Energy intensity of industry	1	3	1	3
Commercial heating electrification	2	3	3	4
Commercial heating that is not electric	2	3	2	4
Storage, demand shifting & interconnection	1	4	2	4

Table 9
Emission intensities of energy sources under each UK energy scenario towards 2050/$tCO_2eq\ MW\ h^{-1}$ [43].

Time period	Low investment in emissions		High investment in emissions		Low investment in energy		High investment in energy	
	Gas	Grid electricity	Gas	Grid electricity	Gas	Grid electricity	Gas	Grid electricity
2010–2014	0.18	0.51	0.18	0.51	0.18	0.51	0.18	0.51
2015–2019	0.18	0.47	0.18	0.46	0.18	0.47	0.18	0.46
2020–2024	0.18	0.42	0.18	0.33	0.18	0.38	0.18	0.32
2025–2029	0.18	0.36	0.18	0.19	0.18	0.24	0.18	0.08
2030–2034	0.18	0.33	0.18	0.05	0.18	0.07	0.18	0.01
2035–2039	0.18	0.35	0.18	0	0.18	0	0.18	0.01
2040–2044	0.18	0.36	0.18	0	0.18	0	0.18	0.01
2045–2050	0.18	0.37	0.16	0	0.18	0	0.18	0.01
2050	0.18	0.37	0.14	0	0.18	0	0.18	0.01

5.1. Research conditions

The instruments which have been selected are considered most appropriate for this application. These case studies are dependent on all the assumptions on which the supporting instruments employed have themselves adopted. Additionally, a number of conditions need be placed so that one can demonstrate employment of the methodologies in a present day business environment. It is very challenging and beyond the scope of this study to develop descriptions of expectations for cost overheads on wholesale energy prices that may affect consumer energy tariffs towards 2050. Therefore, this has been kept consistent with February 2010 observations [44]. The appropriate risk-free rate is also highly dynamic. This study has collected historic market data to freeze an illustrative rate for use in this analysis taken from the Financial Times [45]. It is also not currently usual practice for rental valuations to be absolutely net of costs as they often do not include a depreciation charge. However, for the purpose of this study it is assumed that the rental valuations stated are absolutely net. Further, 'unregulated' electricity consumption from lifts, small power and external lighting is often not sub-metered which is necessary to make fair comparisons between observed and simulated energy consumption when evaluating idiosyncratic factors [46]. Therefore, the following conditions have been necessarily placed on the study:

Condition 1: Energy tariffs remain proportionally consistent with those observed in February 2010.
Condition 2: The risk-free rate can be determined by the yield on a 10-year UK gilt and is equivalent to 1.67%.
Condition 3: The rental values stated are absolutely net.
Condition 4: Metered energy consumption is exclusive of electrical consumption by lifts, small power and external lighting.

5.2. Data collection

A 'market portfolio' of office cases was selected of strategic importance to the research rather than using a representative sample. Table 10 shows the cases selected and the rationale behind the case study design. The selection is intended to maximise the utility of information from office building design, with utmost variation in service strategy and asset depreciation. It is concentrated on geographical areas of the UK at highest risk of temperature change [47]. Such a selection is intended to be a useful example of a diversified pool of UK offices for comparison.

All available 'as built' drawings were collected for each case, supplemented by direct field observations, measurements and photographs taken during two day site visits. Further, pertinent sections of operations and maintenance manuals, including design specifications, were gathered as well as a recent season of monthly readings and the rent currently being paid by the tenants.

5.3. Performance evaluation

The information collected for each case study was used to run ensembles of dynamic building simulations using IES Virtual Environment.[2] To make consistent comparisons between each case study many of the standards of the National Calculation Methodology (NCM) were adopted [48].

To assess energy performance the NCM database of standard activities that describe standard occupancy, temperature setpoints, infiltration and heat gain profiles were used. In cases where the exact U-values of surface constructions were unknown, an estimate was drawn from the NCM material database. However, in order to assess future performance of each case this study used some alternative input data from the current NCM protocol. Energy source emission intensities and delivered energy prices were made test variables and adjusted throughout the time-series according to the scenario descriptions. Weather data was taken from the UKCP09 TRY set of central estimates for the closest geographical location to the case site [31].

Deviations in annual energy costs under each of the eight scenario descriptions were then deduced for each case. The resulting descriptions were evaluated using arbitrage pricing theory described generically in Eqs. (3) and (4).

Eq. (3): arbitrage pricing theory.

$$Er_i = E_i + \beta_{i1}F_{i1} + \beta_{i2}F_2 \cdots + \beta_{ik}F_k + \epsilon_i \tag{3}$$

where Er_i = expected return on investment for the asset. E_i = expected return on the asset using a single factor model. β_{ik} = asset sensitivity on the systematic kth factor, derived from Eq. (3). F_{ik} = excess return (in excess of the risk free rate) on the systematic kth factor. $\in_i$ = excess return (in excess of the risk free rate) posed by unsystematic idiosyncratic factors.

Eq. (4): model of asset sensitivity.

$$\beta = \frac{Cov(r_s, r_m)}{Var(r_m)} \tag{4}$$

where r_s = return to asset. r_m = return to market benchmark.

For the purpose of this study arbitrage pricing theory was applied in the form shown in Eq. (5). Each systematic climate factor is itself described by a set of explorative energy scenarios which are evaluated using Eq. (6). Market variance is taken as the variance of the 'market portfolio' throughout the scenario time-series.

Eq. (5): Evaluation of excess return for energy performance.

$$Er_p = F_{pn} + F_{pb} + (r_{\epsilon p} - 0.0167) \tag{5}$$

where Er_p = excess return for energy performance. F_{pn} = excess return on 'No Climate Change' factor. F_{pb} = excess return on 'Baseline Climate Change' factor. $r_{\in p}$ = standard deviation between monthly simulated and observed energy consumption over 1 year.

Eq. (6): evaluation of excess return on climate factors.

$$F_{pk} = \frac{\beta_{pik}(r_{p1k} - 0.0167) + \beta_{p2k}(r_{p2k} - 0.0167) + \beta_{p3k}(r_{p3k} - 0.0167) + \beta_{p4k}(r_{p4k} - 0.167)}{4} \tag{6}$$

where r_{pk} = excess return on the kth climate change factor. β_{p1k} = simulation sensitivity to 'Low Investment in Emissions' scenario on the kth factor, evaluated using Eq. (2). r_{p1k} = mean deviation of case studies on 'Low Investment in Emissions' scenario on kth factor. β_{p2k} = simulation sensitivity to 'High Investment in Emissions' scenario on the kth factor, evaluated using Eq. (2). r_{p2k} = mean deviation of case studies on 'High Investment in Emissions' scenario on kth factor. β_{p3k} = simulation sensitivity to 'Low Investment in Energy' scenario on the kth factor, evaluated using Eq. (2). r_{p3k} = mean deviation of case studies on 'Low Investment in Energy' scenario on kth factor. β_{p4k} = simulation sensitivity to 'High Investment in Energy' scenario on the kth factor, evaluated using Eq. (2). r_{p4k} = mean deviation of case studies on 'High Investment in Energy' scenario on kth factor.

5.4. Results

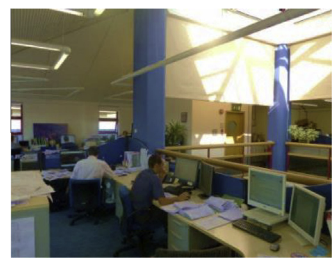
Here cross-examinations are made between cases. Comparisons are made between the idiosyncratic factors of the case studies. Evaluations of systematic factors to energy performance are made for all the case studies as an example market for which each case has a specific sensitivity. Rental values are then compared with these evaluations of excess return for energy performance.

5.4.1. Idiosyncratic factor

An idiosyncratic factor may be defined as residual excess returns not explained by systematic factors such as those described by the scenarios that are evaluated in this study. When making an appraisal of an appropriate required return from the case studies that constitute the market portfolio, idiosyncratic factors may be determined through calculating the standard deviation between simulated and observed energy costs throughout a recent season. A comparison between observed and simulated energy costs is shown in Fig. 3. It is important to note that this comparison would not be fair if we had not assumed Condition 4 in this study.

[2] An integrated building simulation suite that includes approved packages suitable for DSM and SBEM energy assessment.

Table 10
Case study selection and summarised description.

Servicing strategy		
Fully air-conditioned	Mixed mode	Naturally ventilated
<5 Years old (newly built)[a]		
		
Case A, Bristol Rent: £243.41 m^{-2} yr^{-1}. Prime central location in Bristol. 7450 m^2 gross floor area	Case B, Bristol. Rent: £242 m^{-2} yr^{-1}. Located in a business park near Bristol. 11,250 m^2 gross floor area. Mixed mode office	Case C, Bristol. Rent: £263 m^{-2} yr^{-1}. Prime central location in Bristol. 7485 m^2 gross floor area. Mixed mode office
Fully air-conditioned office refurbishment. Mechanical ventilation with air-source heat pumps. Multiple occupants since 2008	Active chilled beams and perimeter heating. Night purge ventilation during cooling season. Multiple occupants since 2009	Displacement ventilation with fan coil units for heating and contingency cooling in case of uncomfortable external air temperatures. Sole occupier since 2010
>15 Years old (near end of service life)		
		
Case D, London Rent: £601.74 m^{-2} yr^{-1}. Prime central location in London. 6340 m^2 gross floor area	Case E, London Rent: £265.48 m^{-2} yr^{-1}. Prime central location in London. 1390 m^2 gross floor area. Mixed mode office	Case F, Bristol Rent: £155 m^{-2} yr^{-1}. Located in a business park near Bristol. 1161 m^2 gross floor area
Fully air-conditioned office. Mechanical ventilation with fan coil units. Sole occupier since 1998	Zoned naturally ventilated with perimeter heating or air-source heat pumps. Multiple occupiers since 1964	Naturally ventilated office. Perimeter heating. Sole occupier since 1990

[a] Occupied for less than five years at time of survey (not publication).

Therefore, the results of this particular analysis are simply indicative and should not be used to support or reject any hypotheses. Table 11 describes excess return posed by idiosyncratic factors for each case study. Note, Case E is not included because of the inadequate readings taken on-site to make this analysis.

5.4.2. Systematic factors

Excess returns on the 'market portfolio' are determined through determining mean deviations in discounted consumption throughout the 40-year time-series for all cases and show a clear difference between climate factors. The sensitivity of each case study relative to the 'market portfolio' is described by its Beta coefficient using Eq. (5). Table 12 shows the results and describes how aggregate energy performance amongst the cases varies significantly between factors, with 'Baseline Climate Change' exposing the cases to significant additional energy performance risk. Case D is most negatively correlated with the market portfolio under all scenarios, whilst Case F is most positively correlated. Case's C and D have quite different servicing strategies, but both exhibit consistent correlations across all scenarios. Sensitivities of other cases changed greatly depending on the level of investment in the energy system. Mixed-mode or air-conditioned cases (Cases A and B) were more positively correlated in high investment scenarios. Naturally ventilated cases (Cases E and F) were less positively correlated in high investment scenarios.

A comparison between the combined excess return from systematic and idiosyncratic factors for each case is shown in Fig. 4. It shows that energy performance contributes between almost 1% and 8% excess return on investment across all the case studies.

In taking away the idiosyncratic factors from the results described in Fig. 4 one can compare the case studies expected responses to systematic factors only. A comparison between excess returns for each case is shown in Fig. 5, showing distinct differences with Fig. 4 in cases where idiosyncratic factors are included. It shows that energy performance contributes between 1% and 8% excess return on investment across all the case studies.

5.4.3. Comparing rental value and financial assessments

Figs. 6–9 provide comparisons between energy performance premiums and rental value for the six case studies. With such a small sample it is not possible to generalise upon gradients, although emerging trends are apparent.

Figs. 7–9 show the same comparison whilst externalising idiosyncratic factors from the analysis. The relationship between systematic excess returns and rental value in these graphs may be described as a Capital Market Line in quantitative finance. Within a large sample such a trend may be used to capitalise on energy management, in which buildings are over-valued above trend and under-valued below trend.

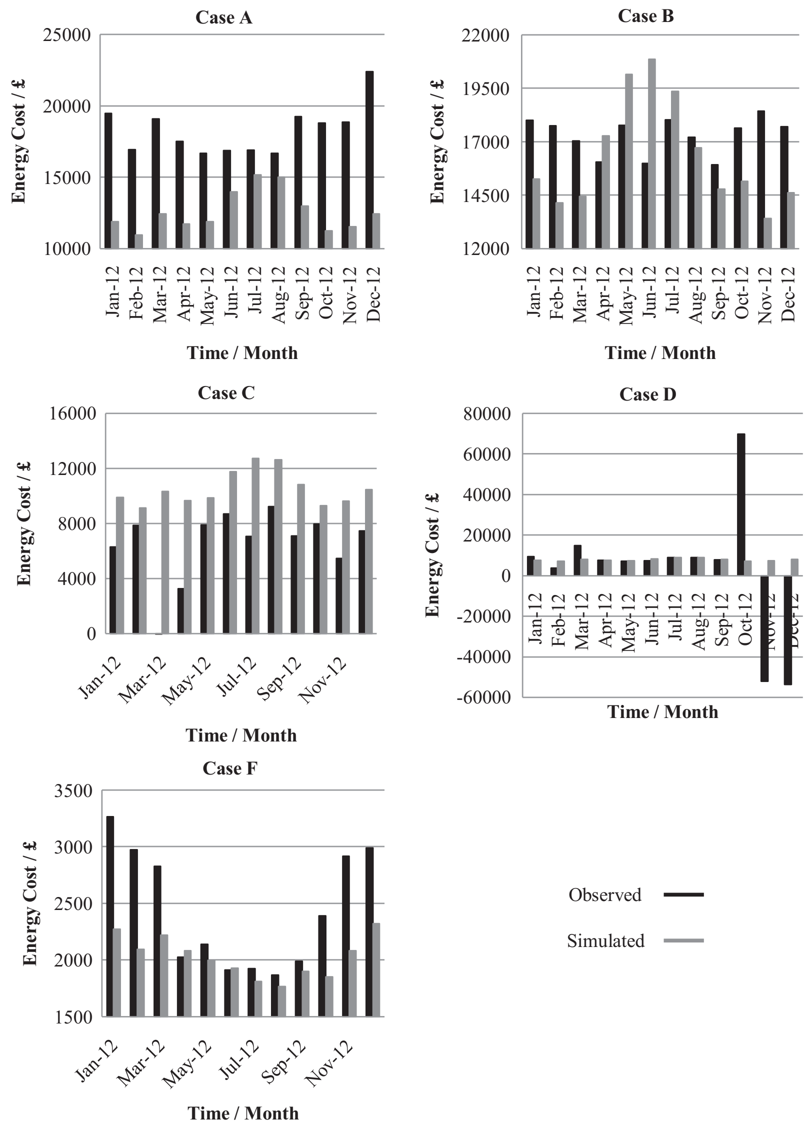


Fig. 3. Comparison between observed and simulated energy cost over one year. Top left clockwise: Case A; B; D; F; C.

Table 11
Case study excess returns for idiosyncratic factors.

Case	Idiosyncratic (%)
A	1.8
B	−1.28
C	0.69
D	−0.29
E	0.00
F	−0.19

By determining the difference between the findings shown in Figs. 7 and 8 one can estimate corrections to expected returns on investment. Fig. 9 illustrates this potentially significant relationship, showing a costly and regressive correction to expected returns in internalising climate change into financial accounting. Such tentative findings describe a condition where assets of highest rental value are least exposed to these downside risks.

Table 12
Market scenarios and beta coefficients for all case studies describing correlations between market and individual case deviation.

Factor	No climate change				Baseline climate change			
Scenario	Low inv. in emissions	High inv. in emissions	Low inv. in energy	High inv. in energy	Low inv. in emissions	High inv. in emissions	Low inv. in energy	High inv. in energy
F_{ik}	−2.4%	−2.9%	−0.9%	−1.7%	4.9%	4.9%	7.1%	6.3%
Case								
A	1.10	1.19	0.45	1.21	1.03	1.23	0.52	1.24
B	0.95	1.03	0.60	1.04	0.93	1.02	0.63	1.04
C	0.88	0.91	0.82	0.92	0.85	0.90	0.80	0.91
D	0.35	0.36	0.35	0.36	0.33	0.34	0.33	0.34
E	0.91	0.84	1.29	0.82	0.92	0.81	1.24	0.80
F	1.81	1.67	2.48	1.64	1.94	1.69	2.48	1.67

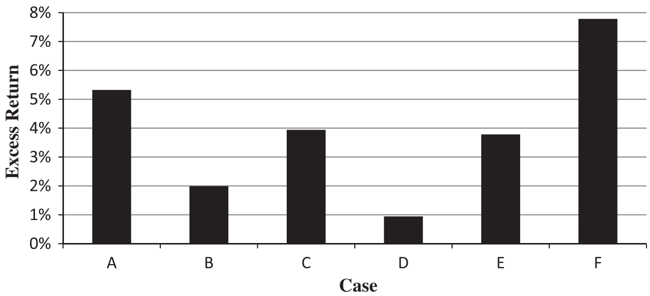


Fig. 4. Excess returns for each case study posed by uncertainty in market expectations for energy performance.

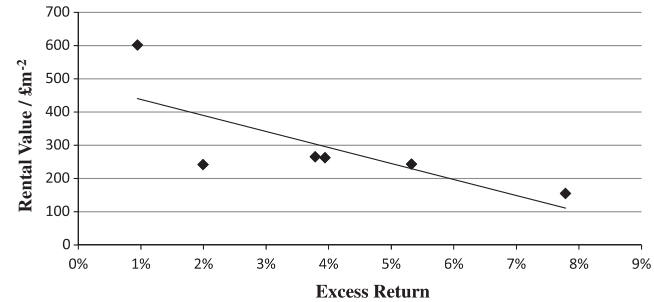


Fig. 6. Comparison between excess returns for energy performance and rental value for the six case studies.

6. Discussion

6.1. Research evaluation

This research explores the future of energy management in the built environment and seeks to make rational ex-post evaluations of historic observed expert judgements, as opposed to ex-ante speculation. Therefore, the findings are highly dependent on the quality of information available to contributors. Its findings may well not reflect the observed financial performance of some markets due to market failures within the socio-technical systems analysed.

The exploration of market expectations was highly dependent on the judgements of those that took part in the driver survey and facilitated workshops by Parkinson et al. [14]. It was also limited by the expense of computer processing, with only the most significant 150,994,944 iterations of the DECC 2050 Pathways Calculator explored. The quality of the DECC 2050 Pathways Calculator is dependent on the invitation of scrutiny from the general public. The tools value is contingent on the quantity and quality of contributions towards it. It is important to note that this analysis rests on a time dependent context. Therefore, perfect execution should involve continuous update, lending itself to being employed through an online application. It may also be necessary to re-orientate the framework in the future through correcting the critical uncertainties adopted if they lost relevance.

By employing building simulation one can remove asset specific idiosyncratic elements from analyses. Once a large number of case studies have been assessed it could be possible for asset managers to make ex-ante investment decisions based upon the trends observed within resulting datasets. By developing a trend between corrections to internalise climate change impacts and rental value one could validate specific energy assessments and re-examine the energy management of buildings accordingly. To date, this has been a major shortcoming of present applications of energy assessment.

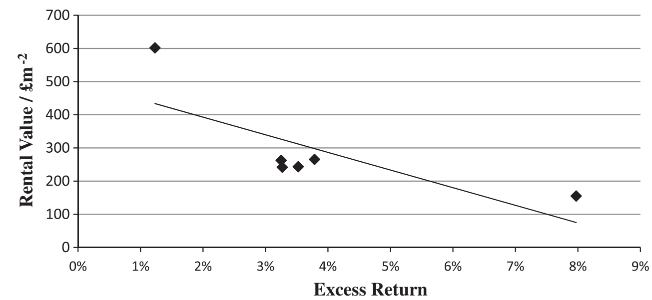


Fig. 7. Comparison between excess returns for energy performance posed by systematic factors only and rental value for the six case studies.

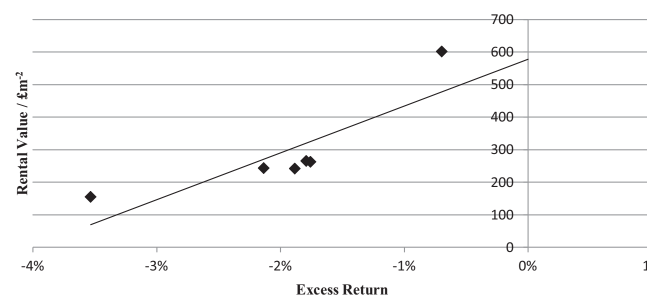


Fig. 8. Comparison between excess returns for energy performance posed by systematic 'No Climate Change' factor only and rental value for the six case studies.

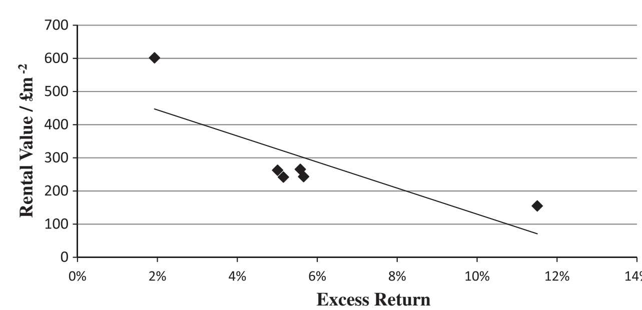


Fig. 9. Comparison between rental value and corrections to excess return for each case study posed by uncertainty in systematic expectations for energy performance due to the internalisation of 'Baseline Climate Change' factor into accounting.

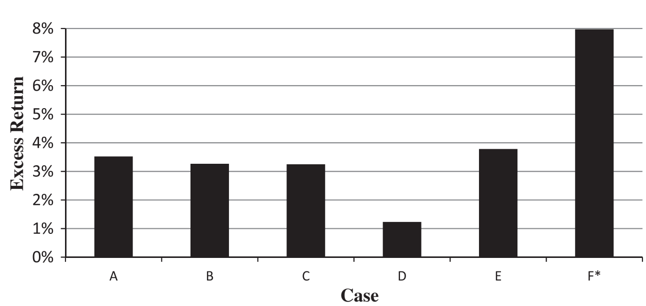


Fig. 5. Excess returns for each case study posed by uncertainty in systematic market expectations for energy performance.

The results of this research are limited in that they only provide point estimates of value at risk from energy performance. Within the framework presented there is scope for developing Bayesian probability distributions to provide further insights and qualification of uncertainty.

6.2. Conclusions

This research asked the question:

> "How can specific market risks arising from expectations for the energy performance of real estate be appropriately evaluated?"

This research addressed this question through designing a value-at-risk framework for appropriate capital budgeting with regard to building energy performance and carrying out a feasibility study on a small sample of case studies to demonstrate implementation.

The key contributions of this research were the result of a novel exploration of supporting systems morphology to develop descriptions of market expectations for energy performance within the UK constraint. They are based upon an exhaustive explorative search of future conditions, are contingent on an axes of critical uncertainties primarily developed through empirical data collection and describe pathways for each scenario that are constrained only by the limits of plausibility. These expectations were then used to make a novel financial evaluation of the energy performance of UK real estate within a present day business environment. Such methods allow the results of energy assessment to be communicated using metrics that can be readily compared to other investment opportunities and asset classes, such as equities. Such methods also readily distinguish between systematic and idiosyncratic factors of risk. They also allow climate change to be appropriately internalised into valuation through employment of widely available tools allowing for immediate application.

The management of energy in buildings can be appropriately evaluated through assessing a large sample of assets using the methods described in this research. Through comparing the systematic factors of energy performance specific to an evaluated asset with the Capital Market Line, residual value at a given level of risk may indicate the degree of error in energy management and an opportunity to capitalise. When applied to the field of building energy management this risk-adjusted indicator of 'alpha' provides an appropriate basis for decision-making which may lead to actions such as: property transactions; increased scrutiny of the assessment; repositioning of assets through retrofit or refurbishment; and/or asset revaluation.

Acknowledgments

The authors would like to thank the Engineering and Physical Sciences Research Council, Modern Built Environment Knowledge Transfer Network and Grosvenor Group for funding this research.

Would also like to thank Bevan Brittan LLP, CBRE, the Environment Agency, WS Atkins, Hoare Lea and Partners and Grosvenor Group for facilitating access to case studies.

Elements of this work were performed using the Darwin Supercomputer of the University of Cambridge High Performance Computing Service (http://www.hpc.cam.ac.uk/), provided by Dell Inc. using Strategic Research Infrastructure Funding from the Higher Education Funding Council for England and funding from the Science and Technology Facilities Council.

I am also very grateful to the inspiring contributions of Dr. Alison Cooke and Dr. Theophilus Hacking.

Appendix A

Wholesale and social cost of carbon (SCC) adjusted electricity prices under each energy scenario within the 'Baseline Climate Change' scenario family/2007 £MW h^{-1} [43,33].

Time period	Low investment in emissions		High investment in emissions		Low investment in energy		High investment in energy	
	Discounted wholesale price	SCC adjusted price	Discounted wholesale price	SCC adjusted price	Discounted wholesale price	SCC adjusted price	Discounted wholesale price	SCC adjusted price
2010	51.98	60.39	51.81	60.22	51.81	60.22	52.00	60.41
2011	50.08	58.74	49.91	58.58	49.91	58.58	50.10	58.76
2012	48.24	57.16	48.09	57.01	48.09	57.01	48.26	57.18
2013	46.48	55.65	46.33	55.50	46.33	55.50	46.50	55.67
2014	44.78	54.20	44.63	54.06	44.63	54.06	44.79	54.22
2015	47.89	56.82	50.12	58.86	50.12	59.05	47.57	56.30
2016	46.14	55.30	48.29	57.25	48.29	57.45	45.83	54.79
2017	44.45	53.84	46.52	55.72	46.52	55.92	44.15	53.34
2018	42.82	52.45	44.82	54.24	44.82	54.45	42.53	51.96
2019	41.25	51.12	43.18	52.83	43.18	53.04	40.98	50.63
2020	43.78	52.80	68.91	76.00	60.34	68.51	45.85	52.73
2021	42.18	51.41	66.39	73.64	58.13	66.49	44.17	51.21
2022	40.63	50.08	63.96	71.38	56.01	64.55	42.56	49.75
2023	39.15	48.80	61.62	69.20	53.96	62.69	41.00	48.35
2024	37.71	47.58	59.36	67.11	51.98	60.90	39.50	47.01
2025	40.42	49.06	71.05	75.61	63.14	68.89	40.28	42.20
2026	38.94	47.76	68.45	73.10	60.83	66.70	38.81	40.77
2027	37.52	46.33	65.95	70.60	58.60	64.48	37.39	39.34
2028	36.15	45.14	63.53	68.28	56.45	62.45	36.02	38.02
2029	34.82	44.00	61.21	66.05	54.39	60.50	34.70	36.74
2030	33.69	42.26	43.47	44.77	43.27	45.09	30.68	30.94
2031	32.46	41.20	41.88	43.21	41.69	43.54	29.55	29.82
2032	31.27	40.17	40.35	41.70	40.16	42.05	28.47	28.74

Appendix A (*continued*)

Time period	Low investment in emissions		High investment in emissions		Low investment in energy		High investment in energy	
	Discounted wholesale price	SCC adjusted price	Discounted wholesale price	SCC adjusted price	Discounted wholesale price	SCC adjusted price	Discounted wholesale price	SCC adjusted price
2033	30.12	39.19	38.87	40.25	38.69	40.61	27.43	27.71
2034	29.02	38.25	37.45	38.85	37.27	39.23	26.43	26.71
2035	28.06	38.03	31.01	31.01	37.10	37.10	18.69	18.97
2036	27.04	37.18	29.88	29.88	35.74	35.74	18.00	18.29
2037	26.05	36.37	28.78	28.78	34.43	34.43	17.35	17.64
2038	25.09	35.59	27.73	27.73	33.17	33.17	16.71	17.01
2039	24.17	34.84	26.71	26.71	31.96	31.96	16.10	16.40
2040	24.81	35.96	15.93	15.93	24.65	24.65	10.95	11.26
2041	23.90	35.23	15.35	15.35	23.75	23.75	10.55	10.86
2042	23.03	34.54	14.79	14.79	22.88	22.88	10.16	10.48
2043	22.18	33.88	14.25	14.25	22.04	22.04	9.79	10.11
2044	21.37	33.06	13.73	13.73	21.24	21.24	9.43	9.75
2045	20.73	32.93	8.86	8.86	17.92	17.92	5.30	5.63
2046	19.97	32.35	8.53	8.53	17.26	17.26	5.11	5.45
2047	19.24	31.81	8.22	8.22	16.63	16.63	4.92	5.26
2048	18.53	31.29	7.92	7.92	16.02	16.02	4.74	5.09
2049	17.85	30.80	7.63	7.63	15.43	15.43	4.57	4.92
2050	16.79	29.92	5.64	5.64	10.87	10.87	1.42	1.78

Appendix B

Wholesale and social cost of carbon (SCC) adjusted gas prices under each energy scenario within the 'Baseline Climate Change' scenario family/2007 £MW h^{-1} [43,33].

Time period	Low investment in emissions		High investment in emissions		Low investment in energy		High investment in energy	
	Discounted wholesale price	SCC adjusted price	Discounted wholesale price	SCC adjusted price	Discounted wholesale price	SCC adjusted price	Discounted wholesale price	SCC adjusted price
2010	17.41	20.38	17.28	20.25	17.43	20.40	17.28	20.25
2011	16.77	19.83	16.65	19.71	16.79	19.85	16.65	19.71
2012	16.16	19.31	16.04	19.19	16.18	19.33	16.04	19.19
2013	15.57	18.80	15.45	18.69	15.58	18.82	15.45	18.69
2014	15.00	18.32	14.89	18.21	15.01	18.34	14.89	18.21
2015	15.89	19.31	15.65	19.07	15.68	19.09	15.65	19.07
2016	15.31	18.82	15.08	18.59	15.10	18.61	15.08	18.59
2017	14.75	18.35	14.53	18.12	14.55	18.15	14.53	18.12
2018	14.21	17.90	13.99	17.68	14.02	17.70	13.99	17.68
2019	13.69	17.47	13.48	17.26	13.50	17.28	13.48	17.26
2020	15.07	18.94	15.20	19.07	14.26	18.12	15.02	18.89
2021	14.52	18.47	14.64	18.60	13.73	17.69	14.47	18.43
2022	13.99	18.03	14.11	18.15	13.23	17.28	13.94	17.99
2023	13.47	17.61	13.59	17.73	12.75	16.88	13.43	17.57
2024	12.98	17.21	13.09	17.32	12.28	16.51	12.94	17.17
2025	14.48	18.80	16.37	20.69	13.05	17.37	14.36	18.68
2026	13.95	18.36	15.77	20.18	12.57	16.98	13.84	18.24
2027	13.44	17.85	15.19	19.60	12.11	16.52	13.33	17.74
2028	12.95	17.45	14.64	19.13	11.67	16.16	12.84	17.34
2029	12.48	17.06	14.10	18.69	11.24	15.83	12.37	16.96
2030	12.96	17.64	16.61	21.28	12.04	16.72	12.87	17.54
2031	12.49	17.25	16.00	20.76	11.60	16.37	12.40	17.16
2032	12.03	16.89	15.41	20.27	11.18	16.03	11.94	16.80
2033	11.59	16.54	14.85	19.79	10.77	15.71	11.51	16.45
2034	11.17	16.20	14.30	19.34	10.37	15.41	11.08	16.12

(*continued on next page*)

Appendix B (*continued*)

Time period	Low investment in emissions		High investment in emissions		Low investment in energy		High investment in energy	
	Discounted wholesale price	SCC adjusted price	Discounted wholesale price	SCC adjusted price	Discounted wholesale price	SCC adjusted price	Discounted wholesale price	SCC adjusted price
2035	10.40	15.53	17.82	22.95	10.02	15.15	10.68	15.81
2036	10.02	15.24	17.17	22.38	9.65	14.87	10.29	15.50
2037	9.66	14.96	16.54	21.84	9.30	14.61	9.91	15.22
2038	9.30	14.70	15.93	21.33	8.96	14.36	9.55	14.94
2039	8.96	14.45	15.35	20.84	8.63	14.12	9.20	14.69
2040	8.47	14.05	24.58	30.16	8.29	13.87	8.74	14.31
2041	8.16	13.83	23.68	29.35	7.99	13.66	8.42	14.08
2042	7.86	13.62	22.81	28.57	7.70	13.45	8.11	13.87
2043	7.57	13.42	21.98	27.82	7.42	13.26	7.81	13.66
4044	7.30	13.14	21.17	27.02	7.14	12.99	7.53	13.37
2045	7.03	12.97	55.13	61.07	6.88	12.82	7.20	13.14
2046	6.78	12.80	53.11	59.14	6.63	12.66	6.94	12.96
2047	6.53	12.64	51.17	57.28	6.39	12.50	6.68	12.80
2048	6.29	12.50	49.30	55.50	6.15	12.36	6.44	12.65
2049	6.06	12.36	47.49	53.79	5.93	12.22	6.20	12.50
2050	5.75	12.13	407.59	413.98	5.72	12.10	5.94	12.33

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