LOW CARBON LIVING CRC

Adelaide Living Laboratory

Value Proposition: Literature Review

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Disclaimer

This report is confidential and was prepared exclusively for the CRC for Low Carbon Living. It is not intended for, nor do we accept any responsibility for its use by any third party.

Peer Review Statement

N/A.

Contents

Acronyms

CFL	Compact fluorescent lamp
GDP	Gross domestic product
LED	Light emitting diode
NatHERS	Nationwide House Energy Rating Scheme
NPV	Net present value

Executive Summary

Value proposition for low carbon living

The value proposition for low carbon living is defined as the articulation of the measurable value an organisation or individual will receive from the experience; where the end value equates to the perceived benefits minus perceived costs. This means that the value of low carbon living is unique to the perspective of the investor, and the set of benefits and costs included in the economic equation are related only to those likely to be perceived by the investor. For example: if the investor is a homebuyer the factors contributing to the value of low carbon living will be different to the range of public benefits and costs experienced by the wider community where the investor is government.

The literature review

The literature documents a wide range of private and public benefits and costs associated with low carbon living. The literature relating to low carbon living is particularly rich, describing the benefits and costs associated with different building typologies, different climates and different development scales. Empirical evidence is available from individual buildings, multiple unit buildings, and collections of buildings.

The literature provides evidence of benefits and costs associated with energy and water saving technology and behaviour strategies, low carbon construction strategies, and the application of renewable energy technologies in low carbon buildings. Evidence is also available regarding the value of innovation that is stimulated by regulatory and non-regulatory actions to deliver low carbon buildings.

The actions taken to create low carbon buildings provide additional positive and negative externalities that should be included in specific value propositions. For example: health, productivity and other benefits due to thermally comfortable buildings are well documented in the literature and may provide individual households and the community with significant benefits, but many of these are yet to be monetised for use in value propositions.

Green building facades and roofs can provide a range of benefits such as stormwater management, air pollution reduction, heat island effect reduction, energy savings, improved acoustic, privacy, better aesthetics and increased biodiversity, but with the exception of predicted energy savings, many of these benefits have not been monetised in a manner that is easily transferable to the value proposition exercise.

The literature also provides evidence that estate design strategies can deliver low carbon outcomes with externalities such as safety and security, increased social interactions, and low carbon impact behaviours such as community gardens and support networks. Less available in the literature is the evidence base for valuing that creation of social capital for encouraging and maintaining low carbon behaviours. Although the literature provides reasonable evidence of successful strategies for creating a sense of community that is valued by residents, and documents some of the benefits to participants, those benefits are yet to be fully monetised and included in value proposition statements.

The Adelaide Living Laboratory provides a unique opportunity to expand the global knowledge base on the value of low carbon living, and address some of the highlighted gaps in the literature.

Adelaide as a research hub for low carbon living

The value proposition exercise is a part of the Adelaide Living Laboratory project funded by the CRC for Low Carbon Living (CRC-LCL), with the South Australia Government (Renewal SA) as the key project partner.

CRC for Low Carbon Living

The CRC for Low Carbon Living is a national research and innovation hub which seeks to enable a globally competitive Australian low carbon built environment sector. With a focus on collaborative innovation, the CRC-LCL brings together experts from industry, government and leading researchers to develop pathways to low carbon living.

CRC-LCL is designed to develop new social, technological and policy tools for facilitating the development of low carbon products and services to reduce greenhouse gas emissions in the built environment.

A key objective of the CRC-LCL is to help cut Australia's residential and commercial building carbon emissions by 10 mega tonnes by 2020, which is the environmental equivalent of taking 2.3 million cars off the road each year.

Adelaide Living Laboratories

The four year Adelaide Living Laboratory venture is an action based research project drawing evidence from three key Adelaide development sites at Tonsley, Lochiel Park and Bowden. Each of these sites has been established to meet specific government policy objects, is physically created by the local building and construction industry and includes detailed monitoring by the University of South Australia.

The Adelaide Living Laboratory project utilises the expertise and skills of community, industry and university participants to undertake site-specific research to build a stronger evidence base supporting government policy and planning, and industry delivery. The unique program of research is designed to help build a better understanding of low carbon living.

Stage 1 of the Adelaide Living Laboratory project explores four research themes: (a) co-creation; (b) integrated energy, water, waste and transport precinct modelling; (c) energy demand management solutions; and, (d) the value proposition for investment in low carbon development.

Value proposition research

Low carbon living provides a value proposition to various stakeholder investors according to the scale and scope of the value equation. From a development scale perspective investigations will be undertaken at single building/household level up to suburb scale development, with each level introducing new economic costs and benefits, and at each level the value proposition appeals to different stakeholders.

The program is designed to develop a total of 8 value propositions and should capture a diverse range of impacts from building energy savings to human health benefits to transport to food system to biodiversity to social sustainability impacts, with each change of scope and level of complexity realising benefits to different stakeholders.

This first report provides the initial literature review for the value proposition exercise. Further reports describing each value proposition will be developed throughout the four year research exercise, and add to this literature review.

Introduction

The value of low carbon living is the net of all benefits and costs perceived by the investor. This means that the particular benefits and costs used to determine a value proposition are only those relevant to the particular investor. Different investors: say home buyers, home builders, estate developers and government regulators; each perceive the value of that investment according to slightly different sets of benefits and costs. For example, home buyers may value low operational energy costs and increased thermal comfort from low carbon homes, whereby the wider society, represented by the government, may value decreased infrastructure costs associated with lower energy use and reduced peak energy demand.

Low carbon living provides a value proposition to various stakeholders according to the scale and scope of the value equation. From a development scale perspective the investigation can be undertaken at single building/household level up to suburb scale development and beyond, with each level introducing new economic costs and benefits, and at each level the value proposition appeals to different stakeholders. The scope can also be varied to capture larger and more diverse impacts starting from building energy impacts to human health to transport to food system to biodiversity to social sustainability impacts, with each change of scope and level of complexity realising benefits to new stakeholders.

The literature demonstrates an extensive and rapidly growing evidence base for many benefits and costs associated with low carbon buildings, low carbon estates and low carbon living. This report summarises the range of economic benefits and costs published in the literature, and provides a platform from which to determine the value proposition of low carbon living at various development scales, and from the perspective of different investors.

The literature provides a range of economic analysis methodologies used to determine the benefits and costs associated with low carbon living. Of particular interest is the value proposition methodology [1] which provides a marketing based approach to understand the creation of products and services valued highly by the defined market, where the value is determined by the customer’s experience of the offering in terms of their wants and needs. This reinforces the investor-centric nature of economic value, whereby only those benefits and costs perceived by the investor are relevant for the value proposition to that investor.

In simple terms the value proposition is the articulation of the measurable value an organisation or individual will get from the offering; where the end value equates to the perceived benefits minus perceived costs [1]. Benefits are the outcomes and experiences of value to the customer, and costs are the financial exposure and other factors (i.e. time, risk) that the customer must pay to receive the product.

The value proposition methodology proposed by Barnes et al [1] has been applied across many field such as health products and services, tourism, manufacturing, and consumer food products. Other authors have applied the value proposition methodology to the concept of sustainable development [2]. For example: Muller [2] combined the principles developed by ‘The Natural Step’, ‘Cradle to Cradle’ and ‘Human Scale Development’ with the three-pillar concept, articulating various requirements for a sustainable value proposition.

For this literature review, the concept of value proposition helps to outline a wider range of possible benefits and costs, to include those experiences of the investor yet to be effectively monetised and incorporated into typical net present value calculations.

The economics of low carbon homes

The economic costs and benefits associated with low carbon homes has recently become the subject of much research [3-16]. Many of these studies consider the direct costs and benefits of low energy homes from the perspective of the household (private impacts), often constrained to energy related impacts, but this approach limits the range of factors that can be included in the economic equation as many of the costs and benefits may be realised by other stakeholders or the greater community (social impacts). For example: the economic analysis used for proposed regulatory change typically incorporates a wider range of private and social impacts articulated from the perspective of the wider community [17].

Proposed changes to the National Construction Code, and other similar building codes, are considered on the basis of economic analysis, in particular, a net present value (NPV) calculation of the economic costs and benefits for both private and social impacts. The process is designed to determine the option which delivers the largest net benefit to society [17, 18].

UK building regulation economic assessments [19-21] have followed a similar approach, whereby construction costs have been estimated according to expected additional materials and technologies installed rather than improvements in climate appropriate design or industry practices. But probably the most significant difference between Australian and UK regulation impact assessments to date is the incorporation of technology specific learning rates for the various building systems and energy technologies expected to be applied [21]. Other market transformational effects of regulation such as stimulating increased industry innovation have been recognised in the UK analysis, as have complementary policy impacts such as increased energy security and trade balance benefits, but are typically not quantified and included in the economic tests.

To encourage a consistent approach to the economic analysis for proposed energy and greenhouse gas emission related changes to the Building Code of Australia, the Australian Building Codes Board commissioned a guidance report [17]. This report describes the range of social and private economic impacts that should be incorporated into the net present value calculation, including: energy network impacts (production, transmission, distribution); air quality impacts; and carbon emission impacts. The report is limited in its search for additional evidence to support an extension to the range of impacts, choosing instead to note that many of the costs and benefits will be difficult to estimate.

The literature discusses a large number of factors that are likely to impact the economic costs and benefits of low carbon buildings which can be categorised into two basic groups: those impacts related to changes in energy use; and those non-energy related impacts, some of which may be associated with the unintended consequences of addressing energy use and carbon emissions in buildings. An understanding of this literature is important to provide the foundations for a more comprehensive range of costs and benefits that may be valued by various investor scenarios. The following sections review the relevant literature for each of the key impacts.

Energy related impacts

The key energy related costs and benefits used in the net present value calculations for building energy regulation can be classified as: (1) direct energy savings due to the application of technologies and materials to meet the higher performance standard; (2) compliance costs, particularly government administrative, industry development and construction costs associated with the application of those technologies and materials; (3) changes in asset value due to improved energy performance; and (4) changes in energy network infrastructure due to improved energy performance.

Direct energy savings

The empirical evidence of energy savings from the monitoring of higher performance homes, including zero energy and zero carbon homes, demonstrates appreciably lower operational energy costs when compared to standard construction for that region [22-25]. For example: Parker [23] analysed energy and cost data from twelve ultra-low or net zero energy homes in the United States and found typical operational energy savings of over 50 per cent for less than USD$0.10 per kWh. Gill et al. [22] reviewed the monitored performance of 25 low energy homes in the UK and found energy savings of 56 per cent and water savings of 39 per cent, when compared to standard construction. Saman et al. [24] and Berry et al. [25] found large energy savings for a large sample of near zero energy homes in South Australia.

These direct energy savings may be related to improvements in appliance and equipment efficiency, the integration of passive solar design strategies or active renewable energy systems, or even changes in the behaviour of building users due to energy end-use feedback.

As thermal performance is improved in homes, some of the expected energy savings are typically taken in additional thermal comfort or other energy services [26-28]. This behaviour, called the direct rebound effect, results in a lower economic benefit than would be expected from energy engineering calculations based on the improvement of the building or its energy systems. This rebound effect is covered in greater detail later.

Other studies of low energy homes estimate savings based on energy simulation software outputs without validation of energy end-use behaviour against monitored buildings [3, 5-12, 14, 29]. Whilst these models provide an interesting insight into the potential for energy savings, without appropriate calibration to account for patterns of actual household energy use it is difficult to understand the likelihood of the models to under or over-estimate average savings.

From a building regulatory perspective, the need for accurate predictions of energy savings is imperative to the economic model. The calibration of the energy performance model by utilising monitored energy use data from a sample of houses incorporating technologies similar to those expected of low energy homes can improve the accuracy of energy saving predictions [30].

Construction and maintenance costs

The literature includes many studies exploring the costs of constructing low energy homes, and their associated ongoing maintenance costs [3-13]. Typically these studies start with a single or set of house designs and add building materials and/or energy technologies to improve net energy performance. This process adds construction costs to a base design to lower total energy use, rather than optimising net energy performance with a combination of changes to floor plans, material specifications and technology application.

Other research has considered the substitution of products, or the reduction of product size, therefore expanding the range of options to include lower construction cost choices [14, 29, 31, 32]. For example: Gamble, Meisegeier and Hall [14] included several window size reduction variations, allowing a negative cost option to be evaluated. Similarly, McLeod and Fay [29] also included the negative construction cost option of reducing window size when calculating the economics of providing human thermal comfort in Tasmania, noting the limitation of not altering the floor plan or orientation to achieve further negative cost energy performance improvements. Sustainability House [31, 32] examined a range of positive and negative cost strategies on a set of twenty house designs at NatHERS 5 and 6 Star performance and found that higher levels of thermal comfort could be delivered for an average decrease in construction costs, primarily through changes to glazing and insulation specification, although performance improvements above 7 NatHERS Stars required a change to more expensive insulated glazing units.

The typical approach begins with a home design and associated specifications and makes sequential changes until the new standard is reached. Typically these studies do not optimise the house design to utilise passive solar design strategies, or apply different construction systems in specific rooms or orientations, or eliminate or reduce the need for various energy service technologies. Yet the authors provide no evidence that house designers create new product to meet revised energy standards based on previous market fashions; systematically adding components and systems and therefore costs until they comply with the new standards. If designs are instead created from scratch specifically to meet new regulatory requirements, then total construction costs may be even lower than predicted by studies which start by adding to existing non-compliant house designs. This argument is supported by recent evidence which found that house designs created specifically to meet NatHERS 5 Star standards in Australia had lower total construction costs than those designed for previous lesser building energy standards [33]. This highlights the value of industry learning processes which will be covered in more detail later.

Step changes in thermal comfort demand can result in step changes to infrastructure sizing, system type or system need [34-36]. Energy Efficient Strategies [34] demonstrated that as thermal comfort energy loads reduce, conditioning system sizing can be reduced with consequent cost reductions. Elberling and Bourne [35] showed that when loads are greatly reduced, the system type needed to meet the lower demand can be changed with consequent cost reductions. Ultimately, as Vale and Vale [36] demonstrated, if the demand for additional energy for heating or cooling can be reduced to near zero, the entire system supplying that service can be eliminated.

Similar cost improvements can be found from reducing the demand for hot water. Elberling and Bourne [35] showed that when hot water demand was reduced for both space conditioning and domestic hot water needs, a combined system could replace separate heating systems, thus delivering a cost reduction.

The combination of daylight, lighting control systems and high efficiency lighting systems can also deliver net cost savings [37]. Vaidya et al. [37] argue that the integration of systems can produce a domino effect, whereby the bundling of changes leads to a net saving, for example: improved daylighting combined with lighting control systems can reduce the need for artificial lighting during the heat of the day, which can lead to lower cooling loads and possibly the reduction in cooling plant capacity.

The elimination of systems, the reduction of loads on energy systems, or the substitution of system type may also result in lower maintenance costs. For example: high efficiency lighting technologies such as CFL and LED lamps each have a considerably longer effective life than traditional incandescent lamps or dichroic (halogen) downlights [38], leading to likely ongoing maintenance savings.

Changes to the technology used in homes may increase maintenance costs. For example: the addition of grid connected solar photovoltaic systems with an expected effective life of thirty years, and the associated DC/AC inverters which currently have an effective life of approximately ten years, have shorter effective lifespans than the expected economic life of the building, leading to increased maintenance from regular system replacement [39].

Building design, particularly in facets that are irreversible in the short term such as orientation, size, shape, and integrated energy systems, has longer-term financial implications [40]. Verbruggen et al. [40] argues that the irrevocability of particular energy performance endowments means that initial investments in building design should be valued more highly to reflect the relatively higher cost of addressing energy performance once those endowments are ‘constructed in’ to the development.

Compliance costs and market transformation

The regulatory environment, and in particular the use of performance-based codes and standards, is a key driver of innovation [41-43], leading to change in industry skills and knowledge, product and supply chain development, and increased production volumes. This market transformation has a material influence on the end cost of housing. From one perspective regulation may drive some costs higher in the immediate term due to additional requirements, but simultaneously regulation creates the transformation that drives the cost of housing lower over the medium and longer term.

The market transformational processes of industrial learning, progress functions, tool development, supply chain development and increased production volumes have been demonstrated to rapidly reduce the cost of achieving a particular performance outcome for products as diverse as airplanes, chemical processes, and semi-conductors [44-49].

Construction and product cost reductions can come from a complex web of interactions relating to commercial risk, research and development, design innovation, supply chain changes, manufacturing processes, installation and maintenance processes, and changes in marketing needs as products and associated markets mature [50].

Research into building product performance and cost has demonstrated that over time, through processes of market transformation, energy efficiency characteristics have increased whilst real costs have decreased [51, 52]. Similarly, research into typical household appliances such as refrigerators, clothes washing machines and dishwashers has found that energy efficiency performance has also increased whilst real purchase costs have decreased [53, 54].

Learning and logistics curves, sometimes referred as experience curves, for energy technology production and application costs have been calculated by various researchers [51, 55-63]. Typically annual savings for building fabric technologies fall in the range of 9 to 27 per cent, with 18 per cent being average, while energy generating technologies such as photovoltaics have averaged around 20 per cent saving rate per annum over a 20 year period.

Researchers have noted the critical link between building standards and industry development [55, 64]. Jakob and Madlener [55] describe a virtuous cycle whereby new building energy standards lead to innovation in solutions; then diffusion of solutions; and finally cost reductions; which encourage policy makers to set higher energy standards. Smith [64] noted that building regulations were a key environmental driver for volume builders but expressed caution on the relationship between building regulation and industry development, stating that an undemanding regulation-driven transformation may not encourage deeper learning.

The Australian experience, although less researched than European and American experiences, has found large cost savings and increased skill development through policy driven building energy efficiency regulation related learning [65, 66]. For example: Energy Efficient Strategies [65] noted builders were able to halve the original construction cost premium of moving to the proposed 5 Star standard by learning about sustainable design concepts, ahead of expected additional savings due to greater economies of scale and supply chain improvements.

The transformation process extends to government or industry costs related to the administration and compliance enforcement of a new standard, where new tools or administrative procedures may increase the cost of each building initially until processes and tools evolve to meet the new needs. In many cases, building energy standards already exist and unless significant changes are made to administrative procedures or the minimum requirement for participant knowledge and training, additional compliance costs are often minor.

Asset value impacts

There is a large body of evidence collected over many years that demonstrates housing markets value energy efficiency, thermal comfort and lower utility bills [67-75]. For example, hedonic modeling was used to analyse the relationship between energy efficiency rating and sales price for a sample of 5,000 houses sold in Canberra in 2005 and 2006, and found a statistically significant relationship between the rating and the sale price [76]. Brounen and Kok [70] also used hedonic modeling to analyse the sale of 177,000 homes in the Netherlands and found that increased energy efficiency resulted in higher sales prices. Fuerst et al. [75] analysed over 325,000 house sales in the UK and found a positive relationship between the published energy rating and the sales price.

Researchers suggest that the economic modeling of residential buildings for regulatory change should incorporate the increase in residual house value due to energy efficiency features [5, 77]. Problematic with the inclusion of asset value impacts in net present value calculations is that they occur only when the asset is presented to the market. In the case of housing, there is no standard period before a house is offered for sale; therefore it is difficult to allocate the likely impact to a specific point in time. Asset value impacts due to energy performance improvements will continue to be available throughout the economic life of the building.

Peak load reduction impacts

Electricity networks are a complex interaction between generation, transmission and distribution systems and the demand for energy. The load varies daily and seasonally, peaking during periods of extreme climatic conditions, whilst simultaneously growing as new energy services are added to the system and falling as energy services become more efficient. In Australia, both average demand and peak demand were expected to grow rapidly at about 20 per cent and 30 per cent respectively for the period 2010 to 2020 [78], although the recent uptake of rooftop photovoltaics may moderate the estimated rate of growth [79, 80].

The difference between managing a peak daily demand on a mild day and that during extreme climatic conditions, such as a summer heatwave, represents a substantial investment in energy supply infrastructure which is used infrequently. In South Australia, data from the electrical network utility shows that one third of the required capacity is needed for just 3 per cent of the year [81, 82].

The market value of electricity increases appreciably when demand approaches the maximum capacity of supply, with analysis showing that peak demand periods that account for only 3.2 per cent of the annual market were responsible for 36 per cent of total market costs [83].

Household energy use reductions, across both the average load and during times of peak demand, plus domestic-scale on-site generation of electricity, can combine to reduce the need for new large-scale generation infrastructure and enhancements to electricity supply networks [78, 84-88].

Considerable savings can be achieved in avoided capital and maintenance expenditure on the electrical network by reducing electricity demand during periods of extreme climatic conditions such as summer heatwaves [78, 89]. The Department of Climate Change and Energy Efficiency [89] found that network costs to address peak demand are a key driver of rising energy prices and the application of energy efficiency actions will reduce expected price increases. Langham et al. [78] found that avoided capital and maintenance expenditure for electricity generation, transmission and distribution could be valued at between AUD$2.4 and $3.3 billion per annum through a comprehensive program of improving building energy efficiency, and went on to calculate the annual rate of infrastructure savings per unit floor area of residential building per percentage of building energy efficiency improvement at AUD$0.024. These savings have yet to be incorporated into the economic models used in building energy regulatory change.

Non-energy economic impacts

Whilst energy savings and associated consequential carbon emission and economic impacts are at the core of the policy intent, the higher building energy performance of low carbon buildings is typically accompanied by externalities [90], which if able to be monetised can add to the depth and sophistication of the economic model. The literature describes a number of non-energy related private and societal costs and benefits such as: (1) mental and physical well-being generated from living in a thermally comfortable and low energy use building; and (2) productivity impacts associated with living in a thermally comfortable buildings.

The value of low carbon living and low carbon buildings can extend beyond the building boundaries. The creation of green infrastructure such as green roofs or green facades, or the development of a community, may provide a range of environmental and quality of living benefits. And direct private impacts may extend beyond the financial benefit of ongoing energy savings. Individuals may derive psychological or physical health benefits from low carbon living, such as intrinsic (warm-glow) satisfaction from taking action to address global climate change [91].

Thermal comfort related impacts

Thermal comfort is a primary want and need for humans. Human thermal comfort is defined as the “condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation” [92]. Human perception of thermal comfort takes into account air temperature, air speed, mean radiant temperature, relative humidity, occupant activity and clothing [93]. Humans play an active role in maintaining their own comfort, through changing their clothing, changing their level of activity, changing the natural conditions in that space (i.e. opening windows or doors), or by using technology to return the indoor conditions to that which matches their perceived needs [94]. Thermal comfort is also a social construct reflecting the beliefs, values, expectations and aspirations of households, with demand for comfort increasing dramatically over the past few decades [95].

The value of thermal comfort reaches beyond the simple calculation of energy costs to maintain the desired level of comfort. Building related thermal comfort has a strong relationship with human health. Australian researchers [96-101] argue that for groups both young and old without ready access to thermally comfortable buildings, extreme weather events such as heatwaves appreciably increased human mortality and morbidity. Strand et al. [101] found that exposure to higher ambient temperatures in the last four weeks of the pregnancy increased the risk of stillbirth. Saniotis & Bi [96] found that heat exposure increased health risks associated with the relationship between pharmacokinetics and physiological changes, and increased health risks associated with the relationship between food-borne disease and temperature. They also noted that some drugs were compromised by exposure to higher temperatures. Bi et al. [97] investigated more than a dozen published Australian studies and found substantial evidence for heat stress related mortality.

Internationally the link between human health and building thermal comfort has been established [102-112]. Many of the studies, particularly those from Europe and North America, contrast with Australian research by investigating the impacts of cold and damp homes rather than higher temperatures.   For example: Gilbertson et al. [105] interviewed households that received thermal comfort upgrades and reported resident perceptions of improved physical health and comfort, even the easing of chronic illness symptoms. What was surprising was the perception of improved mental health and emotional well-being.

The literature also highlights wider social impacts of thermal stress. Australian researchers investigated the link between heat stress and behavioral disorders, observing that above a threshold of 26.7°C there was a positive relationship between ambient temperature and the number of hospital admissions for mental and behavioral disorders [98]. Others noted that some of the secondary characteristics of heat events that are often overlooked are increased rates of injury, trauma, crime, and domestic violence [97].

The literature also describes productivity improvements relating to thermally comfortable conditions such as those expected in zero energy homes [112, 113]. For example: Chapman et al. [112] investigated the impacts of retrofitting insulation and other measures in 1350 New Zealand homes and found lower numbers of 'days off work' and 'days off school' for the occupants of thermally more comfortable homes.

The monetisation of non-energy related impacts is appearing in the building energy performance literature, and although the various authors suggest the value of non-energy related economic benefits may be relatively high when compared to the energy related impacts of low-energy homes, the calculation methodologies have been bespoke to each study and the outcomes show a wide range of results [107, 109, 112, 113]. For example: Stoecklein et al. [110] suggested non-energy benefits could be 2.5 times greater than direct energy savings; Schweitzer & Tonn [109] calculated the non-energy benefits to be slightly greater than the average energy savings; Chapman et al. [112] found that the health related economic benefits of insulation retrofits appreciably outweighed the energy related economic benefits for a large sample of households in New Zealand; while Ürge-Vorsatz et al. [107] cautioned the potential for double counting the value of benefits and suggested that individual benefits could be as high as 43 per cent of direct energy savings; and Williamson et al. [113] similarly found that health related benefits of incremental building energy code change where probably lower than the expected direct energy benefits.

Green building facades

The creation of green infrastructure such as green roofs and walls can provide a range of benefits including, but not limited to, stormwater management, air pollution reduction, reduction of heat island effect, reduction of building energy usage for thermal comfort, and increased biodiversity [114]. Green walls also provide acoustic benefits, privacy and possibly aesthetic benefits [115].

Green facades and roofs come with costs associated with higher construction and maintenance costs, and the additional materials for moisture barriers and to trellis green walls have embodied greenhouse gas emission impacts.

The quantification of economic benefits and costs for green roofs is limited in the literature to mostly operational energy related impacts [116, 117], although a more comprehensive assessment of green facades included various social costs and benefits such as air quality improvement, carbon reduction, habitat creation, aesthetic impact, and urban heat island mitigation [118].

Given the progress of building energy regulations, the literature suggests that operational energy savings from green roofs is likely to be insignificant for new buildings but may provide some benefit to older pre-regulation buildings [116, 117].

Sense of community

Humans, in general, are social animals with both a want and a need to interact. Jackson [119] p193 puts it best in ‘As a gregarious species, people benefit emotionally and physically from interpersonal relationships.’ The creation of social capital, enhanced by designing estates to encourage informal social interaction, can be linked to physical and mental health benefits [119-121]. The creation of social capital has perceived benefits to both participants seeking a sense of community, value to developers in creating more commercially attractive urban developments, and value to government through the creation of healthier and more vibrant communities.

A few case studies are provided in the literature. Of particular relevance is the creation of social capital in the Lochiel Park Green Village. At Lochiel Park the streetscape, building type, linkages to the River Torrens Linear Park, the community garden, the establishment of community groups, and the relatively large allocation of greenspace are all designed to encourage high frequency informal interaction between residents, and between residents and the wider community. Fostering a sense of community was highlighted as a goal within the initial policy documents [122, 123]. In particular, the design of the estate included pedestrian and cycling linkages with surrounding land uses, including the River Torrens Linear Park and the adjacent suburbs and was influenced by a market research exercise which surveyed local foot and cycle traffic [124]. Other initiatives included the creation of a Lochiel Park community website, funded from government sources which was used to facilitate the formation of a residents association; and the involvement of initial residents in the development of a community vegetable garden.

Research undertaken at the early stages of Lochiel Park’s development found that people considered that the regular community meetings held by the Land Management Corporation were important parts of community life, but the authors wondered whether this sense of community could be dissipated once people settle in and develop household routines [125].

By 2012 the residents had a variety of specific formal and informal groups and activities to which to be involved, including but not limited to:

- Friends of Lochiel Park Association
- Lochiel Park Community garden
- Ripples Community Arts Group
- Lochiel Park Book Club
- Seed collecting and indigenous plant propagating group

Research has found that these groups are popular with residents, with 18 of the 25 households interviewed recently engaged in one or more of the community groups or organised activities [16]. And of those who were not participants in regular activities, almost all attended the annual estate Christmas Party. The interview data demonstrates that Lochiel Park has successfully developed and maintained an active and vibrant community. Further analysis is needed to quantify the value of social capital creation to various investor categories including: homebuyers, estate developers and wider society.

Direct and indirect rebound effects

Bridging both direct and indirect impacts is the concept of rebound. Economists have debated for over 150 years that direct and indirect rebound effects result in actors using higher amounts of energy than would be expected from the application of energy efficiency technologies and practices, and some have argued that improvements in energy efficiency will lead to a net increase in energy use rather than the expected decrease [126-129].

In observing the coal consumption of 19th century steam engines, Jevons [129] argued that improvements in engine energy efficiency increased the use of coal by making the technology more economically attractive, rather than delivering energy savings. This concept was taken up by Khazzoom [128] and Brookes [126] who postulated that economy-wide rebound effects, being the sum of direct and indirect effects, will absorb expected benefits and may lead to a net growth in energy use and greenhouse gas emissions. The Khazzoom-Brookes Postulate suggests that if a process is made more energy efficient and economically attractive, there will be greater demand for that energy service and a direct rebound effect in energy use, while any savings would increase demand for other goods and services and hence an indirect rebound in energy services. The greater the efficiency gain, the greater the demand for energy services, and the greater the total energy used.

Khazzoom [128] in studying the likely effects of appliance and vehicle energy efficiency argued that the price elasticity of demand for many energy end-uses was greater than one, therefore increased efficiency would increase demand at an energy use rate higher than the expected saving, and would increase demand for other energy end-uses. Brookes argued that the substitution of energy for labour and capital would lead to increases in total factor productivity and growth in overall output, which would result in increases in economy-wide energy use.

Critics of the Khazzoom-Brookes Postulate point to several key issues in relation to building related rebound effects [127, 130-132]: (a) the elasticity of demand is often less than unity and when demand is close to saturation, elasticity is close to zero; (b) substitute activities may have a lower energy or carbon intensity; and (c) economy-wide rebound effects may be much higher for direct (industrial) productivity improvement related activities than for domestic energy use scenarios.

Evidence of direct rebound effects

There is a substantial body of empirical evidence demonstrating that technical improvements in energy efficiency, including improvements to building performance, do not deliver expected energy savings according to engineering calculations, but deliver smaller than expected savings [26-28, 133-136]. The evidence in the literature strongly supports the critics' key point that elasticity of demand is often less than unity and direct rebound effects are generally less than 100 per cent, and are more typically between 10 and 30 per cent for domestic energy services.

The reference frame is critical in examining rebound effects. At a global scale, because of the relatively strong relationship between artificial lighting and human productivity, the Jevons paradox has been demonstrated across three centuries of lighting technology change [134, 137]. Tsao et al. [134] point out that the historic rebound trend may not continue in all situations as indoor light levels near saturation (satisfies human need for light) and the price elasticity of demand reduces. Fouquet and Pearson [137] tracked income and price elasticity of demand for lighting over the past two centuries and found that rebound reduced as incomes grew, with rebound greater than 100 per cent during the nineteenth century, reducing well below 100 per cent during the twentieth century. Similarly, at the individual household scale, research by Bladh and Krantz [136] found that domestic lighting efficiency gains were delivered with only small levels of rebound.

Evidence of indirect and economy-wide rebound

The evidence for indirect and economy-wide rebound is limited [130, 132, 133, 138-141]. Greening et al. [133] reviewed over 75 studies into direct, indirect and economy-wide rebound and found that the evidence for economy-wide rebound was inconclusive but likely to be less than 100 per cent. Schipper and Grubb [132] examined the relationship between energy intensities and gross domestic product (GDP) and concluded that energy efficiency does lead to energy savings and hence economy-wide rebound was a second order effect in mature industrial economies. Geller and Attali [130] examined a number of studies and found that energy efficiency actions decreased the cost of energy, increased employment and increased personal income, but the economy-wide rebound effect was less than two per cent of the direct energy saving. Allan et al. [139] used an energy-environment-economy general equilibrium model to investigate economy-wide impacts of energy efficiency activity, finding an overall long term rebound effect in the order of 37 per cent. Sorrell [138] argues that this model may have overestimated economy-wide rebound by assuming efficiency gains in the electricity sector where they may be close to thermodynamic limits.

Barker et al. [140] used an energy-environment-economy multi-sectoral dynamic econometric model to determine the impact of UK energy efficiency policies on the local economy and found that direct rebound averaged around 15 per cent, with economy-wide rebound of a further 11 per cent. Interestingly, the application of energy efficiency also leads to decreases in inflation, and growth in GDP. Sorrell [138] argues that this model underestimates rebound by not including factors such as the energy embodied in energy efficiency technologies. Sorrell also found that while there was no empirical evidence presented to support the Khazzoom-Brookes postulate in developed economies, economy-wide rebound is likely to be higher in energy intensive industries or for general purpose technologies such as computers and steam engines, where efficiency gains have momentous productivity impacts. In the case of applying energy efficiency in the domestic setting, Sorrell found the economy-wide rebound was certain, but likely to be at the lower end of the range.

Relevance of rebound for this study

In the case of transitioning to low carbon impact buildings, that is improving the energy performance of mature new housing product from reasonable performance to low energy performance in mature developed economies, the level of direct rebound for domestic energy end-uses and economy-wide indirect impacts would be at the lower end of the range. Whilst little Australian evidence exists, the evidence from similar developed nations suggests that the price elasticity of demand for energy services such as lighting, thermal comfort, water heating, laundry and refrigeration is likely to be very low and hence improvements in energy efficiency to appliances, equipment and the building fabric are likely to decrease household energy use.

Because rebound effects are real, the energy models that provide household energy saving predictions should be calibrated with actual behaviours monitored for similar types of buildings. Without calibration, household energy use models based on technology efficiency alone, are likely to overestimate energy savings and over-value the benefits perceived by building users.

Summary

Value is in the eye of the beholder. The value proposition for low carbon living is defined as the articulation of the measurable value an organisation or individual will get from the experience. The value proposition for the experiencer (the investor) equates to the perceived benefits minus perceived costs. This means that the value of low carbon living is unique to the perspective of the investor, and the benefits and costs included in the economic equation are related to those likely to be perceived by the investor.

Although the concept of value proposition was originally drawn from a marketing based approach to understand the creation of products and services valued highly by the defined market, the concept has also been used to understand the value of environmentally sustainable actions and activities to the market.

This literature review has investigated the documentation of benefits and costs associated with the likely experiences associated with low carbon living. Evidence from both energy and non-energy related impacts has been identified and discussed.

The economic costs and benefits of energy efficient and thermally comfortable homes, and those utilising renewable energy technologies is relatively well-known with a rich history of Australian and international literature, and with evidence available from various climate zones and building typologies. The value of various energy related actions has been monetised, albeit for a limited range of factors, from both a private and societal perspective.

The non-energy related experience of low carbon living is less prevalent in the literature, although coverage of some health and productivity related impacts is documented, and the literature provides some discussion about the value of creating a sense of community. The monetisation of non-energy impacts is less clear, with few methodologies or values documented.

The proposed work program for the Adelaide Living Laboratory provides a unique opportunity to expand the global knowledge base on the value proposition of low carbon living, and to address some gaps in the literature.

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