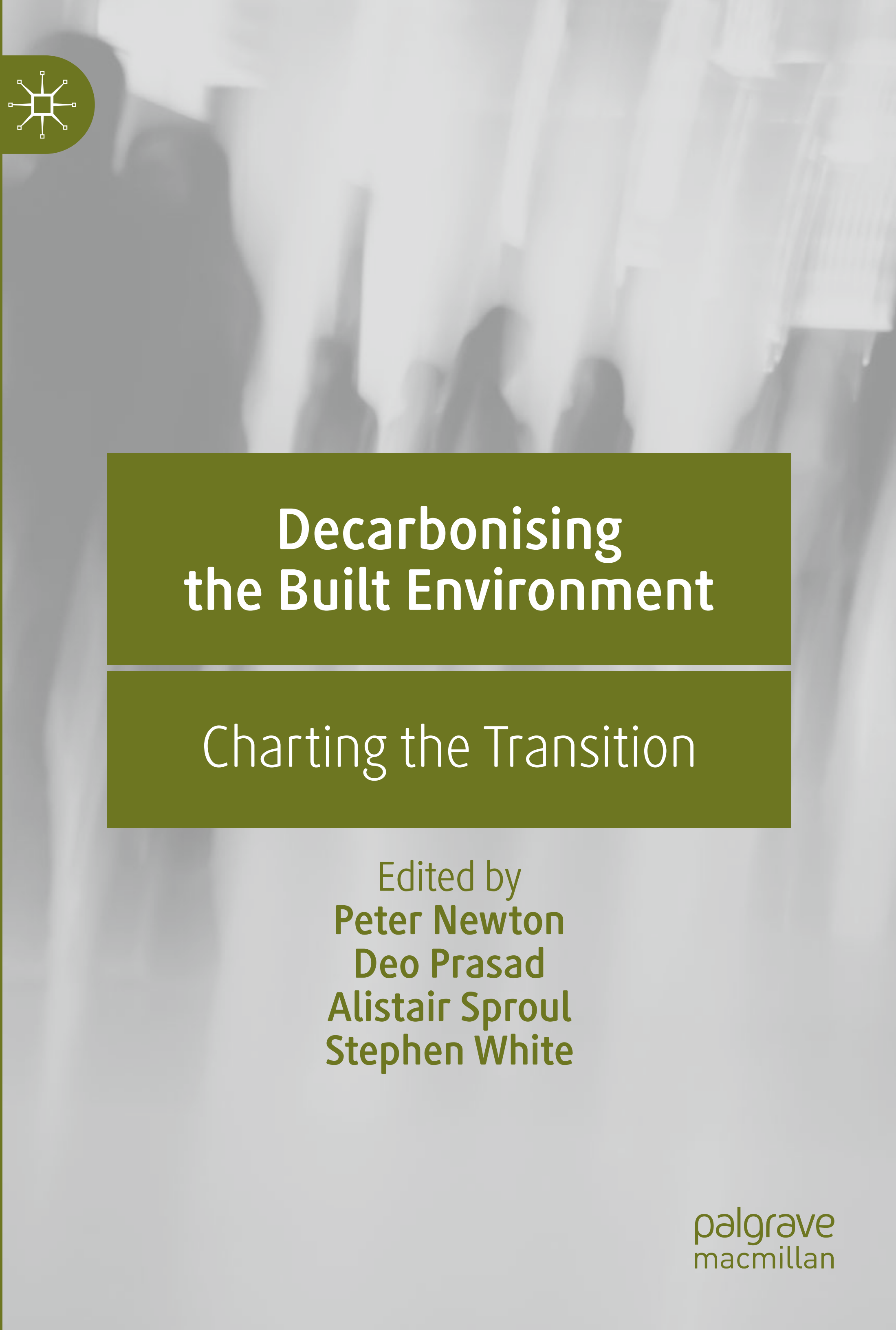

Decarbonising the Built Environment

Charting the Transition

Edited by

Peter Newton
Deo Prasad
Alistair Sproul
Stephen White

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Foreword

This important new book answers a critical question for Australia's future. In the urgent quest to 'decarbonise' our cities, how will we get there? Over seven years of unprecedented collaboration between Australian researchers and the myriad of industries, businesses and government agencies that shape the way we live, the Co-operative Research Centre for Low Carbon Living (CRCLCL) has charted a clear, new evidence-based course. *Decarbonising the Built Environment: Charting the Transition* showcases the substantial body of new knowledge generated by the CRCLCL over its funding period from 2012–2019. The core themes and key projects featured reflect the Centre's ultimate goal. That is, to inform the cost-effective reduction of carbon emissions generated by the built environment, while fostering industry competitiveness, improving the quality of urban life and building resilience to climate change. This was always a deliberately ambitious brief. By providing both the long-term vision needed to guide transformative change and the close-up, detailed understanding of each and every piece in the complex puzzle of sustainable urban development, this book demonstrates the wisdom of setting the bar high.

Australia is among the most urbanised nations on earth. Rapid population growth and intensifying climate change impacts, including protracted heatwaves, are fuelling our voracious demand for power and resources and highlighting the inadequacy and risks of the status quo. Globally, cities consume about three-quarters of the world's energy, and within urban areas it is the built environment that both uses the most energy and generates the lion's share of emissions. Cities must play a major role in slashing greenhouse gas emissions if we are to slow or limit global warming. At the same time, cities must be designed, built or retrofitted to better protect our people and our urban ecosystems in the face of climate change impacts like more frequent extreme weather events and shifting rainfall patterns, and their many consequences. This is a twofold challenge. On the one hand, we must integrate renewable energy systems, smart technologies, low carbon materials and smart design solutions to deliver quality, low and zero carbon buildings, infrastructure and urban precincts. On the other hand, we need a deep understanding of the all-important human factors. What does it take to change our collective behaviour and to trigger, for example, a widespread switch to electric cars or rooftop solar panels, or to inspire entire communities to compost their food waste?

As Chair of the Board of the CRCLCL, I have had the privilege of witnessing the great strides that can be made when Australian researchers and industries work together to tackle a profound national challenge. Only by investigating urban living at every level, from the grassroots questions about our daily habits to the policy decisions that shape our cities, can we begin to understand, and shift, our technologies, materials and behaviours. The Federal Government's CRC program underpins the book's success. Backed by $100 million in government and industry research funding, the Centre brings together the complementary expertise and vision of leading academics, key industries, planners and policymakers—and communities—to forge an unbroken pathway from discovery and verification to uptake and impact. This productive 'hub' model connects stakeholders and experts Australia-wide and enables new science, technologies and design to be matched to the capabilities and needs of Australian businesses and end-users. At the same time, the Centre's 16 'living laboratories' embedded in our communities, have provided authentic measures of usability and community attitudes. With more than 120 projects undertaken successfully across Australia, an independent assessment has proven that the Centre is on track to meet its founding goal of 10 megatonnes cumulative reduction in carbon emissions by 2020, enabling a projected economic benefit to Australia of $700 million by 2027.

Decarbonising the Built Environment: Charting the Transition delivers an effective new road map to the many and varied stakeholders who will drive, or adopt, urgently needed change. The book is organised in four key streams, taking in energy transitions, zero carbon buildings, urban regeneration and human factors, making it accessible to the research, industry and government sectors and many other interested readers. Academics across multiple fields will find the level of scientific detail and rigour they need. Architects, designers, developers and the construction industry will gain valuable new insights into the new materials and design and energy solutions that have proven their worth over the past seven years of research. Planners and policy and decision-makers, likewise, will value the book's holistic perspective, that delivers a new understanding of the complex and interrelated technological solutions as well as the human factors that drive or impede change.

Consider, for example, the scorching record-breaking Australian summer of 2019, the hottest on record. In Perth, the outdoor temperature was hovering around 40 °C. Inside *Josh's House* of ABC TV's 'Gardening Australia fame' it was a comfortable 24 degrees. This 10-star energy efficient CRCLCL 'living laboratory' is powered by advanced solar technology. However, it was not using air conditioning, so no additional energy was needed. Its excellent thermal performance was down to good passive solar design. Meanwhile, in Freemantle, the CRC's White Gum Valley (WGV) 100-dwelling 'living laboratory' was trialling a breakthrough combination of rooftop solar PV, battery storage and peer-to-peer energy trading to provide eco-efficient heating and cooling to the residents. Over in NSW, problematic waste from coal-fired power stations was being incorporated into low carbon geopolymer concrete to make bollards to protect the coastline at Port Kembla from extreme weather events. The CRCLCL has also delivered a trajectory for a revised National Construction Code and recommendations for revisions to the NSW building sustainability index (BASIX).

Decarbonising the Built Environment: Charting the Transition brings together Australia's pre-eminent researchers as well as introducing the work of innovative young researchers and scientists the Centre has fostered. By training over 100 Ph.D. students, the CRCLCL has delivered a once in a generation boost to our national capabilities. The energy and expertise of this new cohort of industry-ready professionals and researchers are vital if we are to achieve meaningful emissions reductions into the future. I would like to recognise the vision and work of the Centre's CEO, Professor Deo Prasad and all the program leaders who have guided both the Centre's research and the writing of this book. I would also like to thank the Centre's 45 participants who have shown real commitment turning research into real-world improvements. Finally, it is important to acknowledge the role of the Federal Government in designing and supporting the CRC program; without which such a comprehensive book could not have been realised. I am very proud of the wealth of information and inspiration that lies within these pages. The Centre's work captured here demonstrates something remarkable; that urban sustainability, liveability *and* affordability can be simultaneously achieved.

Hon Robert Hill
AC, Chair, Board of Directors, CRC
for Low Carbon Living

Acknowledgements

This book brings together a significant part of the seven-year research and implementation program of the Co-operative Research Centre for Low Carbon Living (CRCLCL). The research funded by the CRC for Low Carbon Living Ltd is supported by the Cooperative Research Centre's program, an Australian Government initiative. The highly successful CRC Program of the Australian Government, in operation for over 20 years, has created a collaborative model for research and innovation where industry, governments and research come together to co-create solutions to challenging problems of national and global significance. The success of CRCs is measured by the impact each creates in improving the uptake of innovation.

The CRCLCL has been a National Research and Innovation Hub for a Sustainable Built Environment (2012–2019). It brought together the built environment industry, all levels of government and leading research institutions in this field in Australia to work towards lowering carbon emissions in the built environment while driving competitive advantage for Australian industry. It also aimed to provide high-quality science led evidence, tools and technologies for better design, planning and policies in this area in Australia.

The CRCLCL delivered profound impact. At the time of publication, the CRCLCL was well on track to meet its founding goal of 10 megatonnes cumulative reduction in carbon emissions by 2020, and enabling a projected economic benefit to Australia of the order of $700 million by 2027. The research described in this book helped the Centre reach this important goal.

The editors of this book wish to thank all contributors who have provided research input into CRCLCL projects and particularly all Chapter authors for their contributions. As CEO of the CRCLCL I would also like to acknowledge the contribution of all the Partner organisations involved in this collaboration.

Scientia Professor Deo Prasad, AO
CEO of the CRC for Low Carbon Living

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Pathways to Low Carbon Living

Peter Newton, Deo Prasad, Alistair Sproul
and Stephen White

Introduction

At the end of the second decade of the twenty-first century, Australia continues to face the twin challenges of a transition to renewable energy and a transition to sustainable urban development. We are lagging significantly on both fronts nationally and internationally relative to where the world needs to be (DEE 2018a; DFAT 2018; UN 2018). Yet the two are connected. Decarbonisation of the built environment will provide the basis for low carbon living—the *raison d'etre* of this book—drawing on applied research conducted by the Co-operative Centre for

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Low Carbon Living (CRC LCL). Decarbonisation of the built environment will also drive the growth of a green economy, seen as the next major societal transformation (CPD 2010; Newton & Newman 2015; OECD 2015) that will enable sustainable economic as well urban development. Renewable energy is seen as a core sector of the green economy, but all sectors—especially those with a strong urban focus such as planning, building and construction, transport, manufacturing and services—have a major role in shrinking currently *unsustainable ecological, carbon and urban footprints* (IRP 2018). The co-benefits of these transitions contribute strongly to human health, well-being and liveability (Sallis et al. 2016).

These are not new challenges, but they are now urgent in the context of mounting evidence of how climate change, global population growth, rapid urbanisation, rapidly growing cities, and clear resource constraints will be impacting where and how we live in the future—unless transformational change can be implemented now.

This existential threat of climate change has been consistently broadcast to the world by leaders such as Al Gore (2006) and most recently by David Attenborough at the opening of UNFCCC's Climate Conference (COP24) in December 2018: 'Right now, we are facing a man-made disaster of global scale. Our greatest threat in thousands of years. Climate Change. If we don't take action the collapse of our civilisations and the extinction of much of the natural world is on the horizon' (Attenborough 2018, p. 1). The science of climate change is now firmly established, and its early impacts are now devastatingly clear globally and across Australia.

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The UN Intergovernmental Panel on Climate Change's science-based forecasts of greenhouse gas (GHG) emissions and global warming have underpinned the UN Framework Convention on Climate Change's efforts since the early 1990s to secure international agreements on carbon mitigation. In December 2015 the UNFCCC Paris Agreement saw 195 countries each agree to Nationally Determined Contributions to emissions reductions, designed to limit global warming to 1.5−2.0 °C above pre-industrial levels. Australia's Paris reduction target of CO_2 was set at 26–28% below 2005 level by 2030 and net zero emissions by 2050 (ClimateWorks 2018). The Climate Council of Australia (2015) however, saw the 2030 target as inadequate, suggesting a range in emissions reduction between 45 and 65% by 2030. Current assessments by the Climate Council (2018), UNEP (2018), NDEVR (2018) and Climate Action Tracker (2019) indicate that Australia's emissions are not declining in line with the 2030 target. Unsurprisingly perhaps, the Federal Government believes Australia will meet its target (Remeikis 2018), while Pears (2018) suggests they could be manipulated to fit, and Skarbek (2018) along with others argues that new policies are required to get the nation back on track. More optimistic forecasts are provided by Blakers, Stocks and Lu (2019) who argue that the electricity sector is on track to deliver Australia's entire Paris emissions reduction target five years early. This may be optimistic, given the chaotic nature of the nation's climate and energy politics over the past decade and more (Newton et al. 2018), but is potentially achievable if the current institutions don't continue to erect barriers to renewables, storage and energy efficiency. By comparison to the Federal Government, the Labor opposition has a policy of 45% emissions reduction target by 2030; and state governments that form part of the national electricity grid (in particular NSW, Victoria, SA and ACT) have all set net zero targets for 2050 (Jewell 2017).

The jury is still out on whether global warming can be restricted to 2 °C by 2100 (CDP, WRI & WWF 2015; Climate Council 2018; UNEP 2018). In this context, Australia has a major set of challenges with:

- Its absolute level of emissions that contribute to the global carbon budget (547.0 Mt $CO_{2\text{-}e}$ in June 2018: DEE 2018b)

- Its per capita emissions (at 21.5t/person among the highest in the OECD: DEE 2018b; World Bank 2018)
- Its sectoral emissions, especially in relation to the built environment—buildings and transport (ClimateWorks 2018); and
- The size of its capital city carbon footprints (Chen et al. 2016; Teh et al., Chapter 7).

Additional and related challenges for Australia involve:

- Its rapid rate of population growth over the past decade—almost three times the OECD average (World Bank 2019)—90% of which are absorbed into its cities
- How the major cities have struggled to plan for this growth in a manner that delivers sustainable urban development outcomes (DFAT 2018; House of Representatives 2018). Recent reports point to the size of their urban footprints (Coleman 2017), carbon footprints (Teh et al., Chapter 7) and ecological footprints (Newton 2017).

It was in the context of these challenges that the CRC LCL was established in 2012 as part of the national Co-operative Research Centres Program—a model unique to Australia that has been operating for over 20 years (https://www.business.gov.au/assistance/cooperative-research-centres-programme)—to undertake a 7-year programme of applied research that could assist in accelerating the decarbonisation of the built environment sector.

Pathways for Transitioning to a Low Carbon Built Environment

Decarbonisation of the built environment requires an integrated approach across multiple sectors and multiple innovation arenas. Two key sectors of the Australian economy—the energy sector and the built environment sector—are the focus for the research presented in this book. The objectives: a transition to renewable energy and a transition to sustainable urban development (Newton 2008). Within each sector there are also multiple innovation arenas, where transformative change is capable of occurring in order to achieve these necessary transitions: technology, urban design, institutions (governance) and human behaviour.

Renewable energy has now surpassed fossil fuels worldwide as the main source of new electricity generation (IEA 2018). In Australia, renewables now provide 20% of national electricity capacity (https://opennem.org.au/#/all-regions), up from 7% in 2006; and this is forecast to reach 50% by 2024 (Blakers, Stocks & Lu 2019). Rapid deployment of rooftop solar PV is a major contributor, due to initial incentive schemes, and now due to its fundamental cost competitiveness against fossil fuel-based power generation. Across all sectors of the economy, however, renewable's share of final energy consumption is currently 4.7%, although it has been the fastest growing category over the past decade (DEE 2018a). These trends have led to the Climate Council (2018) proposing that the electricity sector is best placed to reduce emissions, at a lower cost than all other sectors, by decarbonising the national grid. For over a decade however, such a strategy has stalled at a national political level due to the strength of the fossil fuel regime, preventing the policy clarity required for certainty of investment in new power generation capacity that could drive a renewables transition. For this and other reasons—such as the urgency with which decarbonisation of the economy is needed—a multi-sector approach has been advocated globally (e.g. CDP, WRI & WWF 2015; Hawken 2017) and locally (ClimateWorks 2018): '… each sector offers a unique set of opportunities and reduction pathways that need to be pursued and met in order to achieve a 2°C mitigation outcome for the planet' (CDP, WRI & WWF 2015, p. 4).

Approximately three-quarters of energy generated globally is consumed in cities (Kammen & Sunter 2016; Zoellick 2011)—and the built environment is the leading sector of energy use and carbon emissions in cities. Within cities and their built environments, buildings and transport represent major sources of CO_2 emissions as well as water supply, wastewater treatment and solid waste disposal. Within each of these areas, energy consumption (and carbon emissions) are both direct (involving operating energy) as well as indirect (embodied in products and materials), although the latter is yet to be fully incorporated into carbon accounting of the built environment in Australia. There is considerable scope for introducing energy efficiencies across all these built environment sub-sectors, as outlined in the 2018 International Energy Efficiency Scorecard (Castro-Alvarez et al. 2018), where Australia was ranked 18th out of 25 of the world's top energy-consuming countries (10th in buildings and 20th in transportation). The clear shift towards net zero emission buildings for new construction, involving innovation and total building optimisation of the multitude of associated building products, provides the basis for further improvement; but transport remains a more significant challenge, linked more directly to established land use-transport configurations in cities than vehicle technologies, which have capacity for transitioning more rapidly.

In addition to the *type of energy supplied* (e.g. fossil fuel, renewables) and the *energy efficiency performance of each of the components of the built environment*, two additional factors that impact carbon emission profiles of cities also formed a major focus for CRC LCL research featured in this book:

- the *urban forms*, structures, fabrics and densities of cities and their precincts—in the context of their influence on urban mobility (travel mode and trip distance) and energy use; and
- the *behaviour of urban residents*—in particular, their consumption and conservation practices related to energy, water, travel, housing, etcetera.

In this context, the built environment needs to be understood as a complex multifaceted urban system in the framing of interventions, *if* significant decarbonisation is to be realised. To maximise opportunities for carbon mitigation, the nature of the *interactions* across sectors need to be more clearly understood; for example energy-water/wastewater systems, energy-transport, energy-manufacturing (embodied energy), buildings-distributed energy and storage (Taylor et al. 2019).

Since built environments are both energy and resource intensive, attention needs to focus on the development of regenerative technologies that can mesh with urban forms and fabrics to:

- reduce the extraction of raw materials and volume of supply of building materials and products that embody significant amounts of carbon and water that can be reflected in life cycle assessment (LCA) product labelling and green procurement policies
- recycle solid and liquid waste flows as part of a circular economy for cities that operate under zero waste policies
- utilise the building fabric—rooftops in particular—to generate electricity locally from solar PV panels to service the needs of occupants and EVs
- harvest rainwater and stormwater and recycle greywater to service decentralised integrated water systems; and
- decarbonise urban mobility via mode shifts away from the (internal combustion engine) automobile to public transport, active transport and EVs; and increased car sharing. The urban space savings from this shift are significant (e.g. a private car uses 9.7 m^2 per occupant compared to a train or bus which is less than 1 m^2: Institute for Sensible Transport 2018).

To realise these goals of low carbon sustainable urban development require solutions that can incorporate integrated cross-sectoral analyses in any set of future built environment scenario assessments (Newton, Chapter 19).

Sustainable low carbon solutions will only be found by enabling a reshaping of the built environment via innovation in arenas related to (see Fig. 1.1):

- introducing new urban *technologies* that can disrupt and substitute for poorer performing systems and deliver demonstrably superior performance
- overcoming *regime* resistance and barriers to technical and social innovation that have built up around industries, government and communities by creating new governance structures for urban development
- development and application of *smart built environment design* tools, platforms and processes that can more effectively and efficiently scope, plan and assess the massive pipeline of urban development

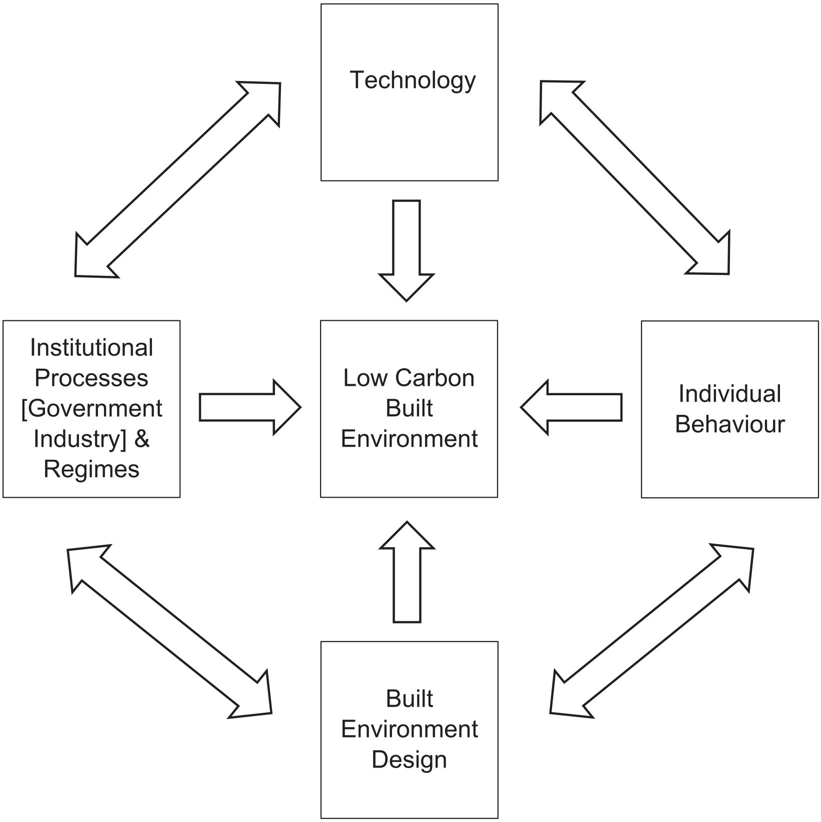

Fig. 1.1 Innovation pathways to a low carbon built environment

projects occurring in twenty-first century cities that are yet to be constructed (over the next 40 years, 230 billion m^2 of additional buildings will be constructed—the equivalent of adding the floor area of Japan to the planet every single year to 2060, according to UNEP 2017)

- encouraging *new low carbon practices and behaviours* among urban residents that voluntarily shifts established high consumption habits, while recognising that the current *built environment provides the context* for a significant component of the Australian population's world leading carbon footprint.

Overview of the Book

The speed with which an economy transitions to renewable energy will influence how effectively built environments, cities and populations can also transition to more sustainable, resilient, low carbon futures. Historically, energy transitions have been driven by resource scarcity and have been relatively slow. The twenty-first century transition from fossil fuels to renewable energy, by way of contrast, needs to be more rapid and well advanced by 2050 to avoid the catastrophic impacts of climate change should global warming extend 2.0 °C above levels representative of the twentieth century, which are now being predicted (IPCC 2018).

Part I addresses key sociotechnical factors in the speed and trajectory of Australia's energy transition, explores solar PV and the role it is now playing as a regenerative urban technology—creating energy from the city—and together with the emergence of electric vehicles and smart homes provides the basis for a wider transition to a green economy.

Transition to zero carbon buildings (Part II) is now established as a clear objective for industry by key national built environment sector organisations (ASBEC & ClimateWorks 2018). Achieving that objective will require a step change in energy efficient building design—and assessment (as built and as operated) in the building and construction sector; higher standards for energy efficiency of built-in and plug-in appliances that will require regulation and audit; developing greater penetration of onsite solar generated electricity and hot water heating capacity; and increased energy conservation behaviours by building occupants, taking advantage of advances in smart meter and sensor technologies that provide real-time feedback of energy use to consumers. A staircase of innovations has been identified, each of which are associated with carbon wedges that can collectively deliver zero carbon outcomes, if implemented. Given the significant stock of existing buildings that are poor performing from an operating energy perspective, retrofitting also represents a major challenge in achieving a low carbon building sector.

Addressing the challenge of life cycle energy (where embodied carbon is also included) remains elusive, lacking government and industry support in Australia due to the dominance of neoliberal regimes in the property development sector that consistently resist the introduction of what they refer to as 'green tape'. Yet as building operations become more energy efficient, the spotlight falls more strongly on assessment of embodied energy and the increasing role it plays in defining the carbon signature of buildings.

Precincts are the building blocks of cities and represent a critical urban arena for achieving radical reductions in ecological and carbon footprints. Part III addresses the challenges of where and how to transition from currently unsustainable patterns of urban development to more regenerative forms of redevelopment in the established low-density suburbs of Australia's cities where a suburban-to-urban transition is required. Compact city development and urban retrofitting needs to be accompanied by a radical reduction in the metabolic flows associated with cites—increasing their self-sufficiency in relation to energy, water and mobility while reducing their carbon emissions and waste to landfill. Particular focus is on the design principles necessary for creating sustainable low carbon resilient precincts that need to be coupled with precinct scale distributed regenerative technologies and smart city planning and management that utilises new digital tools for building, precinct and city information modelling.

There can be no prospect of low carbon living without a low carbon built environment that provides the spatial context for resident decision-making and behaviour. Liveability outcomes are also influenced by where people live and the quality and characteristics of the built environment that surrounds them—extending to population health and well-being co-benefits as well as resilience to global warming and local climate change.

There is considerable evidence to suggest that people's understanding of climate change threats and general aspirations to do the right thing, and reduce carbon emissions, does not translate well into practice. This disconnect between intent and practice has significant implications for how policy-makers can expect to engage citizens in the decarbonisation journey. It appears that simply informing the public of how and why they should reduce their carbon emissions is unlikely to have significant impact on voluntary behaviour change. Part IV explores factors that influence consumer decisions and the extent to which they are linked to attitudes, habits, practices, social and demographic conditions within households and built environment contexts. It investigates some potential approaches for shifting consumer choices, particularly in relation to housing-related decisions—given the significance of residential property in the economic and social lives of the Australian population *and* its role in CO_2 emissions generation.

The fifth Part contains one chapter that summarises the principal findings from a major CRC Project that explored alternative visions of an urban future that is yet to materialise, but with potential 2040 realisations, depending on the success with which synergies between four different transition pathways could eventuate.

Energy Transition

Since the mid-2000s, there have been significant changes in the energy landscape in Australia. Three major trends are evident: the rise of low-cost renewable energy systems—predominantly PV and wind, the increase in recent energy prices and finally the decrease in electricity demand.

Globally the energy transition from unsustainable fossil fuels to renewable energy is well and truly underway (Markard 2018). In Australia this can be seen by looking at the contribution of renewable energy to the National Electricity Market (NEM) in 2006 and in 2018. In 2006, PV and wind energy systems contributions to the NEM were too small to register, while hydroelectricity provided about 7% of total generation (Open NEM 2019). However, by 2018, PV contributed 5%, wind energy 7% and hydroelectricity provided about 8%. This rapid rise of the new renewables has been the result of increasing cost competitiveness of PV and wind energy systems. As the scale of these technologies has increased their installed costs have fallen dramatically. In fact, both PV and wind energy systems are now the lowest cost option for power generation in Australia (Graham et al. 2018).

This cost advantage of the renewables improves as time progresses and remains even if two to six hours of storage is included in the form of batteries or pumped hydroelectricity. In comparison all coal, gas and, in particular, nuclear power is now too expensive (Graham et al. 2018). The question of a shift to a 100% renewable electricity supply is now not a question of whether this transition will occur but how quickly wind, PV, battery and pumped hydroelectricity systems can be scaled up to replace ageing fossil fuel generators over the next 10–15 years.

In addition to the rise of low-cost renewable energy systems, since the mid-2000s, Australian households and businesses have experienced considerable gas and electricity price rises (ACCC 2018a, 2018b). For electricity, the price of electricity ($/kWh) increased by 56% in real terms over this period—which was primarily caused by expenditure on 'poles and wires', driven by rapid growth in air conditioning of buildings creating peak demand on extremely hot summer days. Due to the lack of energy performance requirements in Australia's building code before 2006, air conditioning of inefficient buildings in Australia is a major driver of peak demand, resulting in 30–40% more electricity demand on days of extreme heat (Fan, MacGill & Sproul 2017). Importantly the contribution of environmental subsidies on the electricity price rise was only 15% (ACCC 2018a).

For natural gas, the price increases above the CPI have been associated with linking traditionally low Australian domestic gas prices to the international price. This arose due to the recent increased activity in exporting Australian natural gas to the international market (ACCC 2018b).

These price rises of electricity and gas since the mid-2000s have provided additional impetus to the transition towards renewable energy and energy efficiency. This can be seen by examining the changes in electricity demand in the NEM. From 1980 until 2008, electricity demand in the NEM had grown at essentially a linear rate of 4.6 TWh per year (Saddler 2013). However, by 2008 electricity demand in the NEM peaked at 207 TWh (Open NEM 2019) and since that time has actually fallen—unprecedented over the past 60 years of growth in electricity demand—which has traditionally been linked to increasing population and growth of electric appliances. In the NEM, demand reached a low of 197 TWh in 2014 but has since risen slightly to 203 TWh in 2018 (Open NEM 2019). If demand had continued to increase at 4.6 TWh per year over the period 2008–2018, electricity demand in the NEM would in fact have been 253 TWh in 2018, but instead it is 20% lower—despite continued increases in Australia's population and the increasing electrification of our energy systems. Saddler (2013) has carefully analysed this dramatic and unprecedented reduction in electricity demand in the NEM and concluded that the three principal factors were: the impact of energy efficiency programmes reducing demand of appliances and buildings; the closure of some energy intensive industrial processes such as aluminium smelting; and since 2010, the response of electricity consumers, especially residential consumers, to higher electricity prices.

Within this landscape there has been relatively less focus on the need to make our energy systems more sustainable and in particular the pressing need to reduce Australia's carbon emissions. These issues are explored by Diesendorf (Chapter 2) who examines the critical need to transform our energy systems from a sustainability point of view—an argument now strengthened by the low cost of renewable energy systems and the increasing cost improvements of storage. This chapter examines the technical potential of a 100% renewable energy system supplying Australia's energy demand. Diesendorf describes for us a vision of a sustainable energy future, essentially based on existing renewable energy technologies and end-use energy efficient technologies as well as near term storage options being scaled up to replace ageing fossil fuel plants as they retire. Diesendorf also clearly addresses the barriers to such a transition which are now predominantly non-technical and non-economic in nature.

Adoption of PV systems and wind energy in Australia has advanced considerably over the past decade. However, in the mid-2000s, uptake was slow. As such this saw the rise of a grassroots movement seeking to hasten the transition to renewable energy through the coordinated efforts of community groups in getting RE systems installed. Mey and Hicks (Chapter 4) examine the impact of community owned renewable energy systems with a particular focus on Germany and Australia. The Germans were among the pioneers of community energy systems and their experiences have been useful in informing communities around the world about how to enhance the uptake of renewable energy. However, as mentioned above, PV and wind energy systems are increasingly now cost effective, and hence are increasingly mainstream. In the Australian context, Sproul (Chapter 3) explores the uptake of PV by households, businesses and utilities which has seen PV in 2018 supplying 5% of electricity demand in the NEM with 80% of that coming from rooftop systems on some 2 million Australian homes. In situations where groups of households can combine to achieve a more cost-effective transition to clean energy, community renewables may still be a useful way to increase RE uptake. However, electricity utilities are increasingly installing PV and wind farms as large central generators to lower wholesale electricity prices and householders and business continue to instal PV on their rooftops due to the high cost of conventional retail electricity. Sproul points out that PV is now so cheap, that in many instances it delivers the lowest cost option for reducing carbon emissions in the built environment for daytime electricity loads, cheaper than many energy efficiency measures; for example, such as further improvements to building envelopes.

In terms of carbon emissions, the transport sector is second only to the electricity sector in terms of emissions (DEE 2018b). In addition, the high price of oil over the past decade, concerns regarding air pollution and resource depletion mean that alternatives to our present oil dominated transport systems are urgently required. These issues are explored by Dia (Chapter 5) in examining the difficult problem that is transport in rapidly growing cities. Aiding the transition away from oil, increasingly it appears that renewable electricity can partner with electric vehicles to provide some of the solution. Of course, this is not the complete answer as transport in our rapidly growing urban centres is a complex and multifaceted problem.

Another significant emerging trend in the energy transition is the emergence of smart households and the seemingly unrelenting improvement of appliance energy efficiency. This component of the revolution towards lowering energy demand and lowering carbon emissions is examined by Pears and Moore in Chapter 6. With the increasing uptake of PV systems on homes in Australia, in order to gain the greatest benefit, it is important that our homes become smarter—optimised to not only be as efficient as possible but to shift household energy demand, if possible—into the periods of the day when plentiful, low-cost PV power is available.

An impact of this energy transition means that energy efficiency measures for daytime loads must not only be cheaper than retail electricity prices to compete but need to be cheaper than low-cost RE systems, and in particular—rooftop PV. Increasingly, RE systems, storage and efficiency all need to be optimised together to deliver the energy services that homes, businesses and industry require. Additionally, as explored through the material presented in this book, the technical and economic improvements of RE systems, energy efficiency and energy storage continue—giving great impetus to addressing carbon emissions in the built environment. With costs continuing to decline, and given the vision and will, many homes and businesses are now already well on their way to delivering zero emission buildings and low carbon transport systems.

Transition to Zero Carbon Buildings

There has been considerable research and deployment work over the last 45 years in reducing the energy consumption in buildings and more recently this has focussed on lowering the carbon footprint of buildings as a sector. This period has seen the focus evolve from basic passive solar and climate responsive strategies to use of more energy efficient technologies and systems and both onsite and offsite renewable energy use to drive building-related carbon down to zero and beyond. Despite years of awareness of various energy efficiency design strategies, there still remains little progress in mainstreaming zero carbon buildings in the marketplace.

It is widely understood now that depending on climate and budget, the key approach to delivering zero carbon buildings involves: minimising energy demand while ensuring indoor comfort, use of onsite renewables combined with directly seeking offsets contracted from offsite renewable generation and a decarbonising grid. Within this, a data-driven approach which aims to close the feedback loop through verification and post occupancy monitoring will lead to sustained higher performance goals. The World Green Building Council (2018) has labelled these the key principles for advancing Net Zero Carbon in Buildings (NZCB).

The CRC for Low Carbon Living sought to tackle the lack of mainstreaming NZCB by bringing designers, builders, consultants, manufacturers, governments and researchers together to tackle a once in a generation opportunity to make significant advances through new technologies, materials, improved design approaches, post occupancy feedback (closing the loop), showcasing and engaging larger building firms in delivering high performance outcomes leading to zero carbon. Part II of this book presents findings from these initiatives as well as the global context of the change.

The Global Alliance for Buildings and Construction (IEA & UNEP 2018) puts the operational energy of buildings globally at 36% of global final energy use and 39% of energy-related carbon dioxide emissions in 2017. This is a very significant proportion of the total global carbon budget and presents equally significant opportunities for reductions.

The drive towards zero carbon buildings will need to include the embodied emissions generated through the manufacturing of and transportation of building materials from source to end use. Wiedmann et al. (2017) highlight the importance of embodied energy on a life cycle basis. Even though there is significant variability in the relative proportions of life cycle emissions (embodied versus operational) in different climates and different mixes of building types and materials, a share of around 20% and higher of embodied emissions is not uncommon (and is increasing as operating energy efficiency of buildings improves: Newton et al. 2012). The CRCLCL has developed an advanced carbon accounting tool (Integrated Carbon Metrics—ICM) based on Scope 1–3 emissions (ISO Methods) and this is now widely available for use as a top-down methodology for estimating carbon emissions either at building scale or upwards to precinct or city scale.

The residential building sector poses interesting challenges for zero carbon pathways. Mostly they are not of a technical nature but mainly involve 'people' factors. While communities are beginning to understand the need for low carbon living (see Part IV of the book), this is not adequately reflected in action. The work of the CRCLCL focussed on some technical opportunities (creating new products like photovoltaic thermal hybrid solar collectors, and new materials from recycling); used Living Laboratories around Australia to better understand and demonstrate real-time consumption and user attitudes, test bedding renewables and storage; improved energy rating tools to take account of 'whole of house' energy and carbon; and at the same time explored the use of 'comfort' as a metric for better communicating a consumer's understanding of performance. Byrne et al. (Chapter 8) describe the high performance building and precinct studies and the knowledge communicated to the public from Living Laboratory studies in Lochiel Park (Adelaide) and White Gum Valley (Perth).

Commercial buildings on the other hand evolve from a more commercial focus on price, performance and productivity, where the need for thermal, visual and acoustic comfort is directly linked to worker performance and productivity outcomes. Many commercial buildings are not owner occupied, resulting in split incentives for lowering carbon. However, it is increasingly evident that developers and investors now see the value of high performance and the work of the Australian Green Building Council has brought about higher awareness about better buildings. Oldfield et al. (Chapter 9) explored the challenges of decarbonising commercial buildings and highlights the role of rating systems and building codes in driving ongoing improvements. ASBEC and ClimateWorks (2018) in collaboration with CRCLCL and GBCA undertook the *Built to Perform* project, developing the technical and business case for a set of code changes designed to make it feasible to design and construct zero carbon buildings using the set of established knowledge and principles now available.

Given the know-how is now available to deliver zero carbon buildings on a 'cradle to cradle' approach, there are clearly market failures involved in why these buildings are not mainstreaming fast enough. The role of policy in driving change is therefore important. Harrington et al. (Chapter 10) present strong arguments for regulatory interventions. There have been improvements in building codes over time but these need to be much more frequent and stringent in order to be a vehicle for change and to provide more confidence and certainty to industry to invest in new building processes and products. There has been a lack of energy efficiency and sustainability incentives and this has meant little appetite for change from the built environment industry more broadly. There has however been support for photovoltaics uptake from subsidies for domestic feed in tariffs which has seen significant growth in rooftop PVs now in place in Australia. Recent uptake by large consumers (like universities and city councils) using long term (around 15 years) purchase agreements direct from green power generators is likely to see significant uptake as they prove to be the cheaper option as well. The upcoming Federal election (mid-2019) is witnessing an emergence of a raft of policies related to climate change mitigation (Coorey 2019) which will further drive transition to zero carbon in buildings (especially those targeting solar PV and battery storage). This augers well for the future.

Regenerating Urban Precincts and Cities

Performance goals for cities are now well established (Department of Infrastructure 2011; UN 2017, 2018): economically competitive, productive, equitable, inclusive, environmentally sustainable, liveable, healthy and resilient. *If* cities are to achieve these goals then it will be necessary for their constituent precincts to demonstrate performance outcomes that align with and add to, rather than subtract from, these objectives. Yet there is significant variability between and within cities in all these respects; for example, resource consumption, carbon emissions, waste generation, human health and well-being, urban mobility and access to jobs and services, environmental amenity and vulnerability to a range of climate change threats. The chapters contained in this section of the book are primarily focused on achieving regenerative urbanism, a new objective for smart sustainable urban development that presents an opportunity and challenge to go beyond minimal reductions in environmental impact to a new vision of how cities can be designed and operate in an 'eco-positive' manner, while maintaining or enhancing liveability (Birkeland 2008); that is, removing negative environmental impacts from development and providing ecological gain. This requires regenerative development that is based on urban metabolism principles involving 'giving back as well as taking' (Girardet 2015, p. 11) and needs to operate across all urban sectors and all urban scales: building, precinct and city.

At city scale, Thomson et al. (Chapter 11), Stevenson and Thompson (Chapter 13), and Dia et al. (Chapter 14) all indicate that new metropolitan planning schemes and investments are required to create an enabling environment for an extensive network of 'villages' to emerge—20 minute 'mini-cities'—that can provide a built environment for active transport and public transport and mixed use development at higher densities: a suburban to urban transition for Australia's low density cities (Newton, Meyer & Glackin 2017). The authors demonstrate that cars are increasingly a problem (the source of 80% of transport CO_2 emissions as well as costly urban traffic congestion)—*not* a transport solution. A more integrated land use transport system that has strong public transport underpinning—long advocated by planners seeking more sustainable urban development (but stymied by entrenched regime processes favouring roads and cars) can deliver a more compact city with at least one-third less CO_2 transport emissions than business as usual low-density urban forms (Xing et al., Chapter 12). Using the avoid-shift-share-improve framework, Dia et al. illustrate pathways to achieving low carbon urban mobility in the Australian city. The co-benefits of a more compact city are also significant, including improved human health across a spectrum of non-communicable diseases (Stevenson & Thompson, Chapter 13) and reduced urban sprawl (OECD 2018)—conserving more agricultural land and green space in peri-urban fringe areas (Coleman 2017).

More compact city development needs to be driven by regenerative infill redevelopment where 70% or more of new housing and associated commercial development occurs in established built-up areas of the city, either in brownfields or the more ubiquitous greyfields. These are both more challenging development arenas compared to greenfields, and as such require more local strategic planning, innovative design thinking and retrofitting 'one neighbourhood at a time', accommodating the needs and reflecting the future potential of different urban contexts and fabrics (Thomson et al., Chapter 11)—a challenge for entrenched property development practices in government and industry however. Designing for the 'missing middle' in Australian cities requires greater focus on medium density design and precinct scale projects compared to current suboptimal knock-down-rebuild practices which typically replace an ageing detached dwelling with a small number of townhouses.

Santamouris et al. (Chapter 18) and Kenway et al. (Chapter 15) highlight the environmental and liveability threats of current urban densification trends: significant loss of private green space and tree canopy, loss of land surface permeability and increased stormwater runoff resulting in local flooding, and increased urban heat island effects. Both chapters, however, have outlined and modelled a comprehensive menu of urban heat mitigation and water sensitive urban design strategies that also demonstrate an adaptive capacity to significantly reduce local temperatures and stormwater runoff—if implemented. Mitigation *and* adaptation are increasingly joint urban design processes (see Fig. 1.2).

The emergence of precinct scale distributed urban technologies related to local renewable energy generation and storage (Sproul, Chapter 3; Mey & Hicks, Chapter 4), integrated urban water systems that substitute harvested rainwater and recycled greywater for 'imported' potable water (Kenway et al., Chapter 15), composting of food waste in detached, medium density and high rise apartment settings rather than disposing to landfill (Graham et al., Chapter 17), and local car sharing and ride sharing schemes (Dia et al., Chapter 14) each represent carbon 'wedges' that collectively offer transformative potential for decarbonisation and urban regeneration—once implemented. There are (household) social practice as well as government and industry regime barriers to be overcome in all of these areas, however. Most wastewater treatment in Australian cities occurs at municipal or regional scale at present and here significant opportunities have been identified by Clos et al. (Chapter 16) across the entire industry in Australia for increasing energy efficiency and reducing GHG emissions.

The current inability to adequately and easily demonstrate to developers, clients, consumers and regulators the (multiple) benefits associated with new and innovative performance-based urban designs

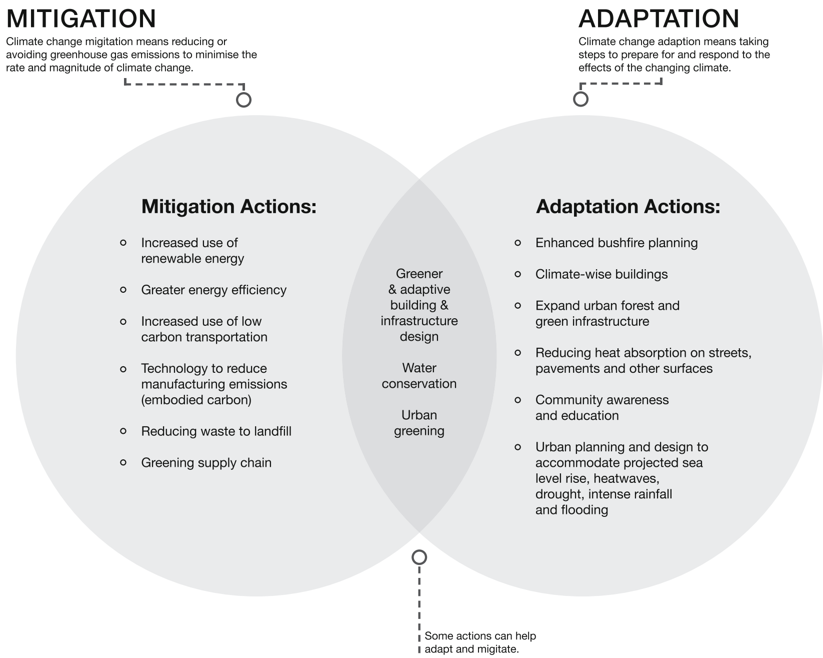

Fig. 1.2 Mitigation and adaptation actions in response to climate change

highlights the significant assessment deficit that currently exists for those urban development projects in Australian cities that are attempting to push the envelope of sustainable low carbon urban development. Newton (Chapter 19) and Newton and Taylor (2019) outline a number of the new tools developed in the CRC for Low Carbon Living that are capable of integrated design assessment of precincts by quantifying the associated performance benefits and costs.

Human Factors in Low Carbon Living

While technologies and design solutions are required to provide the means for reducing carbon, ultimately it is people who implement carbon abatement measures through their everyday (individual, commercial and political) decisions. Thus, any attempt at decarbonising the built environment, must equally focus on the role of individuals, households and groups in transitioning from existing (carbon-intensive) to future (low carbon) practices.

Surveys (Leviston, Greenhill & Walker 2015; The Climate Institute 2017) show that a strong majority of Australians think climate change is happening, and support a wide variety of initiatives to both mitigate and adapt to the potential impacts. Despite energy and carbon policy being used as a partisan political issue, there has been gathering momentum among the business and finance sectors to progress with action on carbon. The Australia and New Zealand real estate sector has achieved eight successive years of sustainable leadership under the GRESB benchmark for real estate assessment scheme. More entities in Australia and New Zealand set internal targets for net zero carbon emissions than in other regions (GRESB 2018).

Despite this, there is evidence that 'concern about climate change' does not necessarily convert into low carbon behaviour (Hall, Lewis & Ellsworth 2018; Newton & Meyer 2013) and some key industry stakeholders (such as the residential real estate industry) believe that Australians are not interested (Gardner et al., Chapter 20). Encouragingly, O'Brien et al. (Chapter 21) found that a new Low Carbon Readiness Indicator is a predictor of low carbon behaviour at household level.

A focus on low carbon behaviour is vital, both for saving emissions and for creating the cultural appetite in which business and political leaders can implement new business models and carbon saving policies. In this context, the CRC Low Carbon Living 'Engaged Communities' Program investigated the 'human factor', particularly setting out to identify levers and intervention programmes that would encourage and enable Australians to adopt carbon emission reduction practices more rapidly.

The CRC intentionally took a somewhat normative position that saving carbon is a good thing for people, and that the CRC's research would actively engage with Australians in the delivery of pilot carbon saving programmes and community engagement processes. In this way, the CRC was often an active participant in carbon saving initiatives, to both: bring knowledge and skills to the design and delivery of initiatives; and monitor and analyse the results of community engagement experiments. This approach was particularly evident in the Living Laboratories work, examples of which are highlighted by Salter et al. (Chapter 26).

The majority of the LCL CRC's research on human behaviour and practices was in relation to house construction and homemaking. Thus, the body of work loosely follows the key stages in the lifecycle of a house, from energy efficient house design rating effectiveness (Gardner et al., Chapter 20); household energy usage practices and behaviour (O'Brien et al., Chapters 21 and 22; Eon et al., Chapter 23); and house renovation (Hulse & Milne, Chapter 24; Podkalicka et al., Chapter 25). Many of these chapters found important links to the property sale and investment moment in the house lifecycle. There was clear evidence of people's general desire to 'do the right thing' in terms of reducing carbon emissions (Gardner et al., Chapter 20; O'Brien et al., Chapter 21). The simple three question Low Carbon Readiness Index (LCRI) showed a reliable correlation between personal attitudes and a wide range of low carbon behaviours. High LCRI was most pronounced among older, female and multilingual Australians. Surprisingly, nearly 20% of people who believed in human-caused climate change were neutral or below the LCRI midpoint. Belief in human-caused climate change, alone, was found to be associated with investment in solar technology, but it did not predict any other measure of low carbon behaviour.

O'Brien et al. (Chapter 22) and Eon et al. go some way to explaining the complexity of converting attitudes into action through the lens of Practice Theory. Eon et al. highlight the need to address each aspect of meaning, skills and technology in relation to home-based practices, in order to create the conditions for behaviour change. That is, people need (i) a compelling reason to change (that satisfies their individual needs, aspirations and values), (ii) the tools to effect the change, and (iii) the capability to use the tools. This is a high bar for scalable transformation, particularly when considering that our daily lives are filled with a plethora of different actions, each of which are intertwined with the actions of others and 'baked in' through habitual practices. Eon et al. see particular promise in the use of emerging automation technologies in the home (a focus of Pears and Moore, Chapter 6) to decouple specific practices (e.g. clothes washing, dish washing, vacuuming etc.) from the Household System of Practice—making them independent of time and occupant.

Governments have attempted numerous education campaigns, aiming to overcome information barriers that prevent financially rational adoption and investment in carbon saving products and behaviours. The limited success of these campaigns is not surprising when considering the complexity of the Household System of Practice. However, potential still exists for information tools (e.g. ratings) to have impact in the real estate market, where house buying is a major one-off purchasing decision rather than a regular habitual practice.

Unfortunately, government information campaigns have typically focussed on energy and dollar savings from improved energy efficiency. This is unlikely to fully resonate with home buyers, whose aspirations are rarely purely financial. Gardner et al. and Hulse and Milne both highlight the need to focus information campaigns on the potential for improving everyday living (e.g. comfort and health), rather than the language of building-performance. They further highlight a trend towards 'financialisation' of housing, where housing is seen as a fund which can be drawn upon, borrowed against and traded as an asset. In this context, the financial touchpoint in renovation is as much about 'adding value' in a dollar sense as in lowering ongoing energy costs.

A key finding is the need to simplify the messaging of energy efficiency and provide highly actionable direction for consumers. Gardner et al. found that a star rating icon, or certification mark, is useful for simplifying and reducing the psychological demands for home buyers, as they weigh up the trade-offs between thermal efficiency and other purchasing criteria. The impact of rating information was shown to be further improved by the addition of brief explanations that draw attention to (i) tangible physical features that contribute to the rating (e.g. insulation, solar) and (ii) demonstrate outcome benefits relating to comfort and property value uplift.

The source and means of delivering information to consumers was also explored in various chapters. O'Brien et al. (Chapter 21) found that people who score higher on the LCRI, typically (i) believe that others are taking action on climate change, and (ii) have the resources and encouragement of family and peers that drive action. This highlights the need to engage consumers through personal stories. These can be broadcast through one-way traditional media channels (for reach) or, more dynamically, through two-way online communities-of-practice using digital and social media (Hulse & Milne, Chapter 24). Podkalicka et al. (Chapter 25) highlight two examples of how trust can be maintained online.

While good message framing and improved delivery channels can improve the impact of energy efficiency information campaigns, the most successful international rating schemes are currently those linked to government policy incentives (e.g. low interest loans or subsidies). Moving forward, towards longer term transformational impact (once government subsidies are withdrawn), a much broader cultural awareness of the value of energy efficiency is still required. This must be achieved with targeted consumer marketing, aligned with key industry intermediaries. Part IV of the book provides a range of insights and advice for targeting and delivering such a cultural shift in the awareness of the many benefits of energy efficiency and low carbon living.

Concluding Comment

The material assembled in this book indicates that there is good prospect for a rapid decarbonisation of energy supply involving large scale electrification of the energy system involving rapid deployment of renewables—predominantly PV and wind—with firming of supply provided by storage systems, most probably pumped hydroelectricity and batteries. Even conservative observers such as BP are now reporting that ‘Renewable energy is the fastest growing source of energy, contributing half of the growth in global energy supplies and becoming the largest source of power by 2040’ (BP 2019, p. 7). The dramatic fall in RE technology costs, brought about predominantly by mass production in Asia means that, in addition to rooftop PV and efficiency, large centralised renewables are now a cost-effective means of addressing carbon emissions in the built environment.

The impact of rising costs of fossil fuels and conventional energy delivery systems, the dramatic lowering of cost of renewable energy systems, particularly PV and wind, the potential for storage both in batteries and pumped hydroelectricity, the unrelenting improvements in appliance energy efficiency, and the huge potential of electric transport means that the energy transition is now well under way. The question remains, are we able to assemble a sustainable energy system over the coming decades quickly enough to seriously address Australia's carbon emissions? Some of the pieces of the puzzle have been outlined above and more will be explored below—but there is enough evidence that a transition away from our conventional fossil fuel systems is increasingly possible from a technical and economic viewpoint. Increasingly what is needed is the vision and will to make this happen across all sectors.

Built environment transitions prove to be more difficult, due to a range of factors embedded in the transition pathways outlined in Fig. 1.1; but there are examples across all sectors where transformative change has been demonstrated, especially in relation to advances in precinct scale design and assessment and the incorporation of distributed regenerative low carbon technologies involving renewable energy, integrated water systems, shared local mobility systems and active transport, and local recycling of domestic waste. The challenge involves accelerating and scaling up. Currently, there is a lack of sufficient transformative capacity in government, industry and community to drive the multiple transitions required to achieve sustainable urban development (Newton, Meyer & Glackin 2017).

At a building scale progress has been faster, given the greater focus on innovation in this area over the past two to three decades. The technologies, tools and designs for climate responsive and zero carbon buildings exist today. There are many exemplars within Australia that showcase these. The CRCLCL has taken existing knowledge and through its own research, innovation and demonstration added significantly to mainstreaming this in Australia. It also has provided an evidence base for policy makers to drive change towards zero carbon buildings in a sector that has traditionally been slow to innovate.

Behaviour change, in the consumption of energy, is already occurring as a response to increasing energy prices. While there is limited evidence for a direct correlation between ‘concern for the environment’ and behaviour change, consumers appear to value the many co-benefits of thermally efficient housing. This suggests that business and government can increase their ambition for reaching out to the Australian public with new low carbon housing products, and with more ambitious policies respectively. Investment in raising consumer awareness of low carbon products will support the transition. This should be done through simple messaging and storytelling, related to everyday living, and taking advantage of new digital platforms.

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Part I

Energy Transition

2

Energy Futures for Australia

Mark Diesendorf

Introduction

Decarbonising the built environment can occur rapidly and effectively if it evolves under a positive guiding vision for Planet Earth and human society. This chapter draws upon the guiding vision of sustainable development, called 'ecologically sustainable development' in Australia. It is defined here as 'types of social and economic development that protect and restore the natural environment and social equity'. 'Development' is interpreted broadly as 'unfolding of human potential' and 'enhancement of human well-being'—it does not necessarily assume endless economic growth on a finite planet. 'Social equity' is interpreted as 'equal opportunity of access to basic needs' (Diesendorf 2001).

At one conceptual level, the drivers of environmental impact are growth in population and economic activity, as well as polluting technologies, as described by the well-known $I = PAT$ identity (Ehrlich & Holdren 1972).

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This chapter focuses on the technology term *T*, interpreted broadly to include hardware, software and 'orgware', the latter being the organisations and other institutions associated with the hardware.

The sustainable development framework enables us to identify clearly the drivers of the present unsustainable energy system of Australia and indeed most of the world: one that is dominated by fossil fuels. Fossil fuels are not only the major emitters of the principal anthropogenic greenhouse gas, carbon dioxide. They are also the major source of air pollution, with associated impacts on respiratory health; a significant cause of water pollution, water overuse and land degradation; and, as they become scarcer, a cause of rising energy prices and energy insecurity. Because fossil fuels are controlled by large multinational and foreign-owned national corporations, their use diminishes social equity by limiting greatly the control that individuals have over their energy systems.

Incidentally, although nuclear power has lower life-cycle greenhouse gas emissions than fossil fuels, it shares with the latter several of the above types of adverse environmental and social impacts. To these must be added the proliferation of nuclear weapons, the risk of rare but devastating accidents, the burden of managing high-level wastes for hundreds of thousands of years, and very high and increasing economic costs (Diesendorf 2014, Chapter 6; Sovacool 2011).

In contrast, most renewable energy sources, together with energy efficiency, will last for billions of years, have very low environmental impacts (exceptions are some hydro-electric and bioenergy projects) and, except for bioenergy, have no fuel costs and so can stabilise energy prices. Solar photovoltaics (PV) in particular can be implemented on all scales—small (household), medium (precinct, commercial, local community, remote mining) and large (grid-connected renewable electricity power stations)—thus allowing individuals and organisations more choice and autonomy in their energy systems.

Therefore, within the sustainable development framework, the desirable future energy system is based on renewable energy together the minimisation of energy waste by means of energy efficiency and conservation. *Energy efficiency* is using less energy to provide the same level of energy service and is mainly based on efficient design and energy efficient technologies. *Energy conservation* is using less energy to provide a lesser energy service and is mainly behavioural. Both are important in transitioning to sustainable energy (Diesendorf 2014, Chapter 4).

A renewable energy future will be predominantly an electrical future (see section 'Vision of a Sustainable Energy Future'). Renewable energy now supplies 26.5% of global electricity, with 16.4% coming from hydro and the rest from wind, biopower and solar PV in that order (REN21 2018). In 2017, annual global investment in new renewable electricity generation was US$310 billion (of which US$45 billion was in large-scale hydro). Renewable electricity investment is more than double the combined investment in fossil-fuelled electricity (US$103 billion) and nuclear power (US$42 billion) (REN21 2018). Nowadays, renewable energy technologies are mainstream rather than 'alternative'.

The structure of this chapter reflects a backcasting approach. Section 'Vision of a Sustainable Energy Future' offers a vision of a sustainable energy future, considering both supply and demand, and small, medium and large scales. All scales are relevant, because the energy use and associated greenhouse gas emissions of the built environment are determined on one hand by local design of buildings and precincts and the behaviour of building occupants and, on the other hand, by the types of energy inputs from electricity and fuels produced externally. After summarising current trends in energy demand and supply in Australia (section 'Trends in Energy Supply and Demand'), the chapter examines scenarios for transitioning rapidly from the present unsustainable system to a sustainable future (section 'Scenarios for the Sustainable Energy Transition'). It concludes (section 'Overcoming the Barriers to Sustainable Energy') with an outline of barriers and policy options for overcoming them.

Vision of a Sustainable Energy Future

Let's consider a hypothetical situation in (say) 2040. All new buildings constructed from the early 2020s onwards are Zero Net Carbon: that is, they are highly energy efficient and produce onsite, or procure, enough carbon-free renewable energy annually to meet the energy consumption of building operations. Furthermore, new materials, such as laminated timber and eco-cement, have reduced the embodied energy of new buildings. Brick veneer homes are no longer built—instead, in temperate regions of Australia, most walls of buildings comprise three layers, an outer cladding, insulation then thermal mass on the inside.

In the early 2020s, the Building Code of Australia was extended to existing buildings. The latter were retrofitted to increase energy efficiency, although they did not have to reach the standard of Zero Net Carbon. Measures for homes include improved insulation, summer shading, more airtight envelope in winter, greater airflow in summer, solar or heat pump hot water, cool roofs and well-ventilated attics. The majority of buildings have space heating and cooling supplied by heat pumps running on renewable electricity, while a minority use direct solar. The poor thermal mass of the old ubiquitous brick veneer home, which is very difficult to retrofit, is partially compensated by means of rooftop solar PVs where solar access is available. Indeed, rooftop solar PV, together with battery storage and smart controls to adjust the timing of demand, is widespread behind the meter for households, commercial properties and local community micro-grids. Double glazing is mandatory in designated regions with low Winter night-time temperatures. Energy audits are mandatory for the sale and rental of housing and the results must be stated on contracts.

Minimum Energy Performance Standards are applied to appliances and equipment used within buildings. Lighting is fluorescent and LED, cooking is mostly by induction and microwave, and showerheads are water efficient and hence energy efficient.

Electricity from the grid is supplied entirely by renewable sources, most from wind and solar PV, with reliability ensured by minor energy contributions from flexible, dispatchable renewables—concentrated solar thermal (CST) power with thermal storage, pumped hydro (both on-river and off-river) and open-cycle gas turbines operating on renewable fuels—and battery storage technologies. Peaks in demand are small as the result of contracted demand response in smart systems. The simulations justifying the technical feasibility, reliability and affordability of 100% renewable electricity are summarised in section 'Scenarios for the Sustainable Energy Transition'.

In cities, electric public transport, cycling, walking and battery electric vehicles have replaced motor vehicles with internal combustion engines (ICE). For air transport, long-distance rural road transport, gas turbines and some industrial processes, renewable fuels have largely replaced fossil fuels. Renewable fuels include hydrogen produced by electrolysis or thermal decomposition of water using renewable energy, ammonia produced by combining renewable hydrogen with nitrogen from the air, and biofuels such as ethanol and methanol from both dedicated crops and agricultural residues.

Cities have been modified into hierarchical structures of sub-centres and local centres, integrating urban planning and transport planning and so reducing urban travel generally and car travel in particular. Major sub-centres and the Central Business District are linked to one another by fast heavy rail. Local centres are connected to their nearest sub-centre by light rail or bus. Cycleways and pedestrian areas encourage active transport within the centre, sub-centres and local centres, where there are higher population densities. This hierarchical urban structure was originally proposed by White et al. (1978) for Melbourne and reinvented by Newman and Kenworthy (2006)—see the summary in Diesendorf (2014, Chapter 7).

In this sustainable energy future, most transport and heating have become electric, for two principal reasons:

- It is easier and less expensive to transition electricity to renewable sources and technologies than to produce liquid and gaseous renewable fuels.
- Electric motors are much more energy efficient than ICE, and electrically driven heat pumps (e.g. air conditioners, refrigerators, hot water systems) are much more efficient than heating and cooling by direct combustion of fuels.

All the technologies mentioned in this section, except renewable hydrogen and ammonia and solar space cooling, were commercially available in Australia in 2018. The non-commercial exceptions had been proven technically by pilot systems. In 2018, the price of rooftop solar PV was typically less than half the price of retail electricity purchased from the grid, and wind and solar PV farms were competitive with new fossil-fuelled power stations (AEMO 2018; Parkinson 2018). Although batteries, CST and renewable fuels were still expensive in 2018, subsequent government policies fostered their further development, rapid growth in sales and big reductions in prices. In 2040, renewable energy, together with various forms of storage and of course energy efficiency and conservation, comprise by far the least expensive energy systems.

Having sketched a technically and economically feasible sustainable energy future, this chapter next considers recent trends and the present situation of energy in Australia and then in section 'Scenarios for the Sustainable Energy Transition' how to transition from the present to the desirable future.

Trends in Energy Supply and Demand

Primary energy comprises the forms of energy obtained directly from nature, before they are converted to other forms. It includes both fossil fuels and renewable energy. The combustion of primary fossil fuels is the principal source of GHG emissions from the energy sector. During the 32-year period from 1975–1976 to 2007–2008 Australia's primary energy consumption was characterised by rapid, consistent growth. After that it plateaued, with a dip around 2014.

The traditional energy flow diagram (Fig. 2.1) starts with primary energy on the left, then flows through transformation processes (e.g. combustion in a power station) in the middle of the diagram—to provide on the right-hand-side, after substantial energy losses, the final energy consumption or end-use energy. This in turn provides the energy services we demand: for example, a warm home in winter, hot showers and cold food.

This direction of flow is conceptually the opposite of that needed for efficient transformation of the fossil energy sector to sustainable energy. To do this, we must start by considering what energy services we really need and then provide them by integrating energy efficiency and conservation with renewable energy. In electricity generation from fossil fuels, reducing the demand for one unit of end-use energy substitutes

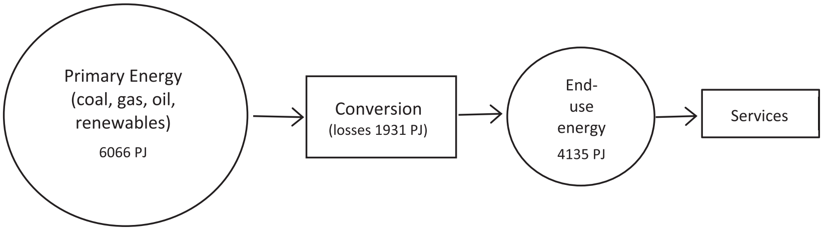

Fig. 2.1 Flow diagram for energy production and consumption in Australia 2015–2016 (*Source* Author, drawn from data provided in Ball et al. 2017. *Notes* 1. Exports and imports not shown. 2. The majority of the conversion losses occur in electricity generation and are due to combustion at the power station; oil refining and transport by ICE also have large losses)

for three to four units of energy in primary fossil fuels. This is because of the low efficiency of conversion of fossil fuels into electricity, typically 25–30% including transmission and distribution losses.

Electric vehicles are approximately three times as efficient as equivalent ICE vehicles at the point of use (Office of Energy Efficiency & Renewable Energy website). However, if they are charged from a grid that is supplied predominantly by coal, the savings in primary energy and hence GHG emissions may be modest or even non-existent in some cases. If charged by renewable energy, the savings are large.

The challenge of cutting GHG emissions can be addressed most effectively firstly in the choice of the types and degrees of energy services required, for example the temperature of one's home in Winter, and secondly at the stage of final energy consumption, that is, end-use energy (Fig. 2.2). The categories Coal, Oil, Gas and Renewables refer to non-electricity fuel uses; the Renewables category includes solar hot water, firewood for home heating and landfill gas, but not solar PV which is included in the Electricity category. Unfortunately, Australian energy statistics do not break down end-use energy into the categories Electricity, Transport and Heat. However, a rough idea can be obtained from Fig. 2.2 by noting that most Oil is used for transport and most Gas is used for heat (supplemented by a little Coal).

In a sustainable energy future, the size of the pie would be reduced by energy efficiency and conservation, and almost all of the Coal, Oil and Gas categories would be replaced by electricity. On the supply side, the

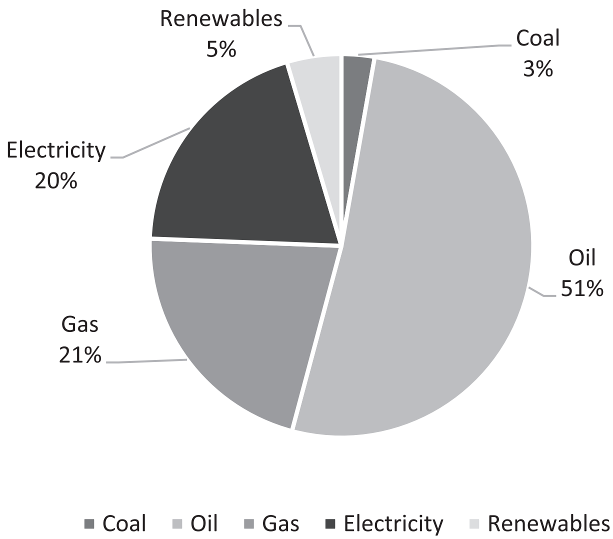

Fig. 2.2 Total end-use energy by fuel in Australia, 2015–2016 (*Source* Author, drawn from data provided by Department of Environment and Energy [2017], Table H1. *Note* Total final energy consumption or end-use energy in 2015–2016 was 4135 PJ)

non-electricity end-use energy may comprise some direct solar heating and cooling, and some renewable fuels for air transport, long-distance rural road transport and a few industrial uses.

Electricity supply from the grid peaked in 2010 and then declined steadily until 2015 (Fig. 2.3). The increased rate of decline in GHG emissions from electricity from mid-2012 to mid-2014 corresponds to the two-year period of the carbon price. After the carbon price was terminated in mid-2014, emissions rose again, peaked around mid-2016 and since then have fallen, resulting from the rapid growth in rooftop solar assisted by the Small-scale Renewable Energy Scheme (SRES), the growth in wind farms driven by the Large-scale Renewable Energy Target (LRET) policy and 'the increasing decrepitude of aging coal fired power stations' (Saddler 2018b, p. 6).

Coal is still the major contributor to Australia's electricity generation, although it has declined from 83% in 2000–2001 to 63% in 2015–2016. Table 2.1 shows the generation mix in 2015–2016 and

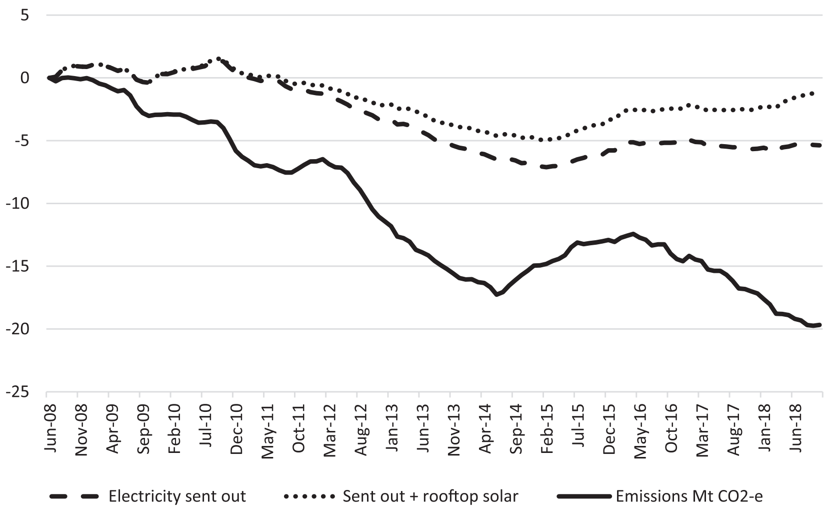

Fig. 2.3 Changes in electricity generation sent out and corresponding emissions, Australia, 2008 to 2018 (*Source* Drawn from data provided in Saddler 2018a. *Note* All expressed as percentage change in annual values, relative to totals for the year ending June 2008)

the average annual growth rates of electricity technologies over the previous decade. At the time of writing (November 2018), there is much uncertainty about the future growth rate of large-scale renewable electricity after LRET is reached in 2020. In the federal government, neither of the two major political parties has proposed an alternative driver of renewable electricity. However, in 2018 the Victorian, Queensland, South Australian and Australian Capital Territory governments have policies to facilitate the growth of renewable electricity.

There is also uncertainty about future growth in small-scale renewable electricity. The Australian Competition & Consumer Commission (ACCC 2018) has recommended the immediate abolition of SRES, although its contribution to retail electricity prices is much less than each of wholesale electricity prices and network prices.

In the spirit of backcasting, the next section investigates how the Australian energy system could be transitioned from the present fossil fuel dominance to the sustainable future envisioned in section 'Vision of a Sustainable Energy Future'.

Table 2.1 Australian electricity generation[c] by fuel type, 2015–2016

Technology	Share in 2015–2016 (%)	Average annual growth rate[a] (%)
Fossil fuel		
Black coal	44	−1.6
Brown coal	19	−1.2
Gas	20	5.3
Oil[b]	2.2	7.7
Renewables		
Hydro	6.0	0.6
Wind	4.7	19
Bioenergy	1.5	−0.5
Solar PV	2.7	59

Source Extracted from data provided in Ball et al. (2017, Table 4.2)
Notes
[a]Average taken over the decade ending 2015–2016
[b]Mostly diesel at remote locations
[c]Total generation in 2015–2016 estimated to be 257 TWh

Scenarios for the Sustainable Energy Transition

The principal Australian national energy and carbon emission scenarios are summarised in Table 2.2.

Since most energy supply in a sustainable energy future is likely to be delivered as electricity, the latter merits special attention. Concerns about reliability have been allayed by hourly simulations of the operation of large-scale electricity systems with high penetrations of variable renewable energy into the grid. Table 2.2 lists electricity simulations either for the whole of Australia (with hypothetical transmission links joining all States) or for the misnamed National Electricity Market (NEM), which spans the interconnected eastern and southern states, but does not include the State of Western Australia or the Northern Territory which are isolated from the NEM and each other. The scenarios establish pathways for approaching sustainable energy.

The electricity simulations have hourly (or half-hourly) time-steps where supply and demand are balanced, and span 1–6 years. They demonstrate that 100% renewable electricity systems can operate reliably without base-load power stations and without vast amounts of storage. Reliability, which is a property of the whole system and not

Table 2.2 Australian energy and carbon scenarios

Reference	Type of scenario	Electricity simulation model	Type of model
Saddler, Diesendorf and Denniss (2007)	Stationary energy, end-point	No	Bottom-up, forecasting + backcasting
Wright and Hearps (2010)	Stationary energy	Yes	In-house simulation
Elliston, Diesendorf and MacGill (2012)	Electricity, end-point	Yes	NEMO (open source simulation originally developed in-house)
Kelp and Dundas (2013)	Electricity, dynamic	No	ACIL Allen's PowerMark LT & RECMark
Turner, Elliston and Diesendorf (2013)	Electricity, dynamic	No	Australian Stocks & Flows Framework, includes life-cycle emissions
Elliston, MacGill and Diesendorf (2013)	Electricity, end-point	Yes	NEMO simulation
AEMO (2013)	Electricity, end-point	Yes	Probabilistic and time-sequential models
Elliston, MacGill and Diesendorf (2014)	Electricity, end-point	Yes	NEMO simulation
ClimateWorks Australia (2014)	All energy	No	Bottom-up sectoral models brought together into a national economic model
Wolfram, Wiedmann and Diesendorf (2016)	Electricity, dynamic	No	Scenario-based hybrid LCA
Elliston, Riesz and MacGill (2016)	Electricity, end-point	Yes	NEMO simulation
Teske et al. (2016)	All energy, dynamic	No	Bottom-up integrated energy balance
Lenzen et al. (2016)	Electricity, end-point	Yes	In-house simulation
ENA and CSIRO (2017)	Electricity, dynamic	No	Roadmap
Blakers, Lu and Stocks (2017)	Electricity, end-point	Yes	NEMO variant simulation
Hamilton et al. (2017)	Electricity, dynamic	No	In-house model of life-cycle emissions
Howard et al. (2018)	Electricity, dynamic	No	In-house model of life-cycle emissions

Note An 'end-point' scenario considers a single year at the end of a transition; a 'dynamic' scenario considers the time evolution of the transition with multiple time-steps between start and end-point individual power stations, can be achieved with high penetrations of *variable* renewables, wind and solar PV, whose fluctuations can be balanced by *dispatchable* renewables—for example CST with thermal storage, existing conventional hydro, pumped hydro (both on-river and off-river) and open-cycle gas turbines using renewable fuels—together with batteries. (A *dispatchable* power station is one that can supply electricity upon demand [Diesendorf 2018].) Reliability can be further increased by contracted demand response, increased diversity of renewable energy technologies and geographic diversity of wind and solar farms, together with a few new transmission links (Diesendorf & Elliston 2018).

Some of the electricity scenarios include costings (e.g. Elliston, MacGill & Diesendorf 2013; Elliston, Riesz & MacGill 2016). Both these studies and recent auction prices for wind and solar farms suggest that a large-scale sustainable electricity system will provide reliable electricity for a levelised cost of energy (LCOE) that's the same or less than that of a new fossil-fuelled electricity system.

The cost of electricity from rooftop PV for households and commercial sites is less than half that of retail electricity from the grid and so is being implemented rapidly in Australia by electricity users who have significant daytime demand. Adding batteries to these systems is not yet economical for most users, however battery prices are declining rapidly as the scale of manufacturing increases. In 2017, 12% of new rooftop PV systems had batteries (SunWiz 2018).

Overcoming the Barriers to Sustainable Energy

The principal barriers to the rapid growth of renewable energy are no longer technological nor, with a few exceptions, economic. The exceptions that are still expensive include batteries, renewable liquid and gaseous fuels and CST, but costs are falling rapidly for these technologies too. The principal barriers result from the institutions of the old energy system, defended by incumbents, and the difficulty of changing them (Hess 2014). 'Institutions' includes existing organisations, laws, regulations, standards and business models. Hence, while continuing technical improvements will always be required, much of the research and development needed now is in non-technical areas.

Specific barriers, that must be overcome by research, development and policy changes at state and federal government levels, and associated policy options include:

- mandating Zero Net Carbon for all new homes;
- extending the Building Code of Australia to existing buildings and further strengthening it;
- mandating published energy audits for sale and rental of all inhabited buildings;
- expansion of the scope of Minimum Energy Performance Standards and energy labelling to all energy-using appliances and equipment;
- implementing compensation to low-income earners for possible price rises resulting from some of the above improvements—these could include strengthening tenants' rights and legislating increases to pensions and unemployment benefits;
- solar access legislation;
- facilitating the growth of community renewable energy and micro-grid projects via seeding grants and legislating the right to interconnect and to receive a fair price for electricity sold to the grid;
- legalising the direct sale of small-scale renewable electricity between neighbouring households at 230 volts, with appropriate safety standards and checks;
- permitting large Virtual Power Plants to sell directly into the wholesale electricity market;
- implementing government-backed power purchase agreements and/or reverse auctions with contracts-for-difference for wind and solar farms in all states and territories;
- providing an additional federal government funding allocation to the Australian Renewable Energy Agency specifically for dispatchable renewable electricity and other forms of energy storage;
- revising the NEM rules to include, for example, a GHG reduction objective, changing the wholesale spot price settlement time from 30 min to the dispatch time of 5 min, and permitting Local Network Credits (Rutovitz et al. 2018);

- facilitating the growth of smart grids;
- integrating urban planning and transport planning;
- requiring government transport funding to be split equally between roads and public transport;
- secure funding for maintaining and upgrading the electricity grid and extending it where really necessary.

In addition, it would be valuable to have a carbon price, to internalise the adverse environmental, health and economic impacts of fossil fuel use, but both major political parties in Australia reject this at present.

Overcoming the barriers and speeding up the transition require prompt action in several spheres—all levels of government, business, industry, commerce, professional organisations, education, training, information, applied research, taxation, design and planning. An important element is the reintroduction of climate risk and liability strategies into the planning of cities, buildings, energy systems, and other infrastructure. Leaving it to the unguided market is a recipe for failure.

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3

Rooftop Photovoltaics: Distributed Renewable Energy and Storage (or Low-Cost PV Changes Everything)

Alistair Sproul

Introduction

Since 2008, the consumption and generation of electricity in Australia has been going through a period of unprecedented change (Fig. 3.1). In 2008, total electricity demand stopped increasing for the first time, then fell and in 2015 it began to slowly rise again. Much of this fall was to do with sharp electricity price increases, predominately driven by expenditure on "poles and wires" to ensure the system could meet peak demand. In response, many consumers used electricity more efficiently as discussed by Mark Diesendorf in Chapter 2. Further decreases in demand (from a grid point of view) came from the uptake of rooftop photovoltaic (PV) systems—predominantly by households. Starting from essentially zero rooftop grid connected systems in 2008, installed capacity of household rooftop systems (<10 kWp) reached approximately 5.5 GW, with total installed capacity of PV in Australia reaching just over 7 GW

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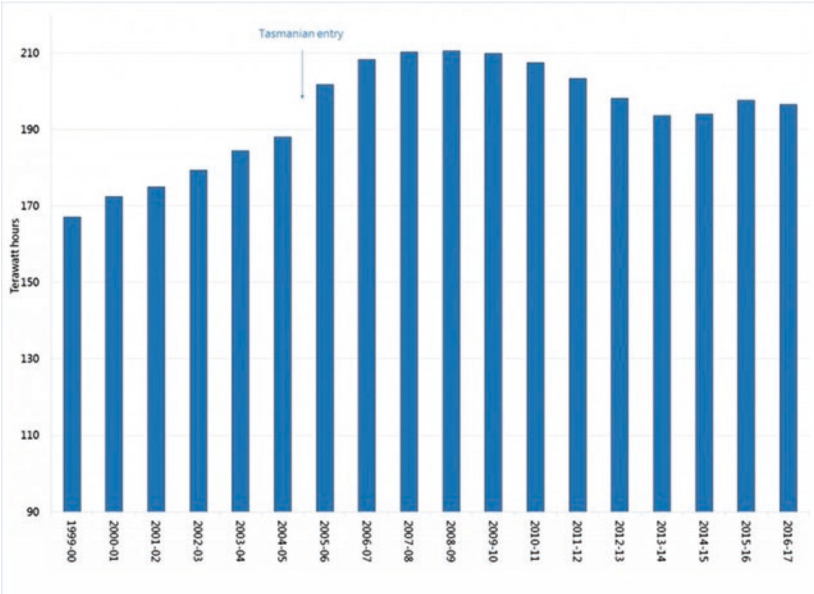

Fig. 3.1 National electricity demand, Australia, 1999–2017 (*Source* https://www.aer.gov.au/wholesale-markets/wholesale-statistics/national-electricity-market-electricity-consumption)

at the end of 2017 and producing about 4% of Australia's electricity. Over this period the cost of installed rooftop PV systems has decreased by about 9% per annum from $2300/kWp in 2012 to $1300/kWp in 2018 (including an Australian government financial incentive which reduces the price to consumers by about $600/kWp) (https://www.solarchoice.net.au/blog/solar-power-system-prices). Without government incentives—the cost of a rooftop PV system in Sydney, installed at $1900/kWp, will produce electricity over its 25-year lifetime at a levelised cost of $0.08/kWh. In comparison, current electricity tariffs in Sydney for residential customers are significantly higher.

PV used to be one of the costlier options for dealing with carbon emissions reduction in the built environment. An installed PV system on the rooftop of an Australian home is now the lowest cost approach for delivering energy into a home. In comparison to conventional electricity, the levelised cost of rooftop PV electricity is now about one-third of the domestic tariff, one-fifth of the peak tariff and about half the off-peak tariff. Furthermore, PV is now cheaper for residential and small businesses than natural gas in many locations in Australia.

This means that all conventional wisdom about how to achieve carbon emissions in the built environment is radically altered. As an example: natural gas for hot water and domestic space heating used to be the lowest cost option with lower carbon emissions than using electricity. However, PV is now able to provide hot water and space heating (as well as cooling) cheaper than gas (which has increased recently in price by factors of 2–3)—utilising highly efficient heat pumps/reverse cycle air conditioners or even resistance heaters! As such, the hierarchy of what measures should be undertaken to minimise carbon emissions needs to be drastically re-evaluated. For example, for residential customers in Sydney gas is charged at ~$0.04 per MJ or $0.144 per kWh. Currently it is now more cost effective to heat your home in Sydney by utilising daytime PV electricity through a resistance heater (with PV electricity at $0.08/kWh) rather than burning natural gas in an 80% efficient heater (costing ~18 c/kWh)—more than twice the cost of PV heating. Utilising a high-efficiency heat pump with a coefficient of performance (COP) of 4 reduces the PV/electric option further to 2 c/kWh!

In fact, buying green power from the grid is now cheaper than buying fossil fuel electricity and gas from the grid. This is evidenced by the University of NSW (UNSW) signing a 15-year power purchase arrangement for 100% solar supply. This option was the lowest cost option on offer when negotiated in 2017—cheaper than black electricity—and no subsidies were required (the City of Melbourne undertook a similar arrangement in November 2017 for a 10-year renewable electricity supply from Pacific Hydro sourcing wind energy). As such, the built environment can now look to decarbonise their emissions through low-cost PV—via onsite or offsite generation.

To compete, any energy efficiency measure needs to be evaluated purely on cost. If it is not competitive with rooftop PV, then it is not justified in terms of carbon emission reductions. For example, increasing the star rating of a residential building to 7 or 8 stars or beyond is probably not economically competitive in comparison to PV combined with reverse cycle air conditioning systems—if the driver is to lower carbon emissions. Energy efficiency measures that are bespoke solutions will not succeed as typically this approach will be too costly. Of course, there may be other reasons for implementing measures that bring another benefit to a building. There now needs to be a greater analysis and emphasis placed on the importance of energy efficient buildings in terms of other factors such as peak electricity demand, resilience to weather extremes, thermal comfort and occupant health and productivity.

Rooftop PV in Australia

The Australian electricity network has an installed capacity for all technologies of about 56 GW (http://apvi.org.au/wp-content/uploads/2018/07/PViA-2018-AU.pdf). The cumulative installed PV capacity in Australia is shown in Fig. 3.2. Note that before 2008, the installed grid connected PV capacity in Australia was essentially zero from the perspective of contributing to Australia's electricity supply. The uptake of PV in Australia since 2008 has predominantly seen the installation of small, household rooftop systems of less than 10 kWp (see Fig. 3.2). This is reflected in part by the various incentive schemes in place from either the State or Federal governments which encouraged residential rooftop systems via guaranteed feed-in tariffs or upfront financial incentives such as the Renewable Energy Certificate scheme. In conjunction with, at times overly generous financial incentives, the underlying price of PV systems has continued to fall as mentioned previously at about 9% per annum. As a result, today, it is estimated that there are over 1.8 million PV systems installed in Australia of which about 1.75 million are rooftop systems—predominantly less than 10 kWp.

Because of these rooftop PV systems, their combined impact on electricity demand is now starting to become visible in the Australian electricity network. Shown in Fig. 3.3 is the National Electricity Market (NEM) electricity data for a 7-day period in 2018 (10/9/18–17/9/18). Rooftop solar systems over this period are providing about 5% of the electricity required in the NEM while utility scale PV—(a more recent phenomena

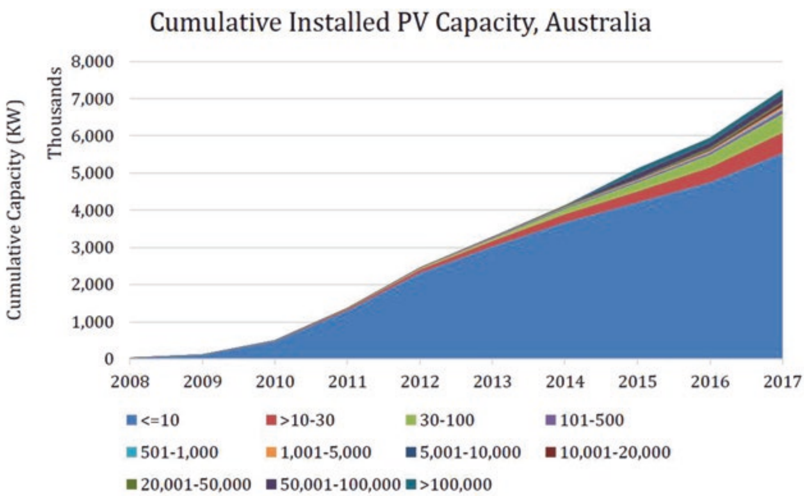

Fig. 3.2 Cumulative installed PV capacity Australia 2008–2017 (*Source* APVI http://apvi.org.au/wp-content/uploads/2018/07/PViA-2018-AU.pdf; accessed from WikiMedia Commons https://wikivisually.com/wiki/Solar_power_in_Australia 3 January 2019)

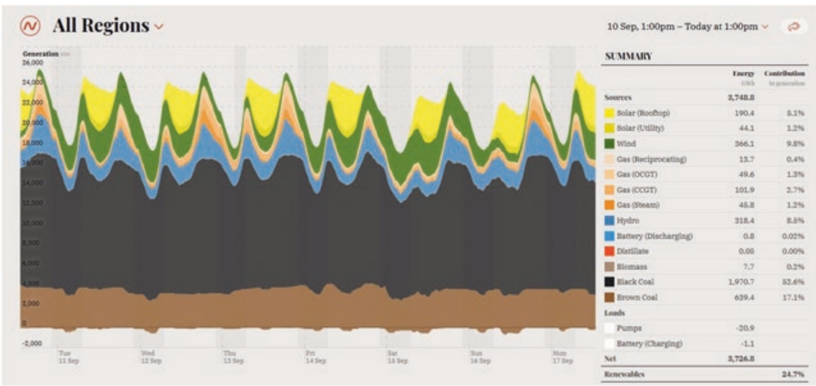

Fig. 3.3 Open NEM data (*Source* https://opennem.org.au/#/all-regions)

in Australia) is supplying about 1%. From this snapshot it is clear that the 1.75 million rooftop PV systems, distributed across the country, when aggregated, supply a significant fraction of daytime electricity demand.

Rooftop PV on residential buildings face some challenges, however. Some critics would point out that as more PV is installed in the low voltage distribution network (i.e. 240 V AC network) then there is the potential of too much power being generated on sunny days when few people are at home and demand is low. This could lead to over-voltage issues on the grid and there is much discussion about the possibility of curtailing PV systems to avoid this problem (https://www.afr.com/news/solar-power-could-have-to-be-curtailed-to-avoid-grid-disruption-20181003-h1675d).

However, without resorting to batteries, which are costly at present, there are many other options that could be implemented in a cost-effective way that already exist to address this issue. For example, as previously discussed, PV is now cheaper than off peak electricity, so it would make economic sense for residents to use their excess PV power to heat their hot water. At present in many parts of Australia this is achieved using off-peak electricity in the middle of the night—typically from power stations burning coal. For example, in the state of NSW residential off-peak hot water is of the order of 2–3 GW. Shifting this load to the middle of the day would allow a significant further increase in installed PV capacity on the low voltage, residential distribution network. This could be achieved in several ways. Some companies are exploring the option of customers installing devices to divert excess PV production to hot water tanks. The challenge here is that this can be an expensive option—as the best way to do this to minimise grid imports is to utilise a solar diverter that essentially is a DC to AC inverter. Alternately, the grid operators could utilise off-peak signals to switch on hot water tanks when sections of the grid have "too much" PV power in the middle of the day. Off-peak periods could then occur in the middle of the day rather than the middle of the night—as is presently the case. This is a paradigm shift that may take electricity utilities some time to accept—that PV power in the middle of the day has created the situation where off-peak is now a daytime issue rather than in the middle of the night.

In addition to hot water, there are several energy loads in the residential sector that could be shifted to the middle of the day when PV systems are supplying low-cost electricity. Residential space heating in the winter and cooling in the summer are ideal candidates. This approach would work best if houses are reasonably well insulated and not leaky in terms of air infiltration. However, this approach would be beneficial to minimise energy usage in homes anyway, as it is the build-up of heat in a home over the day that drives large consumption of electricity for cooling when residents return home in the evening. Even if a home is not thermally efficient, pre-cooling in summer or pre-heating in winter using PV and reverse cycle HVAC systems (now installed in 70–80% of homes in Australia) makes sense. Retrofitting of homes to make them thermally more efficient would be a good approach as well but would need to be sure that only cost-effective approaches that improve the building performance are implemented that are cheaper than installing more PV. Such approaches could include things like: sealing of homes against draughts, improving the performance of HVAC systems (particularly ducted systems) or possibly external shading of west facing windows. The recent ASBEC report *Built to perform* (https://www.asbec.asn.au/research-items/built-perform/) however, found that very few additions to new homes beyond 6 star were cost effective—only PV and LED lighting showed benefit/cost ratio better than 1.

Other loads that are easily shifted into the daytime are pool pumps, dishwashers and clothes dryers. In such cases, residents can minimise their loads by installing more efficient equipment (Fan, MacGill & Sproul 2015). For pool pumps there are several options including 3 speed or multispeed pumps or retrofitting a variable speed drive to run pumps at lower speed and save up to 80% of the pump energy (Zhao et al. 2017). Clothes dryers are also significant residential loads. Increasingly heat pump systems are entering the market, however, at present their higher initial price may make it a costly pathway to reducing electrical demand. Hence, households with PV systems and resistance clothes dryers or even resistance heaters for space heating could usefully utilise PV electricity from their own rooftop systems if the alternative is curtailment of their use or purchasing electricity from the grid at a later time.

Non-Residential Buildings and Rooftop PV

In contrast to the residential sector where demand occurs predominantly out of sync with PV generation, non-residential buildings such as commercial office buildings, shopping centres, schools, universities

Fig. 3.4 Tyree Energy Technology Building, UNSW 6 star Greenstar building with a 150 kWp PV array (*Source* School of Photovoltaic and Renewable Energy Engineering, UNSW)

and hospitals—all typically have peak demand that coincides with peak PV power production. As such these types of buildings are ideal for the uptake of PV rooftop systems. At present in many parts of Australia there is no feed-in tariff on offer for larger scale non-residential systems. As such these systems are typically sized to only supply sufficient power to the internal loads of the building on a sunny day in order to minimise export of electricity for which the owner of the PV systems receives no compensation.

An example of this sort of system can be seen in Fig. 3.4 which shows the 150 kWp PV system installed on the rooftop of the Tyree Energy Technology building at UNSW.

Illustrated in Fig. 3.5 is the electricity demand for the building over a typical weekly period (Monday to Friday, September 2nd–6th, 2013). The total electrical demand for the building peaks at approximately 500 kW, typically in the middle of the day—coinciding very well with PV generation that on a sunny day peaks at about 100 kW. Due to the energy intensive nature of the research laboratories in the building this system can produce at best about 20% of the buildings demand—due to the limitation of roof space. Interestingly the TETB is a 6-star Greenstar building and was originally designed and built to include an 800-kW electrical generator powered by natural gas—which also had 400 kW of heat recovery and an absorption chiller. Unfortunately,

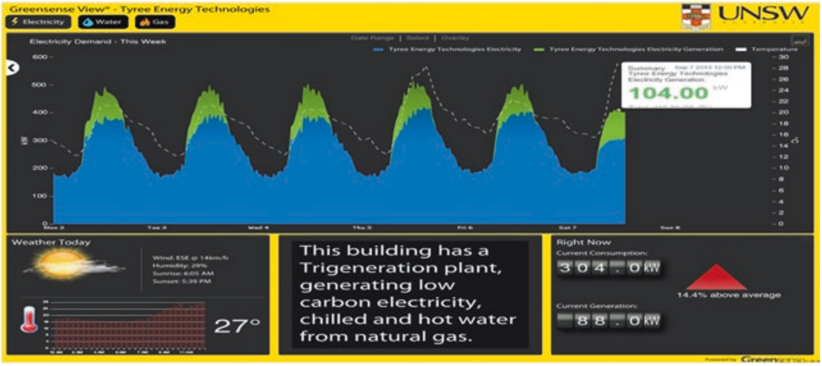

Fig. 3.5 PV generation (green) and remaining electricity demand (blue) TETB, UNSW (Monday to Friday, September 2nd–6th, 2013) (*Source* Drawn by author from data accessed via https://www.estate.unsw.edu.au/live-energy)

the recent price rises in natural gas now mean that this trigeneration system rarely runs except on days when the UNSW Energy Management team are wanting to bring online the 800-kW generator to avoid peak demand charges. Meanwhile, the PV system continues to operate reliably and economically and with no need to be concerned about rising fuel prices.

Another useful building typology for the utilisation of PV systems are school buildings which have peak demand during daylight hours. In fact, this is now becoming so clear a pathway that both political parties in NSW have announced funding commitments to instal PV systems in conjunction with air conditioning systems on public schools across the state of New South Wales.

Behind the meter PV is in fact becoming so cost effective that even industrial plants—that typically pay among the lowest tariffs for electricity—are finding that PV is a cost-effective option. For example, the company Sun Metals Corporation—installed about 100 MW of PV to allow their Zinc refinery to continue to operate its daytime shift (closed due to high grid prices during the day!) (https://www.afr.com/news/sun-metals-goes-solar-to-cut-energy-costs-20171220-h083ym).

Large commercial buildings with few storeys such as Sydney Markets are ideal locations for rooftop PV (Fig. 3.6). Demand is high during

Fig. 3.6 View of part of the 2.2 MW PV rooftop system on Sydney Markets (*Source* Autonomous Energy (used with permission of Matthew Linney))

the day—particularly if the facility has loads such as refrigeration. Importantly PV systems can shade the rooftops—minimising heat loads in summer on the building as well as supplying electricity to the facility.

Conclusion

The era of low-cost PV has arrived—probably far more quickly than most living and working in the built environment expected. The conventional approach to buildings in terms of low carbon has always been: efficient building envelope, efficient appliances and lighting—preferably daylighting, and lastly onsite or offsite renewable energy generation. Today for most buildings this hierarchy is becoming less meaningful. Rooftop PV or PV or Wind purchased via a power purchase agreement (PPA) is becoming the simplest and most cost-effective pathway to deliver a low energy building. For any buildings with reasonable solar access and less than say a few storeys high, then the rooftop of the building can be covered with PV (or as much as the local electricity authority will allow for now!), as city maps of PV installations clearly illustrate (Newton & Newman 2013). Ideally, PV electricity generated on site is best consumed straight away by the building loads. For residential customers, in Australia any export of electricity should be rewarded with a Feed-in Tariff that at least covers the unsubsidised Life Cycle Cost of that electricity. At present that would be approximately $0.08 per kWh. This is in fact as pointed out earlier—the cheapest electricity that can be generated in Australia at present—approximately the wholesale price of electricity. However, it has the benefit of being available right where most customers need it—without transmission and distribution losses. Hence electricity authorities would be best to purchase this electricity from the PV systems owner and on-sell it, rather than curtail it.

At present, residential PV power is often being exported to the grid at a time that coincides with peak power tariffs—hence it would make far more sense economically for all concerned that this low-cost PV electricity is utilised and not curtailed. Hence it would be best if PV electricity generated in the middle of the day, if exported and sold at off peak rates, would encourage electricity demand to occur when the cheapest electricity in the network is most available. If cloudy weather reduces generation—then loads such as hot water, HVAC pre-heating or cooling or pool pumps can be scheduled for other times when cheaper electricity is available. The worst thing to do would be to switch off the cheapest source of electricity on the grid—and it is only getting cheaper. To ignore rooftop PV makes no sense economically or environmentally. It needs to be embraced—it is only going to get cheaper so we need to find more uses for low-cost PV electricity in the middle of the day. The more loads that soak up this cheap electricity—and preferably efficiently the better, as the electricity systems need greater capacity given that another important energy transition is rapidly approaching—the move to electric vehicles. Making buildings zero energy via rooftop PV, and efficiencies that makes sense economically, will free up other sources for electricity in the network to charge electric vehicles. Many people are focussing on batteries going into buildings or onto the grid. However, at present time prices for such systems remain high in comparison to grid electricity prices—especially rooftop PV. However, when compared to the price of petroleum—batteries for electric vehicles—recharged by renewable electricity—make a lot more sense from an economic perspective. As the battery industry grows and prices fall—batteries may well find a place in the stationary energy sector. However, it would seem that their first application should be in electric vehicles.

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4

Community Owned Renewable Energy: Enabling the Transition Towards Renewable Energy?

Franziska Mey and Jarra Hicks

Introduction

Technical transitions, like the one from fossil fuel-based to renewable-based energy systems, are inherently embedded in social contexts (Bridge et al. 2013; Devine-Wright 2011). The advent of renewable energy (RE) technology enables a more spatially and economically distributed means of organising energy generation, leading to changes in how energy systems are integrated into societies around the world. While distributed generation presents some challenges for integration with incumbent energy systems, it also offers opportunities for social innovation, community participation and benefit sharing. Given that rapid uptake of RE is essential in the light of accelerating climate change, consideration of the social dimensions of the transition

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is particularly important as the social context underpins socio-political acceptance and the institutional shifts needed to drive rapid change (Bauwens & Devine-Wright 2018; MacArthur 2016). Such social dimensions include consideration of who participates and how the burdens and benefits of RE development are distributed (Hicks et al. 2018).

Community owned renewable energy (CORE) is a multifaceted socio-technical phenomenon that encompasses many forms through which communities come together to initiate, develop, own and benefit from RE and energy efficiency (EE) technology across the entire energy supply chain. CORE encompasses many different technologies and scales as well as a range of legal, financial and organisational forms implemented by diverse groups of actors driven by multiple motivations. However, they share a common commitment to decentralising, democratising and decarbonising the electricity system (Hicks et al. 2014). Ultimately, each initiative is also shaped by national policy frameworks, institutional contexts and energy market structures.

CORE is well positioned to contribute to faster and fairer transitions to RE through generating innovative, socially inclusive business models and through helping to create the social impetus for systemic changes (e.g. in policy). Many studies have explored the multiple benefits of CORE and confirm positive impacts on a range of social, technical, environmental, economic and political/policy outcomes (Hicks & Ison 2018; Schweizer-Ries et al. 2010; Seyfang, Park & Smith 2013).

In this chapter, we analyse the institutional contexts that enable CORE to emerge and the outcomes that CORE generates at local and national levels to consider the contribution CORE makes to energy transitions. Our main research questions are: What are the institutional contexts that enable CORE to emerge, and how does CORE contribute to energy transitions? We analyse the RE transitions in Germany and Australia from a community energy perspective to explore the contributions of bottom-up approaches to change. The two country cases offer insights into two very different stages of the energy transition. Germany is an advanced example with 36% share of RE in the electricity generation in the past 25 years. In contrast, Australia has achieved a 19% share of RE over the last 10 years.

The chapter first outlines the fundamental characteristics and benefits of CORE. Next, the two country cases are introduced, including an analysis of the enabling factors and forms of CORE in each. Finally, a country comparison reflects on the positive outcomes created for the RE transition when CORE is enabled.

What Is Community-Owned Renewable Energy (CORE)?

Local communities have had a long-term interest in, and influence on, RE development: community ownership of modern RE generation has been in existence since the invention of the technologies themselves. Wind cooperatives in Denmark are heralded as the first forms of CORE, in which local communities co-funded and co-owned single turbine projects, and thus provided fundamental support for developing and testing early models in the 1970s (Kruse & Maegaard 2012; Smith & Ely 2015). Over time, an array of community-led RE projects have been developed to meet the specific needs of local communities around the world (Warren & McFadyen 2010). These projects provide a strong contrast to conventional thinking which reflected the notion that 'a better power station was always a bigger power station farther away' (Devine-Wright 2005; Patterson 2007, p. 61). CORE embeds energy generation at a local level and thus offers a unique setting for influencing the social context of energy transitions.

CORE encompasses a diverse range of activity, including both supply (energy generation, distribution and retail) and demand sides (energy use, including energy efficiency) (Eadson & Foden 2014; Hoffman et al. 2013). CORE includes projects such as a small collectively owned behind-the-meter solar array on a public building, to a wind turbine owned by neighbouring farmers to a bioenergy facility fed by local waste and owned as a joint venture between a local council and residents.

Seyfang, Park and Smith (2013, p. 25) describe community energy as being 'projects where communities (of place or interest) exhibit a high degree of ownership and control of the energy project, as well as benefiting collectively from the outcomes'. Rather than offer singular definitions, some researchers such as Walker and Devine-Wright (2008) and

Hicks and Ison (2018), offer conceptual tools for distinguishing CORE. Both these papers argue that CORE is defined as much by its processes as by its outcomes. The *outcomes* dimension refers to 'how the outcomes of the project are spatially and socially distributed', or 'who the project is for; who is it that benefits particularly in economic and social terms' (Walker & Devine-Wright 2008, p. 498). The *processes* dimension refers to 'who a project is developed and run by, who is involved and has influence' and is 'strongly driven by normative principles of empowerment, participation and capacity-building' (Walker & Devine-Wright 2008, p. 498).

Internationally, there are many thousands of operational CORE projects. For example, the UK government reports 5000 community energy projects as of 2014 (DECC 2014) and Scotland has met its target of 500 MW of CORE (3% of RE) by 2020 (Local Energy Scotland 2017). In Australia, CORE is much newer, with 174 CORE projects in operation (Ison 2018).

Research indicates a range of possible outcomes of CORE, as presented in Fig. 4.1. These outcomes accrue at local, regional and national scales and will be explored further throughout the chapter, particularly with reference to the influence of CORE on wider transitions to RE.

CORE projects deliver obvious environmental benefits of carbon emissions reduction and technological benefits of more MW of RE installed. However, arguably their most valuable and unique contribution is in the range of social outcomes, and the points where social outcomes overlap with economic, environmental, technological and political outcomes, as seen in Fig. 4.1. By engaging people in RE development and involving them as co-owners, CORE helps to increase levels of social awareness of and support for RE (Koirala et al. 2018; Mey & Diesendorf 2018). This has been shown to increase levels of active support for RE uptake (including for other RE developments), for progressive RE policy and for increased environmental behaviour (e.g. energy efficiency) (Hicks 2018). By virtue of involving local stakeholders and being more integrated with local economies, CORE also contributes significantly more per MW to local economies than absentee-owned projects (Okkonen & Lehtonen 2016). Increasing the possibilities for ongoing participation and benefit from RE development

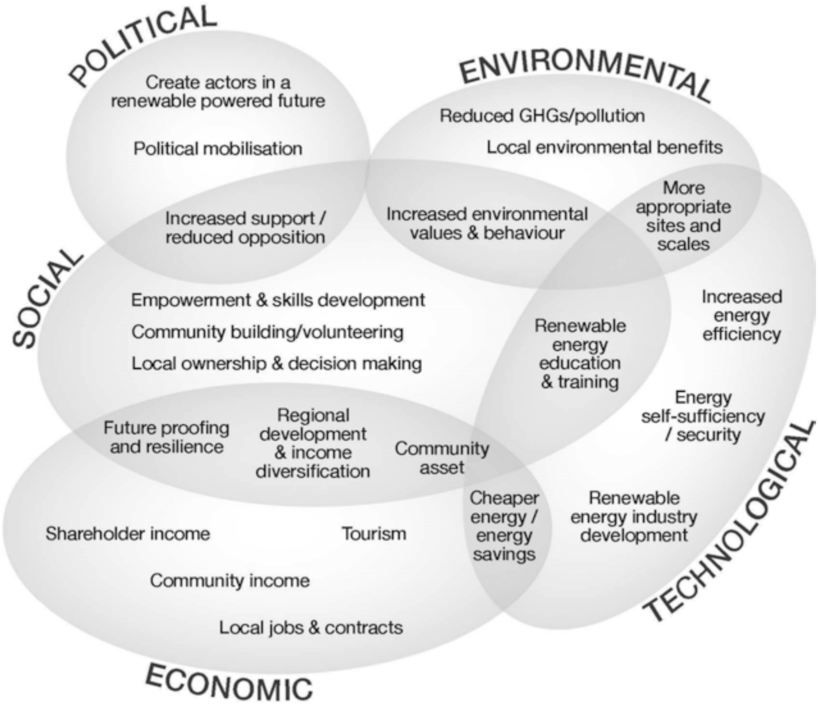

Fig. 4.1 The range of outcomes from CORE projects (*Source* Hicks & Ison 2012, p. 194)

contributes to CORE's ability to build a strong social license (Devine-Wright 2011). As we will see, these local outcomes have flow-on effects in national level energy transitions. First, however, it is important to understand what enables CORE to become established.

Germany as Pioneers of CORE

Germany is often heralded as a role model for successful energy transitions, having already reached 36% RE in the electricity supply (BMWE 2018). Further, they are steadily working towards RE targets of 40% by 2025 and 80% by 2050 in order to decarbonise the economy and meet their climate targets (BMWE 2018).

Germany's energy transition has a long history and is intrinsically linked to a community movement. Since the 1990s the incumbent electricity system (based on highly centralised fossil fuel and nuclear generation) has been losing market share to new RE actors (Bontrup & Marquardt 2015). These include small, decentralised actors involved in Bürgerenergie ('citizen energy', such as CORE projects), household RE installations and farmer-owned RE systems. In some regions, CORE is an outstanding feature of RE development. For example, in North Friesland 90% of wind farms are community owned (Falkenberg, Weiß & Nehls 2014). Together these new actors owned almost 50% of all RE capacity in 2013 and have contributed significantly to both the decentralisation and decarbonisation of the electricity system (AEE 2014).

To understand the emergence of CORE in Germany, we must go back to the environmental and anti-nuclear movements in the 1970s and 1980s, which provided the normative impetus for the rise of alternative energy sources. The Chernobyl nuclear accident in 1986 further spurred these movements (Mautz, Byzio & Rosenbaum 2008) and triggered the institutionalisation and political legitimisation of support structures for energy system change. Ultimately, the Chernobyl disaster catalysed widespread grassroots and policy implementation of previously theoretical discussions and niche activities in RE. Thus, both top-down and bottom-up activities mutually reinforced the support of RE (and CORE) and enabled its growth in the following years.

Early RE policy programs and public support structures in the 1980s and 1990s were geared towards smaller actors since the technology scale at the time and the expected economic returns were unattractive to large incumbent players (Mey 2017). The introduction of the *Stromeinspeisungsgesetz* Act (1990) was instrumental to the growth of CORE, as it reduced some of the biggest challenges facing access to the electricity system. This agenda was further progressed through introduction of the *Erneuerbare Energien Gesetz* Act in 2000. This Act made four major contributions to creating opportunities for CORE: (i) it guaranteed remuneration and increased economic viability through a feed-in-tariff and purchase obligations; (ii) it guaranteed grid access; (iii) it supported a diversity of RE technologies; and (iv) it provided differentiated remuneration according to scale (IEA 2013). This incentivised a range of technology types and system sizes, including small- and medium-scale projects, and created an opening that enabled a greater number of more diverse actors to become involved in RE deployment. In addition, flanking policy measures (e.g. reforms in grid connection processes and local planning rules) contributed to the growth of CORE.

With increased support and impetus for action, the grassroots movement proliferated a range of CORE models emerged, based on a collective vision for decentralisation and participation. These innovations were based on forms of democratic engagement including citizen co-ownership and co-investment. This period saw the emergence of a range of CORE enterprise forms, including cooperatives, associations and companies that involved individuals, local governments, and local businesses (e.g. farmers) in initiating, developing, financing, owning and managing all manner of RE projects. CORE has matured and changed as technology has advanced (in size, costs and output capacity) and following changes in available legal structures (e.g. to accommodate a growing investor base) (Yildiz et al. 2015). Trends over the past 10 years indicate increasing professionalisation and institutionalisation of CORE, as commercial actors and capitalist motivations become more prevalent. In part, this has been enabled by the increased profit margins in RE as the costs of the technology fall and by the greater levels of investment required to fund larger installations.

The growth of CORE in Germany reached a peak in 2011, when 167 new energy cooperatives formed. Since then, the rate has been decreasing (see Fig. 4.2). Although the German policy context provided relative stability and encouragement for CORE up until the mid-2010s, regulatory changes since this time have led to energy system dynamics that challenge CORE's role in the energy transition.

The 2012, 2014 and 2016 revisions of the *Erneuerbare Energien Gesetz* (Renewable Energy Act) have led to a continuous deterioration of conditions for CORE, as the focus shifted towards greater economic efficiency and large-scale development (e.g. introduction of RE auction mechanisms and direct marketing) (Mey 2017). Further decline in

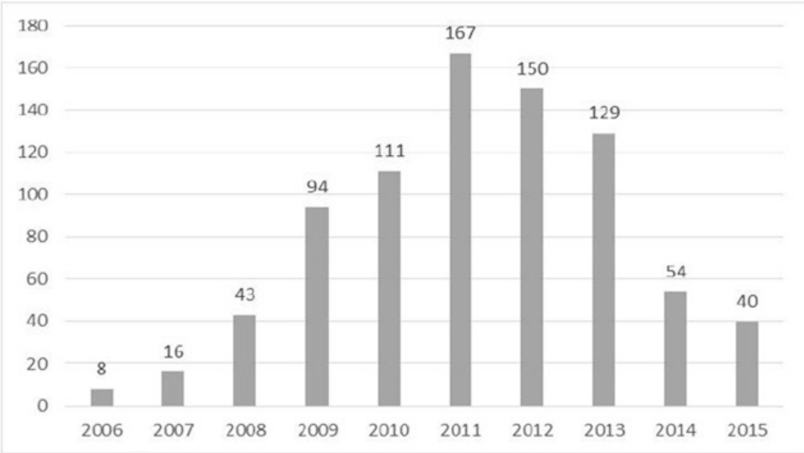

Fig. 4.2 New energy cooperatives in Germany established between 2006 and 2015 (*Source* Author's illustration adapted from DGRV 2016)

CORE will be inevitable if the government does not solve conflicting goals between cost efficiency and actor diversity. Despite public rhetoric to maintain the broad actor base and adding exemptions for CORE projects to the auction requirements, there is a strong political emphasis to decrease costs. This ultimately goes at the expense of smaller actors which struggle to compete with large corporate investors in the tender process.

It is evident that CORE has played an important role in the energy transition in Germany, in terms of involving greater numbers of people, innovating new business models, supporting early uptake of the technology and increased RE deployment. In addition, CORE had contributed to local economic benefit from RE (Gottschalk et al. 2016), and increase levels of social awareness and support for the energy transition (Rosenbaum & Mautz 2011), which in turn has led to increased political support (Morris & Jungjohann 2016). What remains to be seen in the German context, is the ways that policy changes will impact CORE over time, and if levels of CORE decrease, what impact this has on levels of social involvement in, benefit from, and support for RE.

Newcomer: Australia's CORE Sector

Like Germany, Australia's energy sector is increasingly embracing RE, driven by the favourable economics of RE, ageing fossil fuel generators and excellent RE resources. Unlike Germany, the policy context for both RE and carbon emissions reduction has been less supportive and more changeable, and has tended to favour large-scale RE projects. Regardless, CORE is an emerging contributor to the RE transition in Australia, motivated largely by the need to accelerate efforts to mitigate climate change.

The Australian Government first introduced policies to support RE in 2000, with the Mandatory Renewable Energy Target (MRET), which was later expanded to the Renewable Energy Target (RET) of 20% by 2020 (Finkel et al. 2017). The RET is based on a quota mechanism which enables RE generators to issue certificates (Renewable Energy Certificates, 'RECs') to achieve annual targets. The scheme is a market-based approach to encourage low-cost large-scale RE systems. In contrast to a feed-in-tariff, this approach presents a high-risk for small-to-medium investors, since there is no guaranteed payment structure or protection against market changes—it also does not guarantee or streamline grid access for RE generators. In addition, the RET has come under successive reviews and has not yet been succeeded by longer-term RE policy. Australia was also the first country in the world to remove a price on carbon. As such, the policy context and political debate on RE in Australia has presented challenges for the fledgling RE (and CORE) sector.

There are, however, some beacons of success. To foster household RE, the RET was split into large-scale and small-scale certificate schemes. Australia now has one of the highest rates of small-scale RE in the world, having reached two million households with solar PV in December 2018 (Clean Energy Regulator 2018). Large-scale wind and solar projects are also gaining momentum, now supplying 7.3% (1.4 GW/h) of national electricity in 2018 (Parkinson 2018). While both the large-scale and small-scale RET schemes have been successful, they have not provided impetus for medium-scale actors, such as local communities and businesses, to participate in the transition.

Despite a challenging policy context, CORE has been emerging since the mid-2000s, with the first project—the cooperatively owned 4.1 MW Hepburn Wind farm near Daylesford/Victoria—becoming operational in 2011. In the last eight years, CORE activity has risen quickly to 147 operating CORE projects. CORE actors are often driven by a motivation to address climate change, especially in the context of weak government leadership, and thus seek to engage people in increased RE awareness, advocacy and uptake at various scales through a diversity of models. However, to date CORE models in Australia have mostly been small (under 99 kW) due to the structure of the RET, and behind-the-meter due to challenges with grid access and limited options for selling the electricity.

In this challenging operating context, CORE projects are seeking options for coping by focusing on business model innovation. CORE business models encompass organisational-legal, financial, technological and community engagement aspects (Hicks et al. 2014). The two most common models are: (i) behind-the-meter solar PV installations owned by community investment vehicles and installed on the roofs of large energy users; and (ii) aggregating households to do a bulk purchase and installation of solar PV. There are also two MW scale community-owned wind farms (the Hepburn Wind farm near Daylesford, in Victoria).

Despite the lack of national support, state-level support has increased in the past 5 years. New South Wales (NSW), Victoria (VIC) and the Australian Capital Territory (ACT) have developed tailored CORE programs (ACT Government 2015; NSW Government 2018; State Government of Victoria 2018). These policy measures have been advocated for and won by CORE proponents working with state governments to design effective CORE support policies (Ison 2018). For example, state governments have provided grant programs for CORE feasibility costs and funding for research and capacity building. Some have earmarked CORE components in RE auction schemes and provided funding to regional institutional support structures to catalyse CORE projects. Increased interest in CORE has also encouraged local governments to support their communities to adopt RE installations and facilitate community RE initiatives (Mey, Diesendorf & MacGill

2016) and triggered two of Australia's three largest political parties to adopt policy platforms advocated for by CORE actors and their allies. The CORE concept also plays an increasing role in mediating between large-scale RE developments and local communities, where interest in community co-investment and co-ownership of large-scale projects (alongside corporate developers) is growing.

Comparing CORE's Role in Energy Transitions

A cross-country analysis between Germany and Australia reveals that CORE activity is heavily influenced by policy contexts. In both countries, the policy context has shaped the sector's development and influenced the forms that CORE projects take. In Germany, the sector developed over a long period in parallel to RE technological advancement and benefitted from early policy support that was geared towards small and medium scale installations. The removal of significant barriers (e.g. grid connection and accessing a fair price for electricity) for smaller actors encouraged community ownership structures and contributed to mainstream adoption of RE systems at a range of scales with a diversity of actors. Today the CORE sector in Germany is characterised by a great diversity of legal, financial and participatory forms with a high level of professionalism. In Australia, the CORE sector is still maturing, facing a more challenging national policy and regulatory environment. Hence, CORE actors concentrate their efforts on a limited range of innovative models and technologies at smaller scales to achieve their environmental, social and economic goals. Despite this, the public appetite for CORE is growing and policy support from state and local government will promote further community activity in this space. Increased uptake of CORE is also driven by its perceived contribution to accelerating and scaling up RE deployment, enabling broader access to RE to different segments of society and helping to increase the acceptance of large-scale developments.

A cross-country analysis also reveals that CORE plays a unique role in energy transitions. In both countries, CORE can be seen to be playing three key roles to foster the RE transition:

- Mobilising citizens in support of RE policy and specific RE projects;
- Developing innovative forms of RE deployment to enable broader public involvement and benefit; and
- Contributing to RE deployment and thereby supporting RE market development.

These are discussed in turn below.

CORE activities are embedded in social movements which allow it to transcend beyond the local-individual scale, offering alternative solutions in which collectives are mobilised around energy issues. By virtue of being involved in CORE, people's knowledge and awareness of energy issues and the benefits of RE are increased, and their willingness to be mobilised around energy is enhanced (Hicks 2018). This was particularly the case in Germany where CORE was linked with environmental and anti-nuclear movements. In Australia, CORE activities are similarly linked to the climate action movement and motivations to reduce carbon emissions (Mey & Hicks 2015). Further, CORE projects create organisational platforms through which citizens can be mobilised to take action (MacArthur 2016). In both countries, members of CORE projects are being mobilised to participate in RE policy processes (Hicks 2018; Setton 2016). As CORE gains momentum, both countries demonstrate the ability for CORE to mobilise local actors, households and businesses to engage in RE activities and policymaking.

CORE initiatives have spurred the development of innovative, inclusive forms of RE ownership and finance that contribute to an institutionalisation of fairer practice in the energy sector. This is exemplified in the variety of CORE models that facilitate greater actor diversity, which stands in stark contrast to the centralised monopolistic or oligopolistic configuration of the incumbent energy system. The collaborative and democratic models of engagement and ownership often favoured by CORE contribute to greater benefit sharing as their members access lower electricity costs or returns on investment (Mey 2017). CORE offers clear advantages over external, commercially driven developments by contributing to local economic value (Gottschalk et al. 2016; Okkonen & Lehtonen 2016). In contrast to corporate business models of incumbent actors, where decision-making power is accumulated according to shareholding, CORE projects tend to emphasise equality and participation by allocating voting rights democratically. This gives communities' increased influence in the project, and in the energy transition. Thus, CORE projects act as agents of distributive and procedural justice through which actors are empowered to pursue environmental and participatory interests and to access the socio-economic benefits of the transition.

CORE projects contribute to increasing the uptake of RE technologies and supporting RE market development. The scale and pace of the energy transition in Germany would not have been possible without CORE engagement, which enabled the RE sector to grow in size as well as socio-political impact. Starting as bottom-up niche innovations, the capacities of the CORE sector grew when government interventions and institutional changes enabled the new actors to legitimately penetrate the electricity market. The exponential growth in CORE activities in Australia in the last eight years bodes well for the sector. However, additional policy support is needed to allow the actors to better access the electricity market and contribute to its transformation.

All of these roles for CORE contribute to creating a context of stronger social support for a rapid energy transition.

Conclusion

This chapter explored conditions for the emergence of CORE and its contributions to energy transitions. We found that CORE has a unique contribution to make, particularly in generating the social conditions that enable a rapid and smooth transition in which a range of stakeholders participate and benefit. Less community involvement in the RE transition risks losing public participation in and acceptance of RE development, which could jeopardise or slow energy system transformation.

This analysis also indicates the transformative powers of CORE necessarily unfolds in an interplay with incumbent actors and government policy. As such, it is important to be mindful of creating institutional and policy enablers for CORE, alongside other scales and models of

RE uptake. It is, thus, paramount to create awareness about CORE activities and their benefits among policy makers, developers and planners, and to provide continuous institutional support.

CORE constitutes an essential element of a comprehensive RE transition and should be valued for the unique role it plays.

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5

Rethinking Urban Mobility: Unlocking the Benefits of Vehicle Electrification

Hussein Dia

Introduction

As part of a more interconnected world, our cities are playing an increasingly active role in the global economy. According to the McKinsey Global Institute (Dobbs et al. 2012), just 100 cities currently account for 30% of the world's economy. New York City and London, together, represent 40% of the global market capitalisation. In 2025, 600 cities are projected to generate 58% of the global Gross Domestic Product (GDP) and accommodate 25% of the world's population. The MGI also expects that 136 new cities, driven by faster growth in GDP per capita, will make it into the top 600 by 2025, all from the developing world, 100 of them from China alone (Dobbs et al. 2012). The twenty-first century appears more likely to be dominated by these global cities, which will become the magnets of economy and engines of globalisation.

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While the forecast urban growth will be largely driven by economic development and the search for a better quality of life, the resulting success will dramatically change the scale and nature of our communities, and put a tremendous strain on the infrastructure that delivers vital services like transport and electricity (Dobbs et al. 2012). Today, more than half the world's population lives in towns and cities and the percentage is growing. By 2050, two-thirds of the world population will be living in cities and urban areas (Wilson 2012). A multitude of challenges already face our cities including congestion, emissions with ageing infrastructures in many cities at a breaking point and governments' budgets for major infrastructure projects under increasing pressure (BITRE 2015; FIA Foundation 2016; International Transport Forum 2010; WHO 2016; Wilson 2012; Winston & Mannering 2014).

Fortunately, there's been some renewed thinking in recent years about how we provide mobility and access to jobs and economic opportunities in our cities. Some of it has been a recognition that past practices have met with limited success and that new approaches are needed. And some of it is due to the widespread use of technology and innovations, and through the changing context for how we want to build future cities—smart, healthy and low carbon.

These encouraging trends recognise that the ultimate goal of mobility is to enhance access to jobs, places, services and goods. The narrative is changing, the focus has shifted from 'transport' to 'mobility', and more emphasis is given to 'accessibility'. Rather than focusing on the infrastructure we need to move people and goods around, the focus is on providing the mobility we need to access economic opportunities. And instead of giving priority to building additional infrastructure, the focus is shifting to understanding and managing the demand for travel, maximising efficiency of existing assets, and improving their reliability and resilience. These trends are also increasing the focus on the social dimensions of transport to ensure that mobility benefits are equally and fairly distributed for all income groups.

The most significant trend in recent times is the challenge to car ownership models, and in particular car sharing and ride-sharing options that have been made easier and more popular through mobile technology platforms. Still, technology and innovations continue to surprise us with their fast pace of breakthroughs and advances which continue to unfold on many fronts. There are at least six forces which will have big impacts on urban mobility over the next 5–20 years (Fig. 5.1). From self-driving vehicles and the sharing economy, through to vehicle electrification, mobile computing and blockchain technologies, each of these trends is quite significant on its own. But the convergence and the coming together of these disruptive forces is what will create real value and provide innovations. Once converged, they will enhance the travel experience for millions of people and businesses every day. These trends are increasingly pointing to a future mobility ecosystem that is electric, shared, autonomous and on-demand.

Vehicle electrification is therefore expected to have a major role in addressing our modern-day urban mobility challenges. Already, substantial progress has been achieved and the fast pace of development suggests more market disruptions will follow. In particular, the convergence of physical and digital worlds is expected to create unprecedented opportunities to address these challenges. Disruptive and emerging forces—including vehicle electrification, on-demand shared mobility, big data analytics and autonomous vehicles are expected to change the

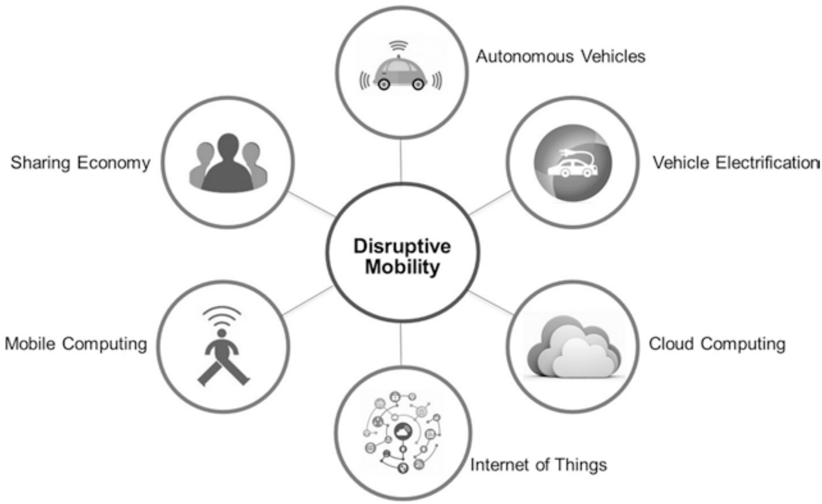

Fig. 5.1 The disruptive mobility ecosystem

mobility landscape and provide travellers with more choices to meet their travel needs while reducing reliance on building additional infrastructure. The coming together of these trends will provide new opportunities to unlock operational innovations and access to high-quality low carbon urban mobility through vehicle electrification. In addition, through data mining, artificial intelligence and predictive analytics, smart electric and connected mobility systems can help city managers monitor the performance of vital infrastructure, identify key areas where city services are lagging, and inform decision makers on how to manage city growth.

The Changing Landscape of Vehicle Electrification

Trends in vehicle electrification have gathered pace over the past few years. The on-going momentum suggests these trends will lead to an inflection point sometime in the early 2030s when it is expected around 20–30% of all vehicles sold will be electrified. This will be the result of a number of converging factors as discussed next.

Changing Consumer Attitudes

In 2016, McKinsey conducted a global online survey of EV consumer preferences which included around 3500 consumers in the US, Germany, and Norway, in addition to another survey of around 3500 consumers in China (McKinsey 2017). The survey found that around 30–45% of vehicle buyers in the US, China and Germany, would consider purchasing an electric vehicle. The survey provided some insights into the forces driving current e-mobility momentum, and how it is likely to develop in the future; the critical considerations for automakers as they create e-mobility strategies; and how automakers can set up e-readiness strategies that also avoid profitability shocks.

The survey also showed that consumer demand is starting to shift in favour of electrified vehicles and has strong disruption potential. This was demonstrated by responses from around half of consumers in the US and Germany who said they comprehend how electrified vehicles and related technology work. Also, between 30 and 45% of vehicle buyers in the US and Germany, respectively considered an EV purchase. However, less than 5% of potential buyers ultimately purchasing an EV over an ICE model (around 4% in the US, 3% in Germany, and 22% in Norway—due in part to government subsidies).

The results also showed that automakers will need greater agility to address challenges that hinder EV profitability. Although consumers were excited about EVs, they were still generally concerned about the driving range and high costs for battery packs which make the cost of offering ICE-equivalent range prohibitive. The findings also suggested that automakers may be capital constrained as they simultaneously invest across multiple mobility megatrends (autonomy, connectivity, electrification, and shared mobility). Therefore, ensuring EV profitability will be critical for automakers as they roll-out broader e-mobility strategies and new EV models to meet emission and fuel economy targets as well as consumer needs for range, convenience, and affordability.

The survey also showed that automakers can increase their EV customer base—more profitably—by offering more tailored EVs and deploying new business models. For example, in the short term, there are segments of consumers who want basic e-mobility solutions with lower range requirements. In the longer term, however, EV buyers will also look for more driving range, increased driving utility, and a broader set of capabilities and features. Automakers can potentially address a wider range of EV consumer segments by deploying new business models (e.g. car sharing and fleet operator) that take advantage of favourable EV economics.

In Australia, surveys of Victorian consumers also show they are interested in purchasing electric vehicles if more government support was available (Parliament of Victoria 2018). In 2017, the RACV undertook an 'electric vehicle consumer attitudes survey', which found over half of their respondents would consider buying an electric vehicle. The RACV reported the key findings from their consumer survey:

- More than a quarter of respondents would be willing to pay more for an electric vehicle rather than a petrol or diesel vehicle if there were more support, incentives and infrastructure in place
- More than 55% respondents thought subsidies to reduce the cost to purchase electric vehicles should be implemented by government and 53% of respondents believed government should implement subsidies to reduce the cost of installing home charging, and provide public charging infrastructure
- Around 80% of respondents considered the availability of public fast charging (i.e. 15 minutes to full charge) to be an important factor in influencing their decision to own an electric vehicle
- The RACV has also found that a significant number of Victorians believed that the development of alternative energy vehicles can provide a 'major solution to reducing the environmental impacts of motoring'.

During 2017, Eastlink also surveyed 15,000 Victorian drivers and similarly found that more than half of respondents were no longer considering a traditional internal combustion engine vehicle for their next vehicle purchase and a quarter were considering an electric vehicle as their next vehicle-of-choice.

Improved Battery Economics

Battery costs for electric vehicles have decreased substantially over the past few years (Fig. 5.2). The price of lithium-ion batteries has fallen steeply as their production scale has increased and manufacturers have developed more cost-effective methods. Recent reports (e.g. McKinsey 2017) suggest that battery costs have come down from around $1000 per kilowatt-hour (kWh) in 2010, to around $227 per kilowatt-hour in 2016 (about 80% reduction). Despite the drop, battery costs continue to make EVs more costly than comparable ICE-powered variants. Current projections put EV battery pack prices below $190/kWh by the end of the decade, and suggest the potential for pack prices to fall below $100/kWh by 2030. These estimates are for complete battery pack costs, not just battery cells.

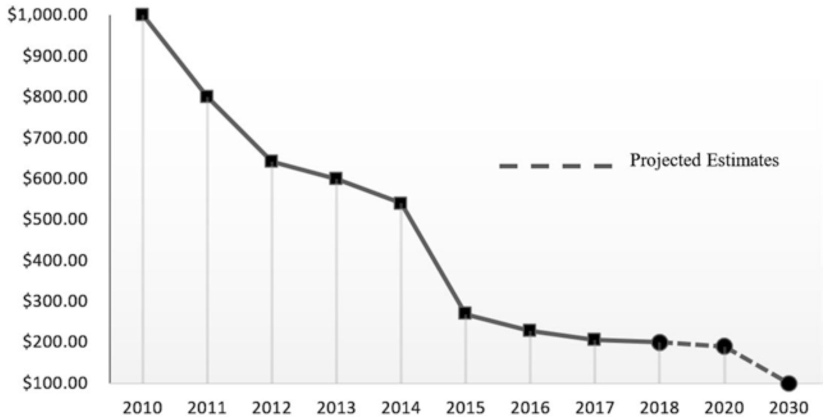

Fig. 5.2 Average battery pack cost (US$ per Kwh) (*Source* Author, drawn from data provided in McKinsey 2017)

Clearly, automakers capable of staying ahead of that cost trend will be able to achieve higher margins and possible profits on electric vehicle sales sooner. Tesla is among the automakers staying ahead of the trend. While McKinsey projects that battery pack prices will be below $190/kWh by the end of the decade, Tesla claims to be below $190/kWh since early 2016 and General Motors' 2017 Chevrolet Bolt battery pack was estimated to cost about $205 per kWh. EVs are forecast to cost the same or less than a comparable gasoline-powered vehicle when the price of battery packs falls to between $125 and 150 per kWh. Analysts have forecast that this price parity can be achieved as soon as 2020, while other studies have forecast the price of a lithium-ion battery pack to drop to as little as $73/kWh by 2030. Today, the rapid decreases in battery prices have helped accelerate EV sales, especially in Europe and China.

Broader Access to Charging Infrastructure

Investment in the supply of charging infrastructure has received considerable attention over the past few years. According to McKinsey's 2016 EV consumer survey (McKinsey 2017), consumers identified easy access to efficient charging stations as the third barrier to EV purchase, after price and driving range. Going forward, with EV prices declining and ranges expanding, the focus is increasingly shifting to overcoming the infrastructure charging barriers which is expected to gather more momentum over the next few years.

The planning and installation of adequate types of EV charging infrastructure, at accessible and widespread locations, should minimise the perceived risk of 'range anxiety'. It should also give way to increased public awareness and acceptance of EVs.

Also, understanding how drivers charge their vehicle is an important consideration in identifying the requirements of charging infrastructure. For example, drivers would normally 'fill up' their ICE vehicles on a needs basis because they can be easily refuelled at a large number of easily accessible service stations. This, however, requires a specific decision to stop whilst on-route or as in some cases, it could be the sole reason for the trip. With EVs, however, drivers might "fill up" or "top up" the battery more regularly (e.g. often to 80% unless they are preparing for a longer trip when they charge up to 100%) as opposed to waiting longer periods for 'filling up'. This provides multiple opportunities for cost-effective and convenient charging either at home, shops or at work. For longer travel, provisions need to be made such that EVs can 'fill up' at interregional fast charging stations while on-route.

This charging behaviour could in due course lead to a widespread distribution of EV charging points, with every existing accessible standard power socket becoming a potential 'topping up' location for EVs. Dedicated widespread public EV charging stations, along with a relatively smaller number of fast DC chargers, strategically located on the road network, will provide for a complete EV charging ecosystem.

According to McKinsey (2017), studies have shown that the most convenient location for EV charging is at home. Increasingly, workplaces and shopping centres are also offering charging stations as an additional benefit to employees and customers. Although a small percentage of all EV charging currently occurs at interregional fast charging locations, the McKinsey research suggests a strong psychological impact of ubiquitous public charging infrastructure on the perceived flexibility of owning an EV, and in turn, how likely a consumer is to purchase an EV (McKinsey 2017).

Stricter Regulatory Policies

A number of countries around the world are increasingly placing stringent targets on emissions reduction and fuel-economy at national, state, and city levels. The first few months of 2018 saw a number of policy-related electric vehicle announcements that sent shockwaves around the globe. China, the world's largest car market, announced it was working on a timetable to stop production and sale of internal combustion vehicles. India also declared its intention to electrify all new vehicles by 2030, with a detailed strategy of how it will carry it out (Shah 2018). The two big markets joined Britain (Condliffe 2017) and France (Chrisafis & Vaughan 2017) in making such commitments to ban the sale of petrol and diesel vehicles over the next 15 years. While these plans may not sound overly ambitious, they represent just the kinds of government policy shifts that are likely to make electric vehicles more pervasive.

In India and Western Europe, air pollution is providing a big motive to go electric. For China, the Beijing Government wants to grab a lead in the global race to develop electric vehicles, both to clean up its smog-stricken cities and position itself as a front runner in the car industry of the future. It is providing billions in incentives to automotive companies and has attracted a host of international car makers to join the local industry. In the past few months alone, a large number of vehicle manufacturers have all formed joint ventures as they try to tap into the market (Dia 2017).

These regulatory trends are reinforcing a swing towards zero-emission driving. Automakers recognise they cannot afford to be legislated out of these lucrative markets, and have followed suit with a flood of announcements where Volvo, Jaguar and Land Rover, Volkswagen, Mercedes, Audi and BMW have all now promised an onslaught on electric vehicles over the next decade (Dia 2017).

Profound Global Impacts

As mentioned before, the future of urban mobility is promising to be not only electric, but also shared, on-demand and eventually autonomous once the self-driving technologies mature and regulators allow them on our roads. This will give way to autonomous mobility-as-a-service business models where the majority of vehicles will be owned not by individuals but by mobility service providers. The world's most powerful auto companies are no longer interested in making a one-off transaction with consumers through the sale of a vehicle. Instead, they are targeting a business model in which they would offer consumers seamless mobility services in which the kilometre of travel will become the main utility. Eliminating drivers would also generate huge cost savings for transport network companies like Uber and Lyft. The mobility-as-a-service disruption will have enormous implications across the transport and oil industries and will also create trillions of dollars in new business opportunities. Vehicle manufacturers, the oil industry and governments are increasingly recognising the disruption that electro-mobility could bring about.

First, the global impact on jobs. Electric vehicles (including batteries) require less manufacturing labour than mechanical vehicles. Generally, electric engines have got about two dozen moving parts compared to hundreds of moving parts in internal combustion engines. A phaseout of combustion engines by 2030 would cost 600,000 jobs in Germany alone, according to the country's Ifo economic institute (Dia 2017). That study showed that a switch to sales of zero-emission cars would threaten 426,000 car manufacturing jobs, with the rest coming from related industries, such as suppliers. But it may not all be doom and gloom. According to the body representing Australian car parts manufacturers, the ban may be good news for suppliers to the Chinese market, like Australia, where Toyota and Holden are due to close their last plants by the end of October. The ban could boost Australian manufacturing and may even revive the local auto industry, according to the Australian Federation of Automotive Parts Manufacturers.

Second, the disruption of oil. Going all-electric by 2030 will place considerable budgetary stress on major oil-producing countries. These changes in mobility solutions and technology could end up changing the geopolitical map of the world. Stanford researchers (Arbib & Seba 2017) push the vision of an electric vehicle revolution a step further, and predict that the disruption will come earlier during the 2020s. They argue that oil demand will peak at 100 million barrels per day by 2020, dropping to 70 million barrels per day by 2030. They suggest this will have a catastrophic effect on the oil industry through price collapse, and that oil companies as well as companies throughout the oil supply chain, will have little room to manoeuvre with few strategies open to them given the speed of the changes. According to their study, the net exporter countries that will potentially be most affected include Venezuela, Nigeria, Saudi Arabia and Russia. They also explain that the geopolitics of lithium and other key mineral inputs to electric vehicles (e.g. nickel, cobalt and cadmium) are entirely different from oil politics. Lithium, which is a critical input in electric vehicles is only a material stock that is required to build the battery (unlike oil which is required to operate an internal combustion engine vehicle). In the short term, unlike oil supply, they see the geopolitics of lithium supply less critical (e.g. Jewell 2018).

Third, the impacts of electric vehicles on government coffers. By 2030, revenues from petrol taxes will be lost or reduced significantly with the shift from individual ownership of internal combustion engines to shared electric vehicle fleets. Governments whose budgets rely on this revenue could shift to road pricing and taxing of kilometres rather than fuels. Modelling by Arbib and Seba (2017) showed that $50 billion from petrol taxes will disappear from the US economy by 2030. Their modelling also showed that a 1 cent per mile tax would raise about the same revenue as petrol taxes raised today. For Australia, the revenue from fuel excise, estimated at $18.7 billion in 2017/2018, will also come under threat. Research has also shown that under future scenarios of shared autonomous mobility, the car fleet size will shrink by around 80% meaning less income from items such as vehicle registration fees and sale taxes, maintenance, insurance and parking etcetera (Dia 2017).

The industry is going to need support in its transformation and governments can do more to set the right incentives. Policies will also be needed to mitigate the adverse effects. These are discussed next.

Future Potential: Autonomous Shared Mobility on-Demand

Shared Autonomous Vehicles that are available on demand are being promoted as a sustainable solution to the urban mobility challenges such as congestion, road crashes, and air pollution (Brownell & Kornhauser 2014; Kornhauser et al. 2013). These systems are aimed at reducing car ownership rates through encouraging people to share vehicles in a similar fashion to public transport. The central premise of this idea is that deploying shared Autonomous Mobility on-Demand (AMoD) systems will translate into fewer vehicles in an urban environment. Further, it is also expected that future AVs will also be electric, which would result in less air pollution. The impacts of AMoD systems on urban and suburban environments have been evaluated in a number of simulation and modelling studies (e.g. Dia & Javanshour 2017; Javanshour, Dia & Duncan 2018). The results showed that under certain scenarios, AMoD system could result in a significant reduction in both the number of vehicles required to meet the transport needs of the community (reductions up to 88% in the size of the vehicle fleet), and the required on-street parking space (reductions up to 83%). However, the simulations also showed that this was achieved at the expense of an increase in the total Vehicle kilometres travelled (increase of up to 29%). It is important to point out that although the introduction of future electric AMoD vehicles under these scenarios is unlikely to lead to substantial reductions in Carbon Dioxide without a shift to renewable energy sources, they will contribute to an improvement in air quality in metropolitan areas particularly given the reduction in the fleet size.

Overcoming Barriers to Widespread Deployment

There are a number of actions that governments around the world can implement to demonstrate leadership and making visible and concrete commitments to the phasing out of fossil-fuelled vehicles over the next

10–15 years. For this to be effective, governments must work with the industry and vehicle manufacturers to agree on consistent timeframes.

Governments must also take steps to embed electric vehicles into all related policies including city and infrastructure planning, air quality, public health, climate change, economic development and the mix of energy sources required for future cities. Public acceptability and adoption of electric vehicles will depend to a large extent on demonstrating that governments have plans in place to ensure that electric vehicles will not rely on coal fired power generation.

Governments should also implement incentive schemes to reward the manufacture and purchase of electric vehicles. These incentives can have a big impact on the cost and convenience of switching to an electric vehicle. Governments should also consider, at a future date, adopting a road pricing scheme such as charging per kilometre of travel or congestion charging for Central Business District areas (electric vehicles would be exempt from such a charge). This will help in raising the needed revenues instead of petrol taxes, registration fees and other charges that are not related to the amount of travel.

It is also recommended that future autonomous and electric vehicle usage be a prime consideration in all future infrastructure investment. Strategies need to be put in place to encourage adoption and remove barriers to the roll-out of future fleets of electric shared autonomous vehicles.

Summary and Conclusions

Currently, the high upfront cost of electric vehicles, compared to similar ICE vehicles, makes them prohibitively expensive for many consumers around the world. However, with battery pack prices becoming more affordable, it is expected that the market uptake of electric vehicles will increase over the next 5–10 years. This will be expedited by a number of converging factors including increasing consumer sentiment and support for vehicle electrification and also tighter regulations around emissions and the lower cost production and sale of ICE vehicles.

The vehicle electrification impacts will extend well beyond vehicle manufacturing and production. The sheer breadth of the potential disruption makes it hard to predict what will happen, especially when the mix of sharing, electric and self-driving technologies all converge to disrupt the mobility ecosystem through mobility-as-a-service business models. Auto manufacturers, governments and the oil industry will have to make some tough decisions and prepare for the transformation. The industry is also going to need support during the transition, and governments will need to do more to set the right policies and where necessary, incentives. The electricity grid will also need to adapt for the increased uptake of vehicle electrification, including diversification of energy sources and renewables. While increasing the number of electric vehicles is unlikely to lead to substantial reductions in Carbon Dioxide without a shift to renewable energy sources, they will contribute to an improvement in air quality in metropolitan areas particularly if supported by policies that prioritise investment in more intensive urban development; transit-oriented and pedestrian-oriented developments; public transport and active travel options. If well planned, they will collectively lead to safer and more sustainable transport provisions while reducing motor vehicle dependence.

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6

Decarbonising Household Energy Use: The Smart Meter Revolution and Beyond

Alan Pears and Trivess Moore

Introduction

Delivering sustainable housing has typically focused on individual measures such as improving thermal performance, elements of energy efficiency (e.g. LED lighting), the inclusion of renewable energy and encouraging changes in occupant behaviours (Berry et al. 2014; Bondio, Shahnazari & McHugh 2018; BZE 2013; Gram-Hanssen 2013; Horne 2017). However, the rapid increase in numbers of appliances and technologies (e.g. smart meters) within dwellings has created complex interrelations with buildings, occupants, service providers and sustainability. This has led to discussions about the roles

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these appliances and technologies could play in a transition to delivering more, or less, sustainable housing outcomes through the concept of the ‘smart’ home.

The concept of smart homes and technologies has received renewed focus from housing researchers and policymakers over the past decade (Balta-Ozkan et al. 2013; Ding et al. 2011; Ford et al. 2017; Strengers & Nicholls 2017; Tirado Herrero, Nicholls & Strengers 2018; Wilson, Hargreaves & Hauxwell-Baldwin 2017). This chapter explores the concept of the smart home, the roles it could play in a transition to a low carbon housing future in Australia, and the resulting uncertainties and tensions.

What Is a Smart Home?

The smart home has no clear definition. For many it conjures up dreams of a luxurious, relaxing lifestyle where verbal instructions, gestures or intelligent controls manage a home to maximise comfort and convenience. For some, it is about delivering a futuristic Jetsons-type home where everything works seamlessly to deliver improved liveability without input from the occupants. For others, it involves improving resource efficiencies or reducing operating costs. It may be a home where the ‘smartness’ is an integral design element, or hidden away, retrofitted or incorporated into new appliances and buildings. It could be that the whole house is smart, or just elements within it. Drivers of demand for smarter homes are the desire on the part of the consumer for enhanced services that deliver valued benefits or needs and on the supply side are the agendas of businesses that profit from emerging products and services.

Smart homes allow occupants to experience improved *services within the home*, such as comfort (e.g. remote operation of appliances), health (e.g. monitoring of indoor air quality), convenience (e.g. automatic maintenance), home security and safety (e.g. light sensors and alarms), entertainment and reliability (e.g. identifying emerging faults). They support improved *management of key inputs and outputs* such as energy, water, wastes, materials and food. And they provide *improved access to and interaction with services and systems beyond the home*, such as health care, education, smart energy solutions, work and information.

As Ford et al. (2017) discuss, this smartness is delivered across user interfaces (e.g. energy portals, in-home displays, load monitors), smart hardware (e.g. smart appliances, lights, thermostats, plugs/switches, hubs) and platforms (e.g. smart home/web service platform, utility facing web services). It is not just new technologies, appliances and homes that are becoming smart. There is an increasing focus on how to make existing technologies, appliances and homes smarter using add-on adaptors or plugs, or data analytics to allow automated or remote control.

As Fig. 6.1 shows, households can have many sophisticated high efficiency appliances and building elements, energy management systems, energy storage and energy generation equipment on their side of the meter, provided and maintained by multiple service providers. Smart meters may monitor usage, generation and energy imports and exports, vary prices and allow others to manage their energy activity. Interfaces such as smart meters and software tools will import and export data and provide access to a range of services. Their electric car may use electricity produced on-site and also act as a mobile battery and/or electricity generator that can supplement on-site generation. This remarkable sociotechnical transition is creating many challenges as explored in this volume.

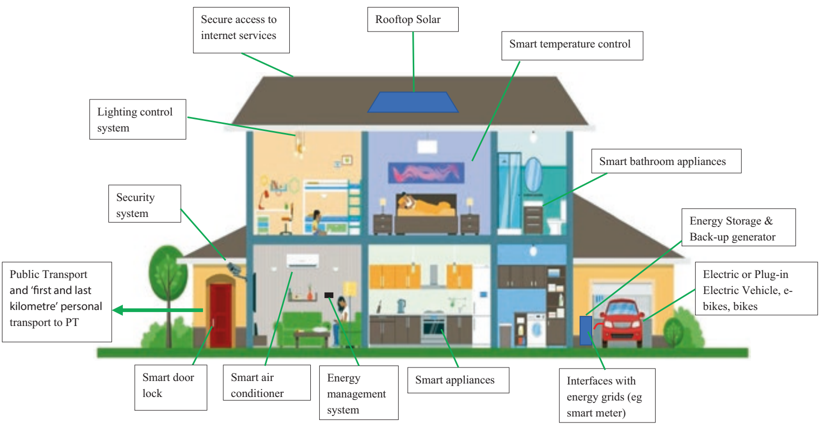

Fig. 6.1 Elements of smartness within a smart home (*Source* Author, adapted from Shutterstock with permission)

Role of Smart Homes in a Low Carbon Future

Smart homes offer benefits including the potential to save energy and reduce greenhouse gas emissions (Wilson, Hargreaves & Hauxwell-Baldwin 2017). For example, real-time monitoring of appliances can extend building and equipment life while improving efficiency, affordability and conducting preventive maintenance or alerting occupants to faults. A smart home could stagger operation of the dishwasher, washing machine and water heating across the day to match renewable energy generation or battery storage. Such outcomes are possible due to increasing access to 'smart' data (from equipment and activity in the home and numerous external sources such as weather, utility prices, etc.) linked to smart appliances. This facilitates provision of higher quality, more 'valuable' services and could close gaps between design intent and actual performance, otherwise known as the 'performance gap' (van den Brom, Meijer & Visscher 2017).

Increasingly, though, smart homes are being positioned as improving convenience, security, comfort, liveability and health and wellbeing outcomes for households (Balta-Ozkan et al. 2013; Balta-Ozkan, Amerighi & Boteler 2014; Bhati, Hansen & Chan 2017; Wilson, Hargreaves & Hauxwell-Baldwin 2017). Smart homes offer the promise of automating activities to reduce occupant effort and save time and money by integrating themselves into our everyday lives (Balta-Ozkan et al. 2013). For a portion of the population (i.e. aged or disabled), this can significantly improve quality of life outcomes (Orpwood et al. 2005; Wilson, Hargreaves & Hauxwell-Baldwin 2017). For example, sensors in lighting could replace the need for someone with a disability to manually operate light switches. Additionally, sensors could pick up faults with appliances or renewable energy systems in real time. Fault identification is particularly important for lower income households who are on the margins for energy affordability (Moore et al. 2017).

Smart homes are increasingly seen as an important step towards delivering a more sustainable housing future, both from an individual dwelling perspective as well as more broadly across society. Wilson, Hargreaves and Hauxwell-Baldwin (2017) discuss the benefits to energy networks of clusters of smart homes, that can help with energy demand

and reduce peak loads, alleviating the need for costly energy network upgrades. High energy efficiency appliances, equipment and buildings underpin low cost smart solutions by reducing energy consumption and peak demand, thereby reducing the size, cost and complexity of energy supply and storage systems and appliances, equipment, controls and on-site electrical wiring and gas plumbing.

Media reports regularly give the impression that energy savings from smart connected equipment and associated data centres and communication infrastructure may be offset by their additional energy use. This view fails to put this energy consumption into context. The International Energy Agency's *Digitalization and Energy* report (IEA 2017) estimates 2040 global electricity use by information and communications technology controls in buildings (ICT) at 275 TeraWatt-hours (TWh), compared with ICT equipment savings of 4650 TWh. It also estimates that global household and appliance demand response technologies could provide 185 Gigawatts of demand flexibility, avoiding US$270 billion of investment in electricity supply infrastructure. Upstream electricity requirements for ICT capacity to service smart home technologies are dwarfed by those for handling entertainment and social media.

Even so, total upstream ICT network consumption is modest, given the benefits it brings. For example, in Australia the National Broadband Network (NBN) total energy use is around 0.25 Gigajoules per 'activated' customer per year (NBN Co. 2017). If we conservatively assume all NBN energy is electricity, and average this over all business and household customers, this is 70 kilowatt-hours per customer, 1.3% of average Australian household electricity use.

With regard to in-home energy use, a government study (EnergyConsult 2015) shows that televisions use over half of household ICT and home entertainment energy, and networked devices use around a tenth. Despite increasing equipment penetration, electricity use for ICT and home entertainment, including TVs, peaked in 2010 at 14% of total residential electricity consumption. It has declined to around 10% (Fig. 6.2). So the share of household electricity due to smart home functionality seems small.

The IEA (2017) also discusses how intelligent digital systems will blur the boundaries between energy supply from off-site, production on-site, energy storage, management of demand and optimal efficiency of use. These systems are also beginning to offer households opportunities to generate, buy and sell energy, and interact flexibly with the grid. Greensync (https://greensync.com/) and Reposit (https://repositpower.com/) are just two examples of the many businesses facilitating such activity.

Smart Energy Systems and Meters

Many elements and systems could be included within a smart home energy system. These typically revolve around provision of on-site renewable energy and battery storage and/or interactive linking of smart

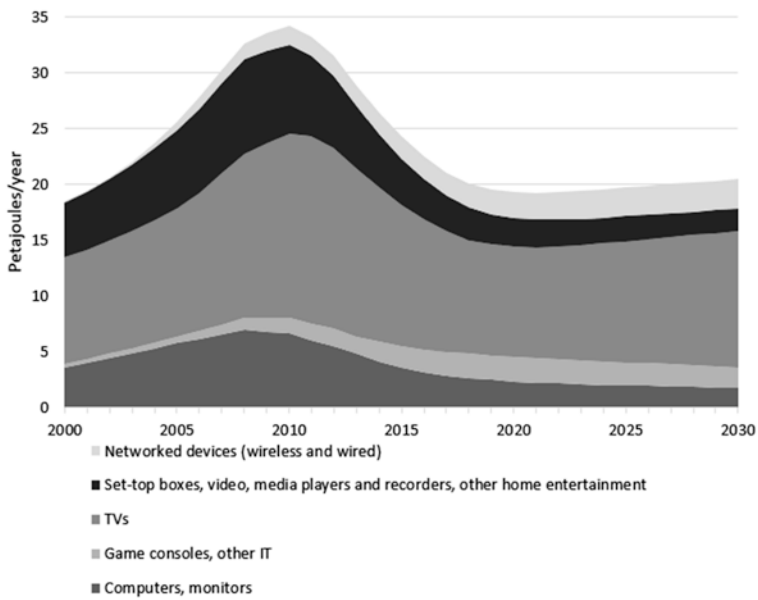

Fig. 6.2 Trends in Australian residential sector electricity use (Petajoules per annum) for ITC and home entertainment equipment (*Source* Author, drawn from data provided in http://www.energyrating.gov.au/document/2015-data-tables-residential-baseline-study-australia-2000-%E2%80%93-2030)

appliances to energy management systems and each other, to deliver more effective and efficient user outcomes.

One key element of the emergence of smart homes is the smart meter. The smart meter provides an interface between home and electricity supply infrastructure that collects energy use data, typically at half hourly intervals. The occupant of the property can access this data, though not necessarily in real time. Often, smart meters are supplemented by third-party monitoring of on-site solar systems and/or smart home energy management systems. At a basic level, a smart meter provides the occupant and energy provider with time-based information on electricity use. This may be utilised in many ways. For the occupant it will: improve understanding of when electricity is used; identify energy waste and equipment faults; help manage usage through behaviour change and optimisation of equipment operation; and provide input to additional monitoring and management systems to deliver improved services. For the energy supplier and other service providers it will: underpin time-of-use pricing options or other incentives to shift usage away from high supply cost periods; analyse household data to provide advice on energy management, and benchmarking as well as performance against dynamic baselines (sometimes called 'digital twins': Jutsen et al. 2018) to identify faults and for predictive maintenance (Anon 2017; Nott 2017); and help develop improved energy policies and programs based upon real data.

Other core smart energy elements and technologies are outlined in Table 6.1.

A Word of Caution

While smart homes offer a plethora of benefits such as providing financial savings, improving environmental performance and enhancing quality of life (Paetz, Dütschke & Fichtner 2012), there are challenges as they become mainstream. These revolve around unintended consequences, security and privacy concerns and implications for practices (Strengers & Nicholls 2017; Tirado Herrero, Nicholls & Strengers 2018; Wilson, Hargreaves & Hauxwell-Baldwin 2017). Research by

Table 6.1 Overview of elements of smart home energy *systems*

Technology elements	Functions	Level of interaction	Roles and outcomes
Sensors: e.g. for temperature, humidity, utility consumption, security, etc.	Components within appliance or related system that provide timely information on relevant parameters to support improved management or security. As sensor performance improves and costs decline, more factors can be tracked	Ideally provides frequent real-time, accurate data for use throughout smart system. Less frequent/accurate data may still be useful	Provides raw data to optimise performance, identify variations from expected performance, provide parameters for automation, links to features such as sensor lights, security services, etc.
Appliances: smart, efficient, flexible, responsive, connected	**'Smart':** internal components can analyse input and operational data to advise users and/or manage performance **'Efficient':** maximises 'value' of service delivered per unit of energy and other inputs **'Flexible'**: design allows it to vary operation in response to signals and decisions made by internal software, users and/or external systems **'Responsive':** has low inertia (e.g. thermal, mechanical, decision-making) so can respond to signals quickly **'Connected':** can use data from many sources (e.g. sensors, weather apps) AND send data to where it can be used (often with other inputs) to inform action to enhance service quality	Smart capability may be located between appliance and consumer (e.g. user interface, smart plug); within appliance; or between appliance and energy supply and/or communication network	Delivers optimised service required or desired by user and provides data for analysis to support other outcomes Manages interaction with sources of energy, water and other inputs Multiple benefits beyond energy may be gained, e.g. managing food inventories, avoiding or alerting of risk of appliance failures, increased convenience, etc.

(continued)

Table 6.1 (continued)

Technology elements	Functions	Level of interaction	Roles and outcomes
Energy storage: electricity; heat/cold; solid, liquid or gaseous fuels	May exist within appliances (e.g. laptop computer, hot water storage service); as plug-in modules (e.g. Uninterruptible Power Supply); for critically important energy services, or on-site (battery, thermal storage, wood pile, etc.)	Appliance or home scale storage separates time of service delivery and import/export of energy from time, price and location where energy is produced and point of connection to energy grids	Supports personal, appliance, home, building and energy network level energy management and peak load, cost management Appliance-level or plug-in module energy storage can avoid cost and time impact of rewiring in-home circuits or hard wiring to existing circuit and reduce risk exposure to system failures Home scale storage supports interaction with other consumers and broader energy supply systems

(continued)

Table 6.1 (continued)

Technology elements	Functions	Level of interaction	Roles and outcomes
Interface between home and external energy supply infrastructure	May involve hardware (smart meter, monitoring systems), software (intelligent analysis, monitoring) and/or communication systems to transfer information and signals for actions	Provides useful information to occupant, service providers and energy system operators. Allows utilisation of multiple data streams to provide enhanced insights, access to analytical tools and management/control systems	Improve understanding for consumers about their consumption practices. Allows energy and service providers to deliver higher value to consumes and optimise their costs. Manages data security
Infrastructure beyond the home	Hardware (electricity and gas grids, microgrids, other energy providers) deliver or accept energy. Service providers manage this infrastructure, but an expanding variety of energy service providers offer trading, management and other services using many different business models and pricing structures	Traditionally one-way transfer of energy with supplier billing customer. Increasing complexity of interactions (e.g. Demand Response, energy trading) and number of service providers	Increasing support for in-home energy management, generation, storage and energy efficiency measures, as well as empowerment to optimise outcomes, trade energy and capture multiple benefits

Wilson, Hargreaves and Hauxwell-Baldwin (2017) identifies a number of risks around the delivery of smart homes. For example, increasing dependence on technology and on electricity networks, but also that smart home technologies are still mostly seen as non-essential luxuries.

There are examples where people do not use smart elements as predicted, which creates negative unintended consequences (Balta-Ozkan et al. 2013). Emergence of new smart technologies has been accompanied by widely variable behavioural responses, new consuming activities and equity issues. Furthermore, there is a body of research which challenges the purported sustainability benefits of smart homes, especially as they may reinforce unsustainable practices (Strengers & Nicholls 2017; Tirado Herrero, Nicholls & Strengers 2018; Wilson, Hargreaves & Hauxwell-Baldwin 2017). For example, practices around using smart thermostats may use more heating and cooling energy to achieve a narrow band in thermal comfort, rather than allowing a more natural adaptive comfort approach.

Maintenance of data security and privacy is critically important. New models for consumer protection will be needed, as households may interact with multiple service providers whose behaviour may deviate from 'best practice'. Large integrated service providers are likely to emerge, that will require regulatory control to manage their potentially substantial market power. We have seen stories in the media about smart technologies breaching privacy issues. In a recent example, a US family had its private conversation recorded by a voice-assistant device, which was then sent to one of the contacts in their phone (Kim 2018). Apparently, the software misinterpreted background conversation as a set of commands to send a message to the contact (Kim 2018). This highlights the sensitivities that emerging smart technologies face and concerns around the trust consumers will place in such technologies. Perhaps though, the biggest concern related to security and privacy is around where the data collected via smart technologies is stored and who has access to it. We have seen several large data security breaches around the world in recent years and it presents a significant concern as we move into a more technologically advanced digital society.

In the same way, there are issues around how secure this technology is (Balta-Ozkan et al. 2013). Just as our computers and other connected technologies can be hacked or receive viruses, so too can these smart technologies (Fernandes 2016). This could leave households exposed not only from a physical security perspective but also other types of crime. There is also the question of how you could operate your house if the energy or data network or smart elements stopped working (Balta-Ozkan et al. 2013; Wilson, Hargreaves & Hauxwell-Baldwin 2017), or if you cannot afford to pay your ongoing usage fees. For example, if you have a fire in your house can you escape through the smart front door?

There are also concerns around potentially higher capital or operating costs of smart appliances and homes in comparison to standard technologies and homes. There is not enough known yet as to whether improved outcomes of smartness offset any higher costs for households, or that households will be able to capture the savings. It also means that possibly there may be a gap between those who can and cannot afford smart technologies (Paetz, Dütschke & Fichtner 2012; Tirado Herrero, Nicholls & Strengers 2018).

Discussion

There is a requirement for housing (and households) to transition to a low energy/carbon future. Arguably this is starting to happen but, to date, progress towards more sustainable performance has been focused on specific solutions like solar panels and appliances. Smart homes have not yet been part of broader sustainable housing policy discussion in Australia, even though the smart home provides a new way of looking at the role energy plays in everyday life, and the evolving relationship between energy utilities and consumers. 'Its development may create opportunities for consumers and utilities alike' (Balta-Ozkan et al. 2013, p. 363).

The emergence of sophisticated data analytics and 'machine learning', as well as declining costs of sensors, increasing 'intelligence' of appliances and more sophisticated metering and monitoring will be transformative. We still do not know what the potential, or end point, of smart homes will be. What is clear is that over the next few years, as our homes become smarter, we will have access to more detailed end use and energy service data. This will not just shape our housing from the occupant perspective but also influence stakeholders and supply chains involved in the delivery and maintenance of housing. For example, instead of home energy audits involving visual inspection and on-site visits, remote analysis and smart phones will allow assessors to identify which appliances are wasting energy, when and why.

But the energy and carbon dimensions will be just part of the picture. The ICT system provides a platform for delivery of many services with both superficial and fundamental attractions to households, the energy sector and governments, with all the opportunities and risks this provides.

New institutional and governance frameworks will be needed. For example, very different consumer protection models will be needed for households with multiple service providers (of energy, on-site equipment, maintenance, interaction with energy markets, analysis/monitoring and advice, etc.).

Governments are increasingly seeing retailing of energy as an area where competitive forces could play a useful role. Yet experience in Victoria, which has led Australian energy retailing deregulation and competition, has led to higher prices, particularly for those least able to pay (Thwaites, Faulkner & Mulder 2017). This is particularly the case as disruptive technologies and business models emerge that offer potential to maximise utilisation of energy supply assets and reduce consumer costs. Many governments have also been attracted by potential to raise funds through privatisation, or to use inflated revenues from government-owned utilities to provide additional revenue without a need to introduce new, visible taxes. Detailed discussion of energy market reform is beyond the scope of this chapter. But a key factor relevant to households is that many of the new technologies and software solutions are installed behind the meter or at a local level, and are paid for by consumers, even though energy companies and broader society also benefit.

Many of the businesses that are developing these solutions are outside traditional energy sectors. Indeed, disruptors include builders, appliance manufacturers, computer hardware and software businesses, energy management businesses, integrators and aggregators. This broadening of participants creates new challenges for policymakers, regulators and households. For example, energy policymakers and regulators are beginning to confront the need to build cooperation with those from a wide range of areas, including consumer protection, building, manufacturing innovation, business development, appliance retailing, social justice and health among others. The challenges work in both directions: policymakers from these other fields must work out how to integrate energy issues into their traditional priorities and practices!

The structure of a low carbon energy future is far more complex than the traditional centralised supply model. Pears (2017) explains that the emerging model is based on the delivery of useful services to consumers. of which energy is one element. The energy system now offers many competing but very different options to provide inputs to this service delivery. It involves multiple overlapping markets with many different participants with very different agendas. Present energy policy fails to recognise many of these participants, so disruption occurs when previously unrecognised participants exert influence.

Conclusion

Smart homes have the potential to help shape a transition to a low energy/carbon housing future. But like most technologies, they offer a two-edged sword, with benefits and risks. They offer potential for improved resource efficiency, lower operating costs, improved indoor air quality, local and broad scale optimisation of energy systems and better-informed planning. But insensitive implementation can undermine equity, encourage wasteful practices, create consumer protection problems and put privacy at risk.

To ensure smart homes achieve identified benefits we need strong standards, protocols, consumer protection and support infrastructure. We need mechanisms that ensure tenants and vulnerable households can share the benefits. We also need to drive research and analysis across a range of disciplines, so that we can learn from experience and drive ongoing innovation. Some of these elements already exist, but there is a greater need for governments, industry, researchers and consumers to work together to deliver improved outcomes.

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Part II

Transition to Zero Carbon Buildings

7

Assessing Embodied Greenhouse Gas Emissions in the Built Environment

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Introduction

The built environment has adverse environmental impacts that are attributable to its use of natural resources, fossil fuel energy consumption and greenhouse gas emissions (GHGE). Buildings account for nearly 40% of annual global energy use and approximately 30% of the GHGE emitted throughout all stages in their life cycle

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(i.e. cradle-to-grave), contributing significantly to climate change (IPCC 2014; UNEP 2009).

Most carbon reduction regulations place more emphasis on decreasing operational energy and their associated emissions, and fail to take a more holistic approach. Whilst operational energy impacts are generally bigger than embodied impacts over the life cycle, their relative proportions are affected by many factors, such as climate, geographic location, and sources of fuel (Dixit et al. 2012; Hegner 2007). A review by Ibn-Mohammed et al. (2013) and IEA (2016) showed that embodied impacts (energy or emissions) of buildings and infrastructure in different countries can vary from 2 to 80%. Miller and Doh (2015) for example, identified that the total life cycle energy of a typical concrete building generally comprises 80% operational energy and 20% embodied energy. However, the ratio of operational emissions in total building life cycle emissions has decreased due to recent improvements in building design and energy efficiency (Dixit et al. 2010, 2012). As a result, this increases the comparative significance of embodied GHGE, which includes emissions from extraction of natural resources, manufacture of building materials, transportation to site, construction, renovation, demolition and disposal of the building (Ibn-Mohammed et al. 2013; Langston & Langston 2008). The current trend towards 'net zero carbon buildings' focuses on significantly reducing operational energy impacts, which will further increase the proportion of embodied impacts in the life cycle (IEA 2016; Lützkendorf et al. 2015). Therefore, the growing importance of embodied emissions when assessing the total carbon footprint of the built environment should be duly recognised. However, embodied GHGE are still rarely assessed in many countries, including Australia.

This chapter provides a summary of current life cycle inventory (LCI) methods and Australian LCI databases, tools and guidance that

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support the analysis of embodied GHGE related to the built environment. The gaps in extant methodologies, databases and tools applied to assessing embodied GHGE are identified. The newly developed Embodied Carbon Explorer (ECE) online tool is introduced to provide a quick evaluation of embodied GHGE for built environment projects. The ECE tool is used to provide the most recent carbon footprint (year 2015) for Australia's construction industry and identify the main contributors of embodied GHGE.

Data, Tools and Methods for Assessing Embodied Greenhouse Gas Emissions

This section describes the main data, tools and methods available for assessing embodied GHGE of construction projects. Three broad approaches for quantifying embodied GHGE are available. These are known as *process analysis*, *environmentally extended input–output analysis* and *hybrid analysis*. The distinctive difference between these approaches lies in the data used and the scope of analysis. Each of these approaches involves modelling a system, based on either specific production processes or entire economic systems.

Process Analysis

Process analysis is a bottom-up approach where a product system (such as a building) is broken down into a series of processes linked to the manufacture and supply of material products used in the construction of the built environment. Process analysis uses data specific to the product under study, enabling the highest possible level of accuracy. This data is typically sourced from the organisations responsible for particular processes, such as miners of raw materials or manufacturers of building materials. GHGE data is obtained for each process and then summed to determine the total embodied GHGE for the product.

While the representativeness of this data for particular products and processes is typically very high, process analysis suffers from systemic incompleteness as it is impossible to exhaustively assess the supply chain of any given product, mainly due to cost and time constraints (Crawford 2008; Lenzen 2000; Suh et al. 2004). Data gaps are most common for higher order or upstream processes (such as the extraction of a particular raw material at the very start of the supply chain, e.g. mining of bauxite); intermediate processes (for instance the manufacturing processes occurring between the production of a material—such as aluminium—and the final product—a window frame); and non-material processes such as the provision of services, or physical inputs considered small enough to be excluded (Crawford 2011).

Databases of process data can be used to streamline a process analysis. The Australian Life Cycle Inventory Database (www.auslci.com.au) or AusLCI, includes data on building and packaging materials, energy and transport as well as data on agriculture, fuels, food, raw materials and waste management. It covers a broad range of resource inputs and outputs for each of the products covered, including emissions of various GHG. In addition, the Building Products Innovation Council (BPIC) has established the Building Products Life Cycle Inventory (BP LCI) (www.bpic.asn.au), a database of physical process data for over 100 different building materials and products, including concrete, concrete blocks, concrete and terracotta roof tiles, bricks, gypsum board, steel, timber and timber products, windows, glass and insulation materials. For each material, data on inputs such as fuels, raw materials, water as well as emissions of waste and pollutants are provided.

Environmentally Extended Input–Output Analysis

Environmentally extended input–output analysis (EEIOA) is a top-down approach that uses input–output (IO) tables containing information on monetary transactions between sectors of an economy, combined with national environmental accounts (e.g. Department of the Environment and Energy 2018). The resulting environmentally extended IO (EEIO) data provides information on the embodied environmental flows per monetary value of output from a particular sector (e.g. tonnes of GHGE per dollar value of construction). With a product's cost information, an estimate of its embodied GHGE can then be calculated. As this data is based on an economy-wide system boundary, it is considered to be systemically complete. IO tables are usually produced on an annual basis with the latest tables covering 114 industry groups (ABS 2018), including four main construction sectors—*Residential Building Construction, Non-Residential Building Construction, Heavy and Civil Engineering Construction,* and *Construction Services*.

EEIOA assumes that a dollar spent on two different products from the same sector results in the same GHGE. This means that it can be difficult to assess specific products and differentiate between practices that take place within the same sector (Lenzen 2000; Treloar 1997). Because of this, EEIOA in its pure form is most useful for assessing entire economies or industries, particularly as an initial scoping tool to help identify the areas with the greatest potential for reducing GHGE.

EEIO data for Australia has been made available within a number of databases, including Eora and The Australian Industrial Ecology Virtual Laboratory (IELab) (https://ielab-aus.info). IELab is a collaborative cloud-based platform for compiling large-scale, high-resolution, economic, social and environmental accounts based on IO tables. The IELab uses a spatial classification based on the Australian Statistical Geography Standard (ASGS) which includes a Statistical Area Level 2 (SA2) subdivision of Australia into 2196 geographical entities (ABS 2010), each containing an average population of 10,000 persons. The Input–Output Product Categories (IOPC) sectoral classification is used, which distinguishes 1284 product groups (ABS 2012). Theoretically, this means that it can be applied to model embodied GHGE for any sector/product group or subnational region.

Global IO databases, including IDE-JETRO, EXIOBASE, GLIO, GTAP, OECD, WIOD and Eora (see Murray & Lenzen 2013 for details), can also be used to model the embodied GHGE of products or regions outside of Australia. This enables inclusion of GHGE resulting from products traded between geographic regions. Such an application is important as GHGE are very rarely confined within the boundaries of a single region.

Hybrid Analysis

In an attempt to address the limitations of both process analysis and EEIOA, hybrid analysis was developed, combining process and input–output data. Four main hybrid approaches exist, namely *Tiered*, *Path Exchange*, *Matrix Augmentation* and *Integrated*. These different hybrid approaches are described in detail by Crawford et al. (2018). Each one represents a slightly different approach for filling data gaps in a process analysis (Fig. 7.1).

A hybrid analysis tends to accentuate the complexity of quantifying embodied GHGE because of the need to work with and combine two distinctively different data types. However, the benefits have shown it to be worth the effort as process analyses that rely on a more limited system boundary may significantly underestimate embodied environmental flows. For example, a hybrid embodied energy analysis of a range of

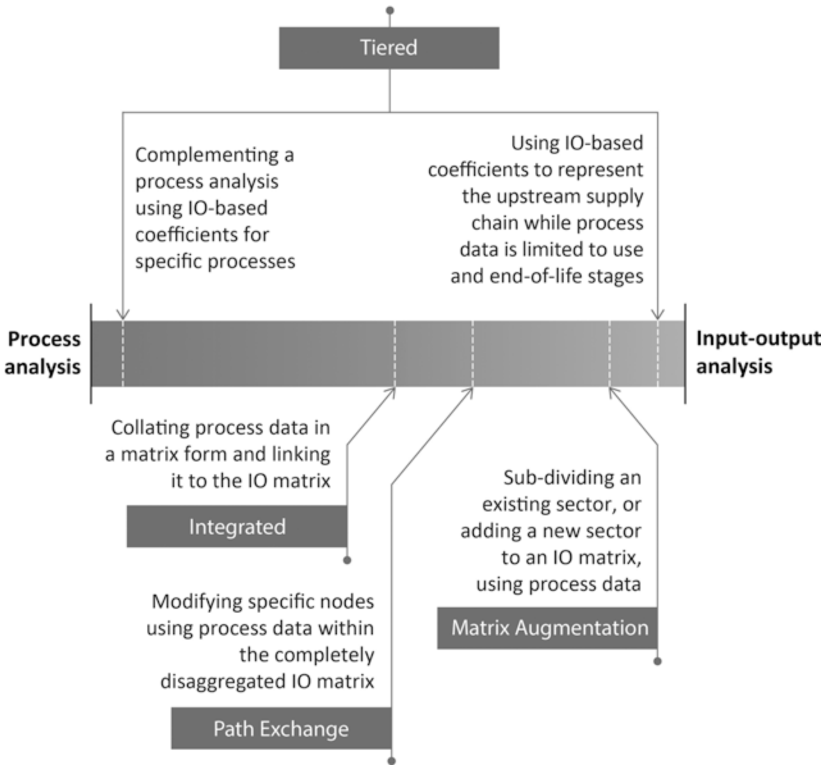

Fig. 7.1 Hybrid analysis approaches for quantifying embodied greenhouse gas emissions (*Source* Crawford et al. 2018 with permission)

different building types showed that on average 64% of energy inputs would be excluded if a process analysis were used (Crawford 2008).

To alleviate some of the complexity in quantifying embodied GHGE, databases of precompiled embodied GHGE coefficients for products and processes can be used. Coefficients (typically in kg CO_2e per unit of product) are multiplied by specific product quantities (e.g. tonnes of steel) to determine total embodied GHGE of a product. A number of coefficient databases exist (Table 7.1), compiled for different geographic regions and using the three different analysis approaches. These most commonly include embodied energy coefficients, which can easily be converted to GHGE using emissions intensity values for different energy types. The values for identical products can vary substantially between databases, due to factors such as region-specific fuel mix and emissions intensity, analysis approach, data source, and process/system boundary coverage. For this reason, when selecting coefficients to use, consideration must be given to using those which are most representative of the product under study, while also striving to maximise supply chain coverage. This helps ensure that analysis results reflect the actual embodied GHGE of a product as closely as possible. The most comprehensive database of embodied GHGE coefficients of construction materials for Australia is that produced by Crawford (2018). This database covers 95 materials and a range of environmental flows, compiled using a hybrid analysis. Developed by the Cooperative Research Centre for Low Carbon Living (CRCLCL), the Integrated Carbon Metrics (ICM) database on embodied GHGE provides coefficients that are specific to Australian construction and building materials.

The next section describes how the Australian construction industry is currently addressing embodied GHGE.

Current Industry Practice in Reducing Embodied GHGE of Australia's Buildings

Even though Australia is at the forefront of embodied GHGE research, the consideration of embodied GHGE in practice has been slow. A recent survey of the Australian construction industry conducted by

Table 7.1 Summary of key material environmental flow coefficient databases

Database	Flows and number of products covered	Country of relevance	Compilation method	Latest update
Inventory of Carbon and Energy (ICE)[1]	Energy, carbon—299	United Kingdom[a]	Varies[a]	2011
Database of environmental flow coefficients for construction materials[2]	Energy, water, waste, GHGE, land, material resources—95	Australia	Hybrid analysis	2018
Database of embodied energy and water values for materials[3]	Energy, water—58	Australia	Hybrid analysis	2010
Embodied energy and CO_2 coefficients for NZ building materials[4]	Energy, GHGE—61	New Zealand	Hybrid analysis	2003
BEES[5]	Energy, GHGE—230	United States	Process analysis	2010
Building materials, energy and the environment[6]	Energy—32	Australia	Process analysis	1996
Balancing Act[7]	Energy, GHGE, water, land—135	Australia	Input–output analysis	2005
ICM database on embodied greenhouse gas emissions[8]	GHGE—400	Australia	Input–output analysis, Hybrid analysis	2019

Notes [a]Data sourced from various geographic regions, using different analysis methods; [1]University of Bath (2011), [2]Crawford (2018), [3]Crawford and Treloar (2010), [4]Alcorn (2003), [5]NIST (2007), [6]Lawson (1996), [7]Foran et al. (2005), [8]Teh et al. (2015), Teh (2018)

Fouché and Crawford (2015), found that over 85% of construction industry consultants providing environmentally related advice tended to focus on providing operational GHGE assessment services. In total, 60% of the survey respondents, consisting predominately of life cycle assessment (LCA) practitioners and sustainability consultants, provided some form of embodied GHGE assessment. For the organisations that did not provide this service, almost 70% said that they would consider providing it as part of their services in the future. This demonstrates that there is an increasing awareness of the need to address these emissions. When asked what software tools are used for embodied GHGE assessment, SimaPro (simapro.com) was the most popular tool used, followed by eToolLCD (etoolglobal.com), a building-specific LCA tool developed in Australia. There was a preference for locally developed tools, but also a need to address the weaknesses in existing data and tools available for embodied GHGE assessment. These weaknesses include a lack of Australian-specific data, inconsistent methodologies, time-intensive assessments, a need for expert knowledge, and a lack of benchmarks and compatibility with building information modelling (BIM). When asked to indicate the top features desired in new or improved tools, over 80% indicated 'material cost' as the most beneficial feature followed by data on recycled materials (62%) and the source of materials (57%). Other recommendations included adherence to Australian regulations and standards, options for quick analysis, integration with existing tools, ease of updating and more transparency and consistency. These tend to coincide with the key barriers affecting the uptake of embodied GHGE assessment within the construction industry, as highlighted in a report published by ASBP (2014). This placed consistency of method at the top of the list followed by availability of comparable data, and mandatory legislation. The inconsistency and poor availability of comprehensive embodied GHGE data are often quoted as key barriers affecting the uptake of both embodied GHGE and LCA (Ariyaratne & Moncaster 2014; Dixit et al. 2015; Schinabeck et al. 2016). The study by Fouché and Crawford (2015) identified several other critical barriers such as a lack of project budget, client disinterest and no clear financial incentive. The effect of budgetary constraints on the uptake of embodied GHGE considerations was also identified by Ariyaratne and Moncaster (2014) and Wu et al. (2016). These studies found that the cost of embodied GHGE reduction is not well understood and more research is required to further understand the financial implications of embodied and life cycle GHGE reduction.

In an attempt to address this, Schmidt and Crawford (2018) developed a framework for comparing the financial and environmental performance of GHGE reduction strategies for buildings. This can be used to assess the life cycle emissions and costs associated with a particular design strategy and inform the design decision-making process in balancing the GHGE reduction and financial goals of a project. For example, the life cycle GHGE and cost of different insulation options for a project can be compared. An appropriate solution can then be selected, prioritising any that lead to the lowest life cycle GHGE and cost, followed by those that reduce GHGE but come at a cost premium. This decision will ultimately be made in relation to a client's 'willingness-to-pay' for a certain degree of GHGE reduction and in the context of other project constraints and priorities.

National Standards and Guidance on Embodied GHGE

Full life cycle assessment that includes both operational and embodied impacts has been regulated in countries including The Netherlands and Germany (Giesekam et al. 2015). However, legislation to measure and reduce embodied GHGE of buildings are not yet in place in most countries including Australia (Birgisdottir et al. 2017). This is due to long-standing limitations such as data, methodological issues, system boundary, uncertainties and lack of consistent framework in the analysis of embodied GHGE (Ibn-Mohammed et al. 2013; Patchell 2018).

In Australia, companies and organisations are required to report Scope 1 (operational) and 2 (electricity) emissions under the National Greenhouse and Energy Reporting (NGER) scheme while Scope 3 (all other indirect/embodied emissions) is not mandatory.

For the built environment in Australia, the building certification schemes which address embodied GHGE are currently voluntary. The Federal Department of the Environment recently released a voluntary National Carbon Offset Standard (NCOS) which provides guidelines for carbon neutral buildings and precincts (Commonwealth of Australia 2017a, 2017b). This is done by (i) preparing a carbon account for Scopes 1–3, (ii) reducing emissions where possible, (iii) offsetting emissions that cannot be reduced or avoided, (iv) preparing a public report on carbon neutrality, and (v) arranging for an audit of the carbon account and public report. Scope 3 emissions deemed to be relevant that are listed in the NCOS are from electricity consumption, fuel use, waste, water supply, wastewater treatment, transport and all other emissions identified (which are assessed for relevance according to a relevance test). However, it is encouraged to include as many emission contributors as possible, and any Scope 3 emissions of more than 1% of the total account is considered to be material and should be reported.

To date, there are no tools in the market directly targeting assessments under the NCOS for Buildings and Precincts, although certifications can be sought through National Australian Built Environment Rating System (NABERS) and Green Building Council of Australia (GBCA) for building operations. Accounting for the multitude of contributions from supply chains is usually a complicated and a time-intensive task using a bottom-up approach. Alternatively, a top-down approach can quantify Scope 3 emissions more easily and expeditiously by using Australia-specific input–output data, making it a more efficient technique. Furthermore, methods and tools based on input–output analysis are referenced in the NCOS to measure Scope 3 materiality thresholds (Commonwealth of Australia 2017a, p. 13).

Based on the top-down approach, the Embodied Carbon Explorer (ECE) online tool was developed by the CRCLCL, specifically to enable a swift evaluation of embodied (Scope 3) GHGE for a project at any level (e.g. precinct, building, organisation, material, etc.). It is well suited for a quick screening assessment before full, detailed assessments are undertaken. The ECE tool (i) quantifies the total impacts related to project life (based on expenditure data), (ii) identifies main contributors to total impacts, and (iii) provides NCOS-suitable functionality. Any contributor (e.g. product or service) can be tested for its Scope 3 emissions in accordance with the NCOS materiality threshold, and those playing a relevant role can be selected for reporting purposes.

The ECE tool supports the realisation of the NCOS and has the theoretical potential to assess carbon neutrality for all new building and precinct developments and refurbishments.

Embodied Carbon Explorer Tool Case Study

Tracking Emissions in Australia's Built Environment

For this case study, the carbon footprint of the Australian construction sector is assessed for the year 2015 using the ECE tool. The aim of this case study is to provide the most up-to-date total carbon footprint (Scopes 1–3 emissions) of Australia's construction sector, to identify the main contributing industries and products, to provide NCOS-aligned carbon footprint results, as well as to provide a national average benchmark for other projects and buildings for the ECE tool. This study will assess the initial embodied emissions of the construction sector encompassing the cradle-to-site system boundary (Fig. 7.2). Identification of the key contributing industries and products will enable emission mitigation strategies as an important part of the solution to achieve carbon neutrality.

Method and Data

The ECE Tool is based on EEIOA, which couples input–output tables with environmental information (e.g. GHGE) to provide an analysis of embodied environmental flows per unit dollar of a sector's output. This data is systematically complete as it is based on a system boundary encapsulating the entire economy. The ECE online tool is hosted on the IELab research platform (https://ece.ielab-aus.info).

The ECE tool uses three main data sources. Firstly, IO data is sourced from the IELab (Lenzen et al. 2014), which provides the most detailed

	Life cycle stages	Cradle-to-Site	Cradle-to-Grave	Cradle-to-Cradle
Production	Extraction of Raw Material	X	X	X
	Processing of Materials	X	X	X
	Manufacture of Building Materials	X	X	X
Construction	Transportation to Construction Site	X	X	X
	Construction of Building	X	X	X
Use	Operation of Building		X	X
	Maintenance, Repair and Refurbishment		X	X
End-of-Life	Deconstruction and Demolition		X	X
	Disposal, Reuse and Recycle			X

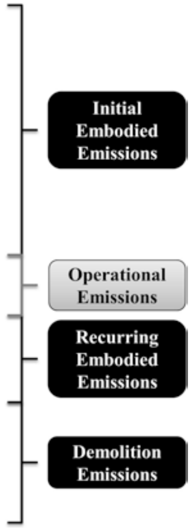

Fig. 7.2 Life cycle stages of a building

Australian IO data with a granularity of up to 1284 sectors. The ECE tool consists of the latest IO data from the year 2014–2015, which are categorised into 334 economic sectors in the form of a national Supply-and-Use Table (SUT).

Secondly, rest-of-the-world (RoW) data is derived from the Eora multiregional input–output database (Lenzen et al. 2013) to account for trades of goods and services between countries. RoW data of all other countries are aggregated into a simplified 26-sector table, and then attached to the 344-sector Australian SUT to construct a two-region, globally closed model of Australia and the RoW for 2015 (see also supplementary information in Wiedmann et al. 2016). Thirdly, GHGE data for 2015 are obtained from the Australian Greenhouse Emissions Information System (AGEIS).

Carbon footprint from the production of goods and services as well as imports are allocated to the intermediate demand of industries.

Carbon footprints are calculated by multiplying the amount of GHGE embodied in each dollar of demand of the products from the construction industry with the construction industry's expenditure data. This facilitates an assessment of the most significant contributors of embodied GHGE in a particular industry.

Results

This case study considers carbon footprint as embodied GHGE in the intermediate demand products of the construction sector (i.e. buildings and infrastructure). Embodied GHGE can be either emissions within Australia or embodied in construction products and services that are imported into Australia as necessitated by local intermediate demand. The 344 sectors are aggregated into Scope 3 categories provided in NCOS (i.e. *Stationary energy*, *Water, wastewater and waste*, and *Transport*) as well as additional emissions categories (i.e. *Agriculture*, *Forestry and fishing*, *Mining and quarrying*, *Food*, *Consumer goods*, *Industrial products*, *Machinery and equipment*, *Construction* and *Services*).

National Average Benchmark of the Construction Sector in 2015

The construction sector is responsible for 9.7 Mt carbon dioxide equivalent (CO_2e) of direct emissions (Scope 1 emissions) and 55.9 Mt CO_2e of carbon footprint (Scope 2 and 3 emissions). The construction sector comprised eight sectors (from the 334 sectors), namely *Residential building repair and maintenance*, *Residential building construction*, *Non-residential building construction*, *Non-residential building repair and maintenance*, *Prefabricated buildings*, *Roads and bridges*, *Non-building construction* and *Non-building repair*. Within the construction sector, the largest carbon footprint stems from *Residential building construction* 20.2 Mt CO_2e (36%), *Non-residential building construction* 16 Mt CO_2e (29%), *Other heavy and civil engineering construction* (labelled as *non-building construction* in the ECE tool) 9.8 Mt CO_2e (18%), and *Roads and bridges* 5.2 Mt CO_2e (9%). The increase in construction activity of residential and non-residential buildings is linked to population growth and increasing demand, whilst heavy and civil engineering works have declined since the peak of the mining boom (Ai Group 2015).

The total impacts of all upstream supply chains to produce the total demand for the main construction sub-sectors are shown in Fig. 7.3. These can be referenced as a national average benchmark against which to compare the environmental performance of a project or building being analysed using the ECE tool. For example, an assessment of an office building can be benchmarked against the *Non-residential building construction* sector in Fig. 7.3. The comparison can be made on a level playing field by normalising the impacts by the total economic output of the sector (i.e. total impacts per dollar of output).

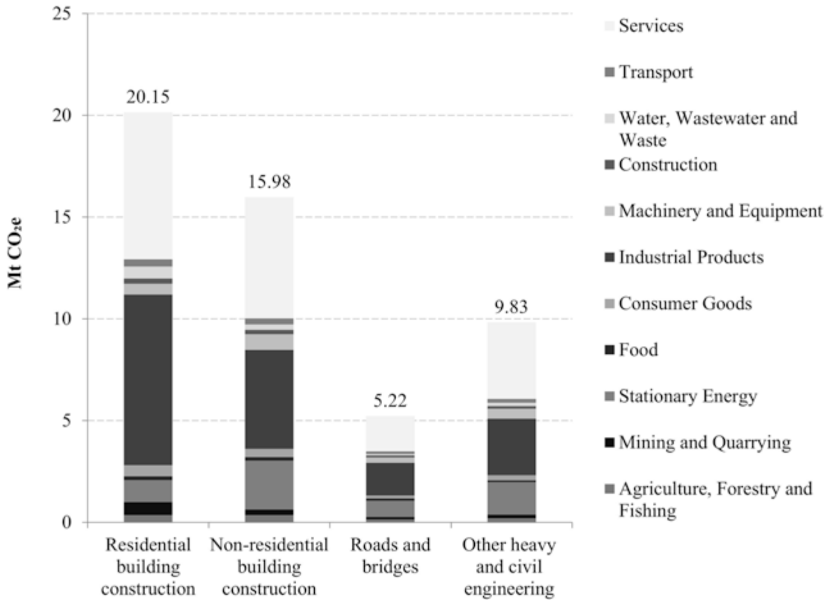

Fig. 7.3 Total impacts of the main construction sectors

Carbon Footprint Breakdown of the Construction Sector in 2015

The total carbon footprint of Australia's construction sector is the total of Scopes 1, 2 and 3 emissions. Scope 1 emissions (9.67 Mt CO_2e) and Scope 2 emissions (4.82 Mt CO_2e) constitute only 22%, whilst Scope 3 emissions (51.03 Mt CO_2e) make up the most substantial proportion (78%) of total emissions. Scope 1 emissions are direct GHGE stemming from the construction industry, such as onsite energy generation, and petrol and gas used for transport. Scope 2 emissions refer to embodied emissions from electricity supply, which depends heavily on fossil fuels at present. Scope 3 emissions include all embodied GHGE from the large upstream supply chains.

The main contributors to the Scope 3 emissions of the Australian construction sector (51.03 Mt CO_2e) are identified as *Services* (32%), *Industrial products* (28%) and *Machinery and equipment* (4%) (Fig. 7.4).

A further breakdown of *Services* shows that *Trade*, such as wholesaling of building materials is responsible for 48% of embodied *Services* GHGE, followed by *Professional, scientific and technical* (19%) which includes architectural and engineering services (Fig. 7.5). The largest contributors within the total embodied GHGE of *Industrial products* are identified as *Cement, lime, plaster and concrete products* (39%),

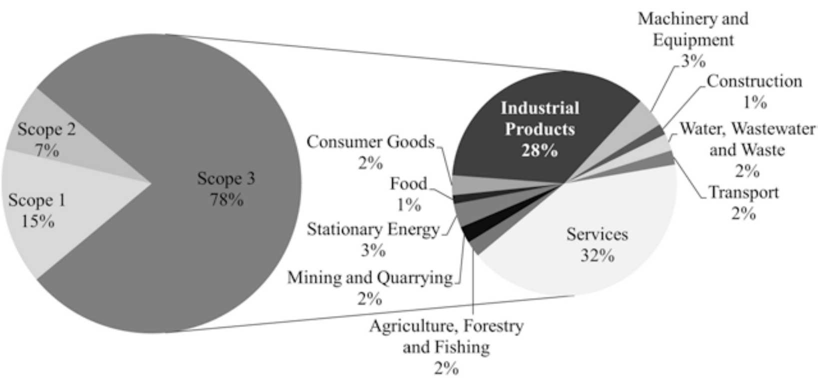

Fig. 7.4 Carbon footprint of Australia's construction sector in 2015

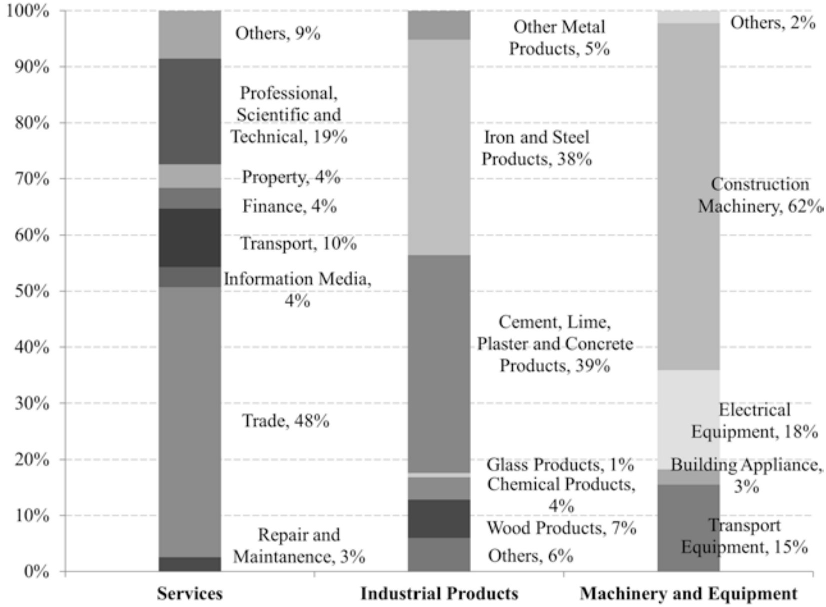

Fig. 7.5 Further breakdown of the three main Scope 3 emission contributors (i) *Services*, (ii) *Industrial products* and (iii) *Machinery and equipment* to the construction sector

Iron and steel products (38%), and *Wood products* (7%) (Fig. 7.5). This is because Australia manufactures around 30 Mt of building products annually, which are predominantly concrete (56%), bricks (23%), and steel (6%) (Miller et al. 2015; Walker-Morison et al. 2007). The choice of building and construction products can play a vital role in reducing embodied impacts. Mitigation strategies to reduce embodied GHGE of building products include substituting emission-intensive products with low-carbon alternative products, reducing the use of carbon-intensive products, and increasing the reuse and recycle of building products (Teh et al. 2017a, 2017b, 2018). Within the *Machinery and equipment* sector, the main source is *Construction machinery* (62%), followed by *Electrical equipment* (18%), and *Transport equipment* (15%) (Fig. 7.5).

Conclusion

This case study using the ECE tool provided the most recent assessment of direct emissions and carbon footprint of Australia's construction sector (for the year 2015). The carbon footprint of the construction industry is almost five times more (478%) than the direct emissions, as emissions are embodied in upstream supply chains mainly stemming from *Services*, *Industrial products*, and *Machinery and equipment*. Carbon footprint results by NCOS-aligned categories allow the identification of specified Scope 3 categories as well as embodied GHGE from other additional categories such as *Stationary energy*, *Mining and quarrying*, *Construction*, *Consumer goods*, *Agriculture, forestry and fishing*, and *Food*. The total impacts of the main construction sub-sectors were established as a national average benchmark against which the environmental performance of an analysed project or building can be compared using the ECE tool.

Research on embodied GHGE in the built environment is fast growing and evolving, as evidenced by the increasing number of guidance publications on the subject. Although some aspects require further study, the immediate aim is to promote adoption of the assessment and reporting frameworks in the construction sector. Some of the concerns, including complexity of method, time requirement, region-specific data, and alignment with existing standards can be tackled with the newly developed ECE tool. When substantive guidance materials have been made available to foster the adoption of these assessment methodologies, it will provide an important aid to both the public and private sectors to commit to addressing climate change by applying the available frameworks to reduce carbon impact.

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8

Transitioning to Net Zero Energy Homes—Learnings from the CRC's High-Performance Housing Living Laboratories

Joshua Byrne, Stephen Berry and Christine Eon

Introduction

The Paris Agreement (UNFCCC 2015) contains a pledge to hold global temperatures to a maximum rise of 1.5 °C above pre-industrial levels. As buildings are the largest user of energy globally (International Energy Agency 2012) and responsible for a significant share of anthropogenic greenhouse gas (GHG) emissions, reducing energy consumption in our homes represent a key action to address global climate change (IPCC 2014). The Australian building sector constructs approximately

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200,000 new dwellings per year, subject to the prevailing economic conditions (HIA 2018). Notwithstanding any significant change in national household energy efficiency policy, the addition of each dwelling below a net zero energy standard increases the need for electricity generation capacity and associated energy supply infrastructure, and adds to national and global GHG emissions.

Internationally, governments have employed a variety of policy mechanisms to reduce household energy use, including energy retailer obligation programs, the provision of financial incentives to encourage the take-up of energy efficiency products or services, energy performance disclosure schemes for both appliances and buildings, and the setting of minimum house energy standards through building or planning codes. Overall, regulatory instruments such as building standards are more effective at reducing household energy use than information, retrofit or voluntary instruments (Koeppel & Ürge-Vorsatz 2007).

Australia has similarly employed a range of policy instruments, establishing the Nationwide House Energy Rating Scheme (NatHERS) in the mid-1990s to encourage thermally improved housing, regulating minimum energy standards in the Building Code of Australia (part of the National Construction Code) in the 2000s, and providing various incentives for householders to install energy efficient and renewable energy products such as insulation, solar hot water systems and solar photovoltaic (PV). At a regional level, some jurisdictions have introduced energy retailer obligations and mandatory energy performance disclosure schemes.

Most recently, driven by the need to meet international obligations to address global climate change, many nations and regions are looking to mandate net zero energy or nearly net zero energy homes (NZEH) as a policy solution. For example, in Europe the EU Directive on the Energy Performance of Buildings (European Commission 2010) specifies that by the end of 2020 all new buildings shall be 'nearly zero energy buildings'. In the USA, the California Long-term Energy Efficiency Strategic Plan sets out the goal to have all new homes achieve a zero net energy standard by 2020 (CPUC 2011).

In Australia, while there is a degree of government reluctance to meet international best practice in building energy regulation (Moore, Horne

& Morrissey 2014), industry is driving the change towards net zero energy buildings by documenting a trajectory to a net zero-carbon built environment (ASBEC 2018; Bannister et al. 2018). This does not mean that Australia is barren of housing innovation, as there are many excellent examples of innovation demonstrating net zero energy or nearly NZEH in a variety of climates and across building typologies. The following case studies explore some of the key learnings from the CRC for Low Carbon Living's high-performance housing 'Living Laboratories'.

Case Studies

Pushing Beyond the Norms: Lochiel Park Green Village—Adelaide, South Australia

The Lochiel Park Green Village in South Australia represented the first genuine attempt by government policy in Australia to create a suburb of (nearly) NZEH in a near zero-carbon estate. The suburban infill development includes 103 homes of various sizes, all utilising solar thermal and PV systems. The energy used and generated at each house is being monitored and analysed as a 'Living Laboratory' to extend our understanding of what happens when households bring their energy habits and expectations to high-performance homes. Appliance and equipment audits, surveys and householder interviews extend our knowledge of this intersection between technology-rich high-performance buildings and the energy service expectations of contemporary digital-age lifestyles.

Lochiel Park homes are built to a relatively high environmental standard, published in the project-specific Urban Design Guidelines (Land Management Corporation 2009). Table 8.1 lists some of the key design and fit-out requirements. These Guidelines established a new set of rules, calling for practices outside existing institutional and professional norms, requiring the application of technologies and systems uncommon to the mainstream building industry at the time, involving the consideration of new performance indicators bringing new concepts

Table 8.1 Mandatory and guidance standards for Lochiel Park homes

Energy service	Minimum requirement or typical fitout
Thermal comfort	7.5 NatHERS stars thermal comfort (i.e. <58 MJ/m^2 per annum)
	Ceiling fans in all bedrooms and living spaces
	Cooling: evaporative coolers or ducted reverse cycle or split system reverse cycle
	Heating: reverse cycle air conditioners, small gas room heaters or underfloor heating
	Space conditioning system capacity limited to 4 kVA (input)
	Fixed or seasonal shade devices on all North, East and West glazing
	Insulation levels: Roof/Ceiling = R4 plus foil, Walls = R2.5 plus foil
	Thermal mass: concrete slab on ground for lower level
	Double glazing and spectrally selective filters (e.g. low-e coating)
Water heating	Solar thermal with natural gas boost or air source heat pump
	Water efficient shower heads and tap fittings
Lighting	Compact fluorescent lights (CFLs) or light emitting diodes (LEDs)
Plug loads	High energy star rated (energy efficient) appliances
Feedback	In-home energy feedback display in main living zone
Renewable energy	Minimum 1.0 kW photovoltaic system for each 100 m^2 of habitable floor area

to building design and construction practices. These requirements also meant that households were exposed to different technologies and styles of house design compared to that commonly available in South Australia (Berry, Davidson & Saman 2013).

Lochiel Park homes are detached or semi-detached two-storey buildings, ranging in size and style from 1 bedroom 'studio' apartments to 4 bedroom detached houses; the most common form being 3 bedroom detached houses. The average habitable floor area for Lochiel Park is 203.3 m^2, similar to the 199.3 m^2 South Australian average for new homes at that time (Australian Bureau of Statistics 2010).

Passive design strategies are implicit within the Urban Design Guidelines, with mandated North facing living spaces, thermal mass requirements, and relatively high levels of insulation; implicit in the minimum house energy rating requirement. The NatHERS 7.5 Star rating (<58 MJ/m^2 per annum) minimum standard for thermal comfort and energy efficiency represents a significant increase above the stock average which approximates NatHERS 2.5 Stars (<270 MJ/m^2 per annum) (Australian Greenhouse Office 2000), and the building regulatory standard of NatHERS 5 Stars (<125 MJ/m^2 per annum) applied at the time when most of these homes were approved for construction. Further detail on the NatHERS energy rating scheme is available from www.nathers.gov.au.

The monitored results reveal a strong outcome. Lochiel Park households use significantly less energy annually than typical similar age homes, the average for the South Australian building stock, and the national average (Berry et al. 2014a, 2014b). This is due to a more thermally efficient building fabric, the application of passive solar design, higher lighting and appliance efficiency, and the use of solar technologies. Figure 8.1 shows that the average energy use per floor area for Lochiel Park homes is less than half that of comparable houses, and when the local generation of electricity is included (self-supplied), the delivered energy (grid demand) is less than a third. Although not reaching the net zero energy standard on average, this represents a significant

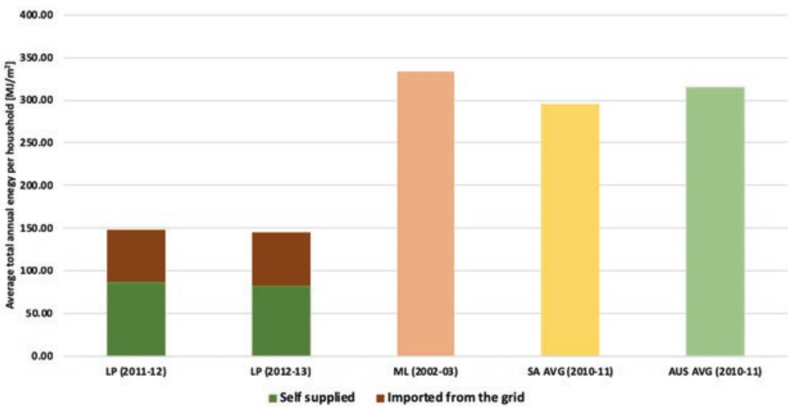

Fig. 8.1 Comparison of Lochiel Park (LP) homes against a sample of Mawson Lakes (ML) homes, and both State (SA) and National (AUS) averages (*Source* Berry et al. 2014a)

improvement in performance against typical homes in the same climate. A small number of homes within the estate regularly achieve a net zero energy operational outcome.

The economics also tell an important story. Analysis from Lochiel Park homes has found that the value proposition of net zero energy housing is overwhelmingly positive to owner-occupier households with a conservative NPV of $24,935 if the home was built in Year 1 of a policy change to net zero energy housing, and with larger net benefits received for homes constructed in subsequent years (Berry & Davidson 2016a). Many of the impacts are externalities not typically incorporated in policy analysis or the business case, yet are real and valued experiences to householders. The benefits far outweigh the costs associated with creating a low energy use, thermally comfortable home environment for low carbon living, powered by renewable energy.

From a public policy perspective the economics are equally strong. The value proposition of regulating all new homes in South Australia to the net zero energy standard would be overwhelmingly positive with a conservative NPV of $1.31 billion for a 10-year policy action, and a benefit/cost ratio of 2.42 (Berry & Davidson 2016b). The results would be similar in other States and Territories, and stronger in regions of more extreme climate where more energy is used for heating or cooling. The research also demonstrates that low carbon living will provide many benefits to the local economy including a net increase in employment, downward pressure on energy prices, increased economic activity within a more efficient economy better able to respond to global energy price increases, energy network infrastructure savings, improved human health and well-being, carbon emission reductions, and benefits from increased social capital. The benefits far outweigh the costs associated with creating net zero energy housing.

Exciting the Market and Testing Innovation: Josh's House—Perth, Western Australia

Josh's House is a three bedroom, two bathroom detached dwelling located in the Fremantle suburb of Hilton, Western Australia. Built in 2013, the home achieved a 10 Star NatHERS rating (i.e. <4 MJ/m^2 per annum) using volume building industry construction methods, materials and trades, demonstrating that high-performance houses can be delivered for little or no extra cost in Perth's climate (NCC climate zone 5; NatHERS climate zone 52).

The house design is based on well-established solar passive design principles (Byrne et al. 2019b) to ensure maximum thermal comfort year-round, with no air conditioning or artificial heating requirement. Key climate responsive features include east-west orientation of the building envelope with maximum glazing to the north for winter solar gain (shaded in summer) and minimal glazing to the east and west to minimise summer heat entry. Effective use of thermal mass inside the home including 'slab on ground' construction, reverse brick veneer perimeter walls (east and west) and brick internal walls help to stabilise internal temperatures. Careful consideration was given to internal room layout and window apertures to ensure good cross ventilation for summer night time heat purging. The thermal shell incorporates climate zone appropriate insulation values to roof and walls to minimise uncontrolled heat loss/gain, low-E glazing, and pelmeted curtains on the windows to reduce heat loss in winter.

The result is a highly thermally efficient home providing high levels of comfort throughout the year (Josh Byrne & Associates 2014). Energy and water efficient fixtures and appliances, combined with onsite power generation, rainwater harvesting, and greywater recycling all contribute to the environmental performance of the home (Eon & Byrne 2017).

What makes this case study unique is that in addition to operating as a family home for two adults and two young children, it has also functioned as a 'living laboratory' (Morrison, Eon & Pickles 2017) for applied research on high-performance housing, as well as providing opportunities for industry and community engagement. Detailed performance monitoring has been undertaken over five years via a carefully planned network of sensors and meters (Eon & Byrne 2017) enabling close scrutiny of the home's thermal performance and household energy and water consumption. This period of data collection spans three distinct stages that relate to changes in the home's energy supply infrastructure and major fixed appliances that were made in response to the availability of innovative technologies and emerging consumer trends. These are described in Table 8.2. The energy use (by load), the energy source and the subsequent calculated GHG emissions for each stage from operational data across these respective stages is presented in Fig. 8.2.

The energy source for the original house design included both grid connect electricity and reticulated natural gas to service the gas cooktop and instantaneous gas booster for the solar-thermal hot water system. The PV system was sized for the home to operate as a NZEH, that is, it was designed to meet or exceed net household operational energy requirements over the period of a year, including offsetting natural gas usage. At the time of designing the home (in 2012), this was considered a pragmatic and cost-effective approach in keeping with the volume market demonstration intent of the project.

The Stage 1 PV system configuration didn't include battery storage. Annual energy demand for the household during this period was 3148 kWh, compared with the local area average of 6570 kWh (Josh Byrne & Associates 2014). Energy demand was met with 35%

Table 8.2 Energy system and major fixed appliance upgrades at Josh's House 2013–2018

Stage	Cooktop	Hot water	PV system	Battery storage	Other
Stage 1: 2013–2014 Original design	Gas	Solar thermal with gas booster	3 kW PV 2.5 kW inverter (grid connected)	None	NA
Stage 2: 2015–2017 Inclusion of battery	Gas	Solar thermal with gas booster	3 kW PV 2.5 kW inverter (grid connected)	8 kWh lithium chemistry based battery	NA
Stage 3: 2018+ Solar-electric upgrade (gas disconnected)	Induction	Heat pump	6.4 kW PV 5 kW inverter (grid connected)	10 kWh lithium chemistry based battery (upgraded)	Electric vehicle introduced and charge point installed

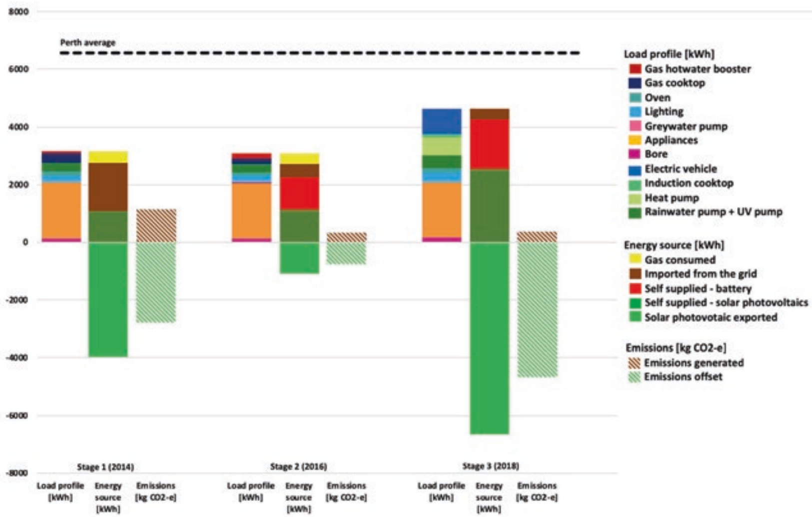

Fig. 8.2 Energy use by load, energy sources and related GHG emissions for Josh's House over three stages of energy system and fixed appliance configuration

self-supply from PV, 52% from grid and 12% from gas. Annual PV export was 3970 kWh, or 78% of total production. Total calculated annual GHG emissions from household operational energy use was 1157 kg of CO_2-e, which was offset by 140% or 2779 kg of CO_2-e by exported solar.

Stage 2 was marked by the introduction of a LiPO battery (BYD DESS 8kWh), representing the first residential grid-connected lithium chemistry-based battery on the South West Interconnected System (the regional electricity network). The objective was to increase the amount of self-supplied energy by storing surplus PV electricity produced during the day for use at night. All other energy infrastructure items and appliance remained the same. Self-supply (PV plus battery) represented 73% of demand (an increase of 38% from Stage 1). GHG emissions reduced by 71% to 332 kg of CO_2-e, and grid export reduced by 71% to 474 kWh as the result of the increased self-consumption enabled by the battery, plus losses due to the parasitic load of the specific battery product (Byrne, Taylor & Green 2017).

Stage 3 upgrades involved replacing the gas stove with an induction cooktop and substituting the gas boosted solar hot water system with an electric heat pump, negating the need for the reticulated gas service. One of the two household cars was replaced with an electric vehicle (EV) (Mitsubishi iMiev) and a domestic charging point was installed in the garage. The PV system was increased to 6.4 kW of PV with a 5 kW inverter, with sizing calculated to cover the anticipated load of the now 'all-electric home' plus cover the net energy requirements of two EV's (the current one and a second in the future). The battery was also upgraded to more contemporary model (LG Chem Resu 10) to eliminate the parasitic load issue. The heat pump hot water system was programmed to operate during the middle of the day and, when practical, the EV was charged during the day to utilise available PV electricity.

In Stage 3, household operational energy usage increased by 50% to 4628 kWh, including 19% (or 867 kWh) for EV charging. Self-supply was 92%, made up of 59% PV and 41% battery. Grid import was 367 kWh and export was 6647 kWh. The inclusion of a second EV (as intended in the system sizing) will reduce this figure. The retail cost for the Stage 3 upgrades was $31,000 (excluding EV). Annual household financial savings from reduced energy bills, fuel costs (realised from the use of the EV), plus feed-in tariff is around $3500, resulting in a payback period under nine years.

Mainstreaming Net Zero Energy Homes: Z-Range Display Home—Melbourne, Victoria

During 2017 and 2018, a national research project was run by the CRC for Low Carbon Living to better understand the cost barriers and market interest in NZEH. The project, 'Mainstreaming NZEH' involved recruiting major land developers and their nominated volume builders to build NZEH display homes in new developments in different locations around Australia, representing different climate zones and different markets. Partners were recruited in Townsville (Stockland and Finlay Homes), Canberra (Riverview Group and Rawson Homes), Melbourne (Parklea and SJD Homes) and Perth (Mirvac and Terrace).

The project approach began with a collaborative design review workshop involving each set of partners with the aim of methodically working through the required steps to make a builder's nominated display house design meet ZEH status. The workshops included the builder, building designer and cost estimator, along with developer representatives and members of the research team.

The pre-existing display house design presented by the builder was considered a BAU (or baseline) scenario and proposed energy improvements were allocated into three alternative scenarios according to their ease of implementation and cost-effectiveness, with costs provided by the builder. Principles of passive solar design (e.g. appropriate glazing, insulation, ventilation, thermal mass, shading, orientation) guided the first part of the conversation, which was followed by a discussion about energy efficient options for appliances and lighting, and finally the inclusion of PV and batteries.

Design modifications were modelled using CSIRO's AusZEH Design Tool (Ren et al. 2011) which combines a thermal energy simulation model, a projection of energy used for lighting, water heating and major household appliances, and house occupancy profiles. The software SAM (System Advisor Model), developed by the U.S. National Renewable Energy Laboratory (NREL), was employed to determine adequate PV sizes to cover annual energy demands for each of the three modelled scenarios under specified occupancy patterns. This software predicts hour-by-hour PV electricity production based on variables such as house location and associated solar radiation, the size of the PV system and inverter (NREL 2014).

In all four cases, energy efficiency gains were obtained mainly from additional insulation, glazing upgrades and energy efficient appliances (hot water systems and air conditioners in particular). In addition, only a relatively small sized PV system was required to cover the modelled net energy demand, provided that the building envelope was designed appropriately for the climate and the appliances were energy efficient (Byrne et al. 2019a). The Z-Range Display Home by SJD Homes in Officer, south east of Melbourne, is provided here as a working example.

Completed in late 2018, the four bedroom, two bathroom house was designed as a ZEH with relatively minor modifications to the building fabric, specifically additional ceiling and wall insulation, double glazing, thickened slab for increased thermal mass and inclusion of internal sliding doors for conditioned space zoning. Appliance upgrades included split system reverse cycle air conditioning to replace ducted gas heating and a heat pump hot water system and induction cooktop, eliminating the need for reticulated gas and enabling the timed use of appliances with available PV energy. The design modelling indicated a 4 kW PV system would be adequate to make the home ZEH under typical occupancy (Ren et al. 2011).

Costings provided by the builder for the upgrades needed to meet this performance benchmark totalled \$19,750, representing an 8% increase in the house price, originally set at A\$247,900. The projected payback period is around 10 years based on an estimated savings of \$1,780 on energy bills per annum, assuming a 2.5% annual energy price increase and the continuation of the A\$0.099/kWh solar feed in tariff as shown in Fig. 8.3.

As well as being an active display home for SJD Homes, visitor surveys are being conducted to gain insights into market interest in high-performance housing. The house also serves as a demonstration site for the New Home Energy Advisory Service program run by the South East Councils Climate Change Alliance (SECCCA) in partnership with Sustainability Victoria. The Townsville display home has also

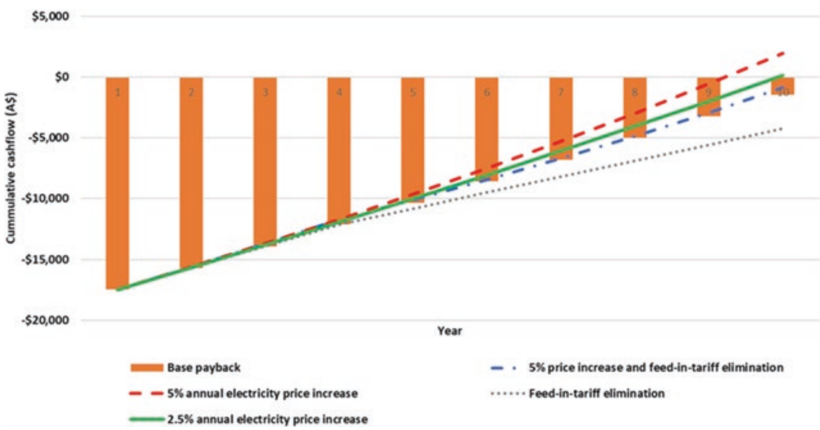

Fig. 8.3 Estimated payback period scenarios for the ZEH upgrades for the Z-Range display home

been completed and is operating as the Stockland's sales office for the display village, whilst also participating in the consumer survey phase. Construction of the Canberra and Perth NZEH display homes are scheduled for early 2019.

Scaling Up: WGV Precinct—Perth, Western Australia

WGV is a 2.2 ha medium density residential infill development in the Fremantle suburb of White Gum Valley led by the Western Australian State Government Development Agency, LandCorp. Located on a former school site, the land availability provided a unique opportunity to take a precinct approach to the design and delivery of the development. WGV accommodates a diverse range of building typologies (detached houses, group houses and apartments) and incorporates climate sensitive planning considerations, innovative water management and creative urban greening strategies (Byrne, Green & Dallas 2018). The precinct will eventually include around 100 dwellings and as of early 2019, is approximately 60% complete.

As a LandCorp 'Innovation through Demonstration' project, WGV is being used as the basis for several concurrent research programs designed to explore novel approaches to urban densification, affordable housing and sustainable development in 'middle suburb' areas. These include a four year 'living lab' research project supported by the CRC for Low Carbon Living, an ARENA funded study into strata-body operated solar energy storage, and an industry-led initiative that showcases the urban water initiatives.

WGV is targeting 'net zero energy' status, meaning the precinct has been planned with the aim of generating as much energy as is used for operating dwellings, balanced over the year. This will be achieved through a combination of energy efficient building design, coupled with rooftop solar energy generation and battery storage in the multi-residential buildings.

The development model at WGV is one where LandCorp (as the developer) develops the land, including managing development scale planning approvals and undertakes site-wide civil works before offering 'construction ready' lots to the market. The larger lots intended for multi-residential buildings are typically sold following a call for expressions of interest from the market where proponents respond to specific criteria, including any building performance or broader sustainability requirements. Lots designated for detached housing are typically sold directly to the public, who then engage a builder to construct a home. In some instances, an architect may be involved, but often the design is handled by the appointed building company. The use of Design Guidelines as a means of facilitating the construction of energy efficient houses on these lots is the focus of this case study, as an example of how the types of energy efficiency initiatives identified earlier in the chapter can be rolled out at greater scale.

Table 8.3 presents the mandatory energy-related initiatives for the detached lots at WGV. These are known as 'Design Controls' and are seen as the minimum requirement for developer endorsement prior either Planning Approval or Building Licence application to the Local Government Authority. In addition to Design Controls, the Design Guidelines at WGV for detached houses include 'Design Guidance'. This represents advice only and is typically at or above 'good practice', and where the uptake of such initiatives, while desirable from the

Table 8.3 Design guideline design controls & developer incentives

Item	Requirement/incentive support	Review/approval stage
Dwelling design	Over shadowing, orientation, layout and cross ventilation assessed pre development application	Pre-planning approval
Thermal comfort	Minimum 7 star (i.e. <58 MJ/m^2 per annum)	Building licence
Renewable energy	Minimum 1.5 kW Incentive: Upgraded to 3.5 kW via developer contribution	Building licence
Water heating	Solar thermal or heat pump (minimum 5 stars)	Building licence
Air conditioning	Reverse cycle (minimum 3 star)	Building licence
Drying court	Mandatory	Building licence
Landscaping	Space allowance for shade trees Incentive: Advanced shade tree via developer contribution	Building licence

perspective of optimising the performance of a building, may be expensive and therefore be resisted by the market.

In addition to the Design Guidelines at WGV, LandCorp provided a 'Developer Sustainability Package' as an incentive and engagement strategy for lot purchasers. The initiatives, which included the upgrading of the minimum required PV system of 1.5 kW to 3.5 kW (the size estimated to make the homes NZEH), as well as the supply of an advanced shade tree of a suitable species (deciduous or evergreen depending on the location of planting in relation to the house design), and a rainwater tank and pump to compliment the mandatory dual plumbing for rainwater to supply the toilets and washing machines. Table 8.3 presents the Design Controls mandated under the WGV Design Guidelines against the relevant stage of dwelling planning and building licence approval, as well as the energy-related incentives provided under the Sustainability Package.

Figure 8.4 presents the results of energy demand modelling and estimated GHG emissions for an 'As Built' scenario for detached dwellings at WGV, compared with 'Compliance' based performance for a new, comparable size dwelling in the same area. The As Built assumptions are based on the implementation of the WGV Design Controls and Sustainability Package initiatives outlined above, adjusted for what has been built on site at the time of modelling (Kinesis 2019). This includes 7 star NatHERS thermal performance (i.e. <58 MJ/m^2 per annum), a mix of mix of hot water systems, including solar thermal (both electric and gas boosted), along with the specified 3 star air conditioner and LED lighting requirements, and an average PV system size of 3.6 kW. The Compliance results are based 6-star NatHERS thermal performance (i.e. <70 MJ/m^2 per annum), gas hot water heating, standard air conditioning (2-star, single phase), and standard lighting. No PV is accounted for.

The estimated annual operational energy demand for the Compliance case on a per dwelling basis is 5362 kWh, made up of 4645 kWh of grid electricity and 717 kWh of natural gas (or 2581 MJ). The resultant calculated GHG emissions is 3753.4 kg CO2-e.

The 'As Built' case shows a reduction in overall operational energy demand of 16% from the Compliance case resulting from improved

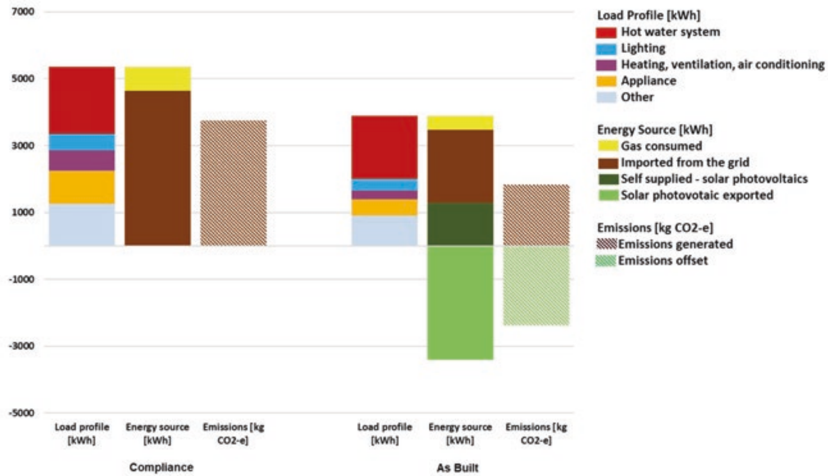

Fig. 8.4 Projected annual dwelling energy demand by load, plus energy sources for the detached lots at WGV, alongside Compliance case. Estimated GHG emissions for each scenario is also provided

performance across hot water heating, space heating and cooling, lighting and appliances. The energy make-up is expected to be 32% self-supply from PV, 56% grid and 11% gas. PV export is expected to average 3402 kWh/year, which equates to 156% of annual import. The calculated GHG emissions is 1531 kg CO2-e offset by 156% by the surplus PV export.

Performance monitoring of individual detached dwellings is now underway at WGV (along with the monitoring of other typologies) with early data supporting the modelling predictions.

Conclusion

The CRC's living laboratories are demonstrating pathways to transition to NZEH. The evidence documented at these highly innovative residential developments is showcasing different technical solutions, identifying a wide range of private and societal benefits, and validating the economic viability of the transition.

Most importantly, these living laboratories have been instrumental in documenting the user experience of NZEH, finding that residents appreciate the improved levels of thermal comfort, lower energy bills, and associated health and well-being benefits.

The ramifications of inaction are exposed by the wealth of documented evidence. The lack of policy action means lost opportunities to improve electricity network security, to reduce the impact of peak energy loads, to improve the resilience of homes to extreme weather events such as heat waves, to improve levels of thermal comfort for occupants, to improve the overall affordability of housing to owners and renters, to improve energy productivity, and reduce global carbon emissions.

These living laboratories have documented the benefits of pushing beyond industry norms, exciting the market for better housing, mainstreaming innovative technologies and scaling up to mass production. Net zero housing is significantly better for the residents, the local economy and energy networks, and can play an important role in helping Australia meet its international climate change commitments. Due to these and other demonstration projects Australia is well placed to transition to a low carbon housing sector.

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9

Decarbonising Commercial Buildings

Philip Oldfield, Roger Swinbourne and Kriston Symons

Introduction: Current Trends and Performance

Commercial buildings make up an estimated 163 million square metres (net lettable) of building stock in Australia, with growth occurring at around 2.5 million square metres per year between 1999 and 2020 (Commonwealth of Australia 2012). The commercial building sector is also a major contributor to national carbon emissions; while the building sector as a whole is responsible for 23% of Australia's carbon

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emissions, 44% of this is due to commercial buildings (42% commercial electricity; 2% commercial fuel) (ASBEC 2016).

The commercial office building sector in Australia has long been a global leader in setting itself targets and achieving them. New building standards and improved energy efficiency, for example, is estimated to have contributed to a 32% reduction in carbon emissions from new-build office buildings between 2002 and 2012 (Climateworks 2013). Beyond this, the Australian listed real estate investment trusts are leaders in sustainability across their property portfolios, as recognised by GRESB for the past eight years (Bleby 2018). While codes and standards represent the minimum legal requirements for building design in terms of carbon performance, the private sector very much operates at the opposite end of the spectrum, seeking to continuously improve on previous projects and differentiate their buildings from others in a competitive leasing environment (Fig. 9.1). For example, many of Australia's leading property trusts have committed to being carbon neutral by 2030 across their property portfolios (GBCA 2018a).

This chapter explores the decarbonisation of existing and new Australian commercial office buildings. In doing so, it firstly summarises

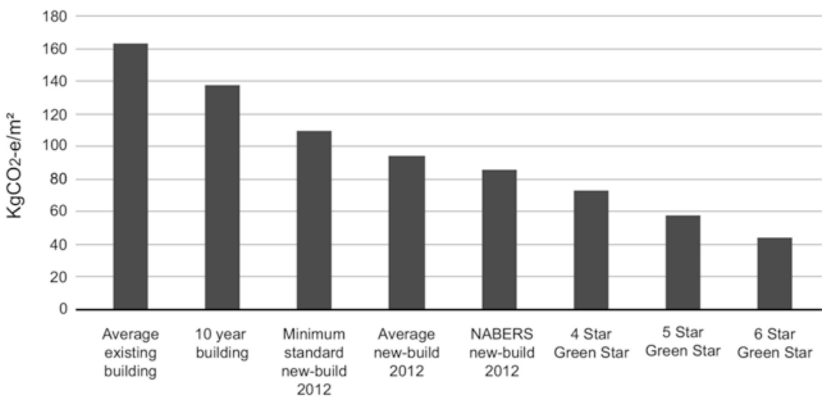

Fig. 9.1 Comparison of Australian office operating carbon emissions in 2012: best performance, fuelled by a competitive market, is achieved far beyond minimum standards (*Source* Author, drawn from data provided in Climateworks 2013)

government frameworks and rating systems to outline targets, pathways and strategies that have already been put in place. It then highlights opportunities for commercial building design teams to reduce operating emissions under the headings of 'energy efficiency', 'active technologies' and 'grid decarbonisation'. Specific challenges to the commercial building industry are presented, along with additional considerations in terms of embodied carbon and precinct level carbon reduction. The chapter concludes by identifying key areas where industry focus is necessary to accelerate the decarbonisation of the commercial building sector beyond current trends.

Government Frameworks

Commercial Building Green Rating Systems: Green Star and NABERS

In 2002 the Green Building Council of Australia (GBCA) created a peer-assessed industry benchmark rating tool for the design of green buildings called Green Star, with the objective of cutting through 'greenwash' and unsubstantiated claims from developers and consultants at the time. Since then, the Green Star rating has become the norm when designing a new office building with over 2000 buildings rated over the 16 years. In 2017, the GBCA and the International WELL Institute agreed to work collaboratively and interest from landlords and tenants in achieving a WELL Rating has increased over recent years. NABERS, the benchmark for assessing the energy consumption and carbon emissions of a building, has evolved from a voluntary rating to being mandated for any office building sale or lease over 1000 m^2. Its impact has been significant as over 20 years of operation, the NABERS rating tool has contributed to the reduction of 830,000 tonnes of carbon emissions (NABERS 2018a).

In 2018, the GCBA released its 'Carbon Positive Roadmap' with industry consultation and support for the next version of Green Star to move towards carbon neutrality. It states 'these requirements will include high levels of energy efficiency, use of 100 percent renewable energy from both on-site and off-site sources; and the avoidance of all fossil fuels' (GBCA 2018b). This applies for new commercial office buildings by 2030 and existing office buildings by 2050. This pathway creates a clear signal for industry on the direction that the GBCA is heading. As shown in the past, industry will respond, innovate and adapt to achieve these targets.

National Construction Code Focus

The National Construction Code (NCC) states minimum requirements for energy efficiency of buildings. This is revised every three years, and a great deal of effort and advocacy has gone into advising the Government that a clear pathway for the Code through to 2030 to achieve carbon neutrality is important for industry, designers, contractors and suppliers, to prepare, respond and deliver.

The latest ASBEC report *Built to Perform* provides a clear trajectory, calling for changes to the NCC in 2019 and the inclusion of a clear pathway for further updates towards carbon neutral buildings (ASBEC 2018). The report suggests designing for energy efficiency through simple strategies such as increased insulation, improved equipment efficiencies, better air-tightness and switching gas heating to electric heat pumps could save between 22 and 32% of a typical office building's energy use by 2030, as compared to the 2016 NCC. The figures are between 34 and 38% in a retail scenario. In addition, it suggests the remaining 'gap to zero' can be met by a mix of best practice design, onsite renewable energy generation, improved appliance efficiency, and the future decarbonisation of grid electricity. For onsite renewables, it is suggested these could meet 28% of the energy needs of a typical office building, and 67% of the needs of a retail building (ASBEC 2018).

Opportunities for Carbon Reduction

Some of the simplest design solutions can have a significant impact on the reduction of carbon emissions in Australian commercial buildings. Since most energy used in commercial buildings comes from HVAC

(43%), followed by lighting (20%) and equipment (13%), strategies to reduce energy loads in these areas are of particular value (ASBEC 2016).

Energy Efficiency

Passive Design Principles

The importance of following 'first design principles' in the creation of commercial buildings is of paramount importance. Designing with solar orientation in mind, use of appropriate insulation for climate, improving air-tightness and shading glazed facades should be first considerations. Given that commercial buildings have high internal heat gains, they are often cooling dominated, so strategies to reduce over-heating, and unwanted heat gains are of value—especially in a warming climate, with increasing heat waves. Once the passive design elements are optimised the active elements should be considered including efficient air conditioning systems, hot water and lighting. Finally, potential renewable energy sources can be explored. Renewable energy in commercial buildings is most commonly provided onsite by solar panels on the roof and offsite through carbon offsets and power purchase agreements.

A framework to consider is the *Carbon Cost Hierarchy Pyramid* (see Fig. 9.2). Effectively, this suggests that key principles such as optimising building form and fabric are more effective at reducing carbon and more cost efficient than renewable technologies in the first instance; as such, form and fabric should be the first design drivers to a low carbon solution (Harrington 2016).

Air-Tightness

The commercial building sector in Australia has been gradually warming to the idea that air tight building envelopes can offer energy savings, air quality and thermal comfort benefits. Increased industry awareness in recent years has been driven by a combination of

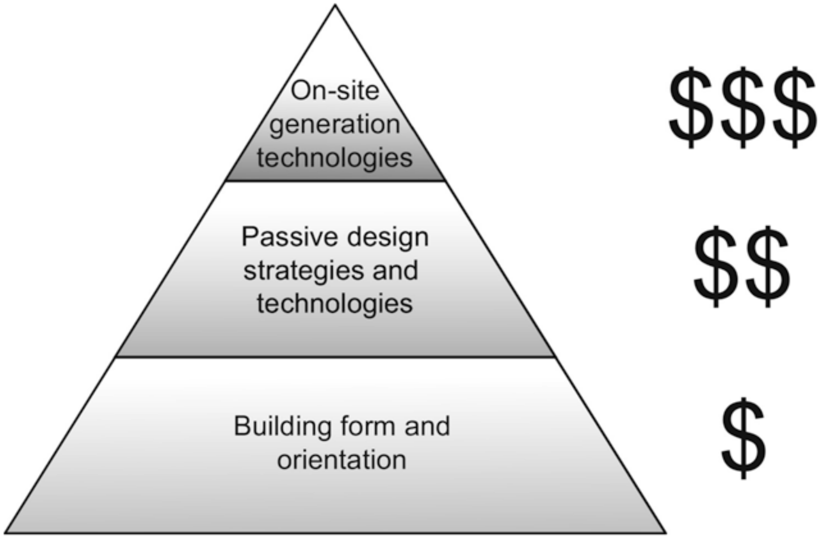

Fig. 9.2 Carbon cost hierarchy pyramid (*Source* Author, adapted from a graphic by Faithful + Gould in Harrington 2016)

minimum compliance, sustainable design ratings and issues with performance.

While there is little research on air-tightness performance in Australian commercial buildings, a sample of seven offices in Victoria provided an average air permeability of 13.4 m^3/hm^2 @ 50 Pa (McLauchlan et al. 2016). Good practice suggests figures in the region of 3.5–7.0 m^3/hm^2, with best practice closer to 2.0–3.5 m^3/hm^2 @ 50 Pa (GBCA 2015)—although this will differ based on both climate zone, and the building's ventilation strategies.

In 2013, Green Star first introduced air leakage testing as an innovation challenge with one point awarded for undertaking a whole building test and sharing the data to educate the industry, with a second innovation point awarded for achieving best practice levels defined in the UK building code. The most recent version of Green Star (Design and As-built v1.2) now requires air tightness tests as part of the commissioning credit.

From 1 May 2019, air-tightness testing will be required to achieve minimum compliance through inclusion in the rewritten National Construction Code, although it is limited to particular climate zones and building types.

Increasing the Range of Temperature Band

Increasing the temperature band one degree each way from a range of 20–24 °C, will reduce energy consumption of the air conditioning system and hence carbon emissions of the building. The rule of thumb is every one-degree reduction in setpoint can save 10% of energy usage. There would also be a need for occupants to dress up or down accordingly with the external ambient conditions. But this benefits in reducing thermal shock between internal and external temperatures as occupants move between buildings.

Use of Mixed Mode Air Conditioning Space

The use of openable windows and the design of tenancy spaces to facilitate zones of winter gardens or mixed mode conditioning areas where occupants can connect with nature and at the same time reduce building energy usage should be considered when designing workspaces. With advances in façade technologies, any building can be designed or retrofitted to include such spaces.

Agile Working, Flexible Working or Activity-Based Working

The adoption of various forms of flexible working by employers, along with advances in mobile phone and internet technologies provides a great opportunity for office space to be designed differently. With more employees working from home, staggering employee hours, or choosing furniture and desk solutions that suit their work needs, there is less reliance on traditional layouts permitting more flexible spaces to be created, such as common areas and winter gardens.

Active Design Technologies

Air Conditioning Ventilation Systems

Air conditioning solutions have evolved over the past ten years with many new office buildings utilising active and passive chilled beams or underfloor displacement air conditioning. Initially these systems were required in order to obtain high NABERS ratings above 4.5 stars. However, over time it has been realised through energy modelling and operation that variable air volume air conditioning systems are more than capable of achieving 5.5 stars and beyond. Any risk in achieving the rating has been met with back-up micro-turbine cogeneration systems for minimal cost—less than the cost difference for chilled beam solutions or underfloor displacement systems.

Thermal Plant

Cooled chilled water systems have been the preferred solution for greatest energy efficiency. However, depending on the overall NABERS aspirations of the building, high technology screw chillers and air-cooled plant are capable of comfortably meeting 5 Star NABERS. The need for greater aspirations in targeting high NABERS ratings, either through tenant demand or government guidelines, will continue to ensure the most efficient thermal cooling plant is utilised, maximising the ability for onsite renewables to offset building electrical loads.

There is a trend towards considering all electric buildings and either designing for all electric energy, taking advantage of a decarbonised grid, or having a pathway to replace gas plant at the end of its commercial life with electric plant. In commercial office buildings, this is focused on the hot water boiler plant that serves both the heating system and domestic hot water used in sinks and basins.

Lighting Systems

LED lighting has become the norm for office lighting with increased functionality over the years in terms of controls and dimming. Many older buildings are having lighting upgrades undertaken to replace fluorescent lights with LED benefitting from short payback periods. The future trend is towards more task-based lighting solutions that give users more control over their preferred lighting solutions. In addition, the use of motion and daylight sensors result in lighting levels turning down or off when not required, saving energy and associated carbon.

Renewable Systems at the Building Scale

The primary use of renewables on commercial buildings has been solar photovoltaic (PV) panels or solar hot water panels on the roof. Many new buildings integrate these technologies, while many existing buildings have them retrofitted.

The cost reduction of PV cells across the industry has led to commercially acceptable short payback periods for buildings owners and accelerated uptake. This provides a point of difference for the building in attracting tenants but also enables industry designers and contractors to become familiar with the technology and installation strategies. Familiarity is important in the construction industry and less uncertainty is met with less pricing risk and hence better value pricing assisting payback period and cost-based justifications for the application of new technologies.

It is worth noting, that generally, roof mounted solar photovoltaic systems can only supply enough electricity to serve three floors of a building, so commercial buildings of any greater height will require different renewable energy solutions and most likely use offsite carbon offsets solutions.

There have been a few instances of roof mounted wind turbines however cost and performance has meant to date that take-up of this type of building technology has not become widespread.

Decarbonisation of the Electricity Grid

The decarbonisation of the electricity grid is an important consideration in the design and retrofit of commercial office buildings. Figure 9.3 shows the reduction in carbon intensity of the electricity grid over the

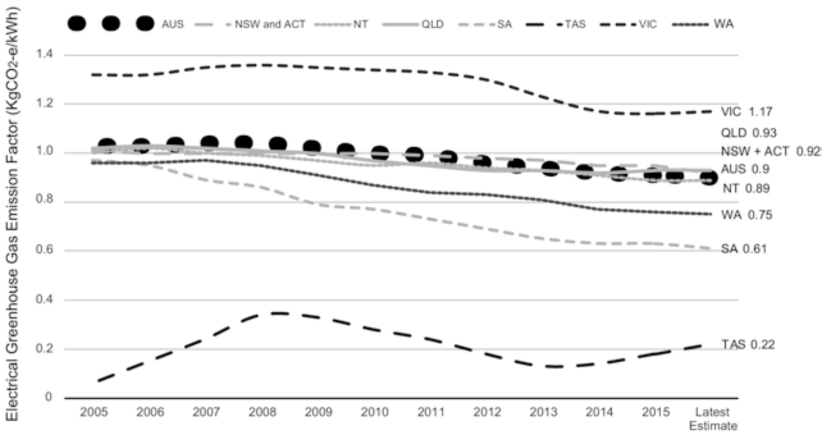

Fig. 9.3 Carbon intensity of delivered electricity (*Source* Author, drawn from data provided in Commonwealth of Australia 2018)

past ten years by state. It is expected that the carbon intensity of electricity will drop rapidly across many states in the coming years, as substantial wind and other renewable energy sources comes online.

As the electricity grid decarbonises the use of gas for heating and other purposes in a building becomes more carbon intensive than utilising electricity. Hence many buildings are being designed as all electric, moving away from gas as a fuel; or are at least providing provision for future conversion from gas to electric at a suitable point in time.

Figure 9.4 shows the tipping point has been reached across Australia (noting that some variation does exist by state) where the carbon intensity of air source heat pumps is lower than natural gas condensing boilers; hence from a carbon perspective, moving away from using gas for hot water generation can achieve the optimum outcome.

Challenges to Carbon Reduction

There are a number of challenges in the commercial building sector that make achieving greater reduction in carbon emissions difficult. We highlight a few of these below:

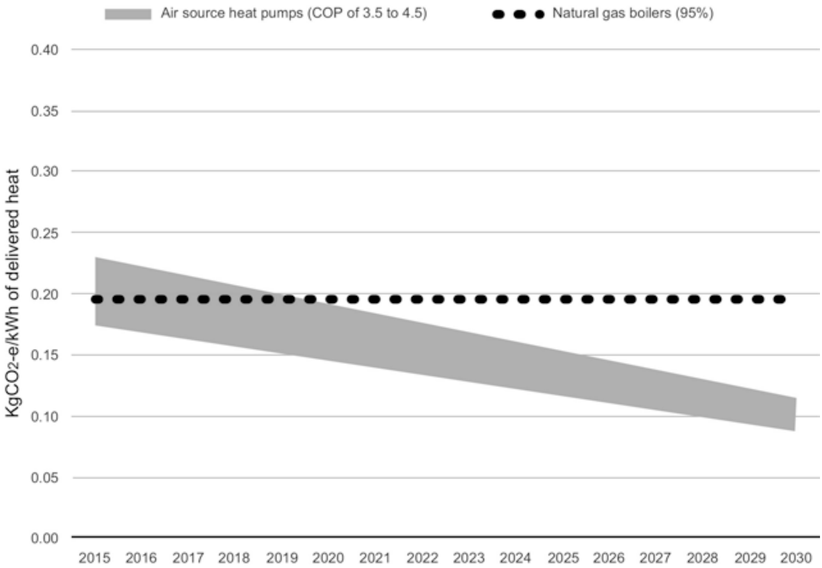

Fig. 9.4 Carbon intensity of air source heat pumps versus natural gas condensing boilers

Split Incentive Between Tenants and Landlords

The nature of the commercial office building sector is that landlords develop and own buildings and seek tenants for the available net lettable area in the building. However, once the lease is signed between the tenant and the landlord, normally for an industry standard duration of ten years, there is little incentive for each party to improve the building efficiency or reduce carbon emissions. This leads to locked in performance of the building for at least a decade. Initiatives such as the Cityswitch programs (which educate tenants on what they can do to improve their carbon emissions) and Environmental Upgrade Agreements (EUAs) (a building upgrade finance mechanism that allows a landlord to agree with the tenant to upgrade parts of the building and provides a low interest rate secured on the property statutory title) have assisted in undertaking building upgrades. EUA's enable the building owner to benefit from the savings with protection for the tenant through a 'no worse off' mechanism.

Regular communication between landlords and tenants around a joint vision to reduce carbon emissions and discuss each party's respective mechanisms under their control is important. Some upgrade initiatives such as air conditioning controls, lighting systems, metering and solar panel installations can benefit both the tenant and the landlord if discussed and worked through with a common vision for the building.

Green Leases

Many building tenants require the landlord to provide a base building that achieves a certain NABERS rating in relation to energy usage. However, few of these leases exert onus on the tenants to achieve a tenancy NABERS rating. With the introduction of the Commercial Building Disclosure program, most landlords will be required to report the NABERS rating of the building on an annual basis. However, there is no such requirement for tenants who generally use around 50% of the building's electricity. Improving tenant awareness and embedding a variety of environmental initiatives in the workplace including energy efficiency will assist in reducing overall carbon reduction initiatives of the commercial building sector.

Air Conditioning—Heating and Cooling

Air conditioning is the most energy-intensive part of a commercial building, and as such, the design of the air conditioning system is a critical component to achieving the buildings NABERS rating but also to occupant comfort.

The use of mixed mode ventilated spaces has not been taken up to any significant extent in commercial office buildings in Australia; however, that is starting to change. The more flexible, interactive and openable the facades of buildings are, the easier it is to design for mixed mode air conditioning. Creating spaces on the perimeter of a floor plate that allows the heating and cooling to be turned off when ambient conditions are suitable, not only reduces emissions but also provides an opportunity for occupants to connect with the external environment.

These spaces tend to be great locations for planting, improving occupants' wellbeing and satisfaction with the buildings they occupy during working hours.

The challenge is current trends in commercial building design are towards larger floorplates meaning there is greater internal areas versus perimeter envelope, and hence less opportunity for mixed mode air conditioning. In addition, leases between landlords and tenants have a fixation for temperature control bands generally in the region of 21.5 °C ± 1.5 °C. Relaxing this one lease clause creates a great opportunity for the commercial building space across Australia to reduce carbon emissions.

Existing Small and Medium Commercial Office Building Stock

Retrofitting existing commercial buildings represents very different challenges to the design of new buildings. A report by City of Melbourne in 2013 titled *The Next Wave* and an update in 2018 titled *The Next Wave Refresh* highlights the opportunity that upgrading small- and medium-sized commercial building stock has in reducing carbon emissions. Acknowledging that the large listed property trusts generally have achieved higher levels of energy performance across Premium and A-Grade PCA rated commercial office space, the B, C and D Grade stock has not achieved the same outcomes (Sustainability Victoria 2018).

Embodied Carbon Emissions in Commercial Buildings

The carbon impact of buildings is not only due to their operation—their heating, lighting, ventilation and appliances. Buildings also contribute towards significant GHG emissions through their materials, construction and eventual demolition. This is known as embodied carbon. A building's *initial embodied carbon* refers to the carbon emissions caused by the extraction of the raw materials, their fabrication, transportation and installation in the initial creation of the building. *Recurring embodied carbon* refers to the emissions from maintaining, replacing and retrofitting the building over its effective lifecycle (for more on this, see Chapter 7).

The materials we use in commercial buildings have a significant impact on the environment. Cement, for example, is responsible for 8% of all global carbon emissions—a figure which is higher than total emissions from every country, bar the USA and China (Andrew 2018; Rodgers 2018). Historically, most environmental design thinking has considered embodied carbon to contribute around 20% of a building's total carbon footprint, with 80% from operations (Kestner 2009). However, in more recent years research has suggested this can be much higher—closer to 45% embodied and 55% operational for a high-performance office building (Sturgis and Roberts 2010). The problem is reducing a building's operational carbon emissions almost always requires additional embodied carbon. This can be in the form of extra insulation, aluminium to create solar shading, additional layers of glazing, etc.

One of the challenges with our current thinking in terms of getting 'down to zero', is that most definitions of 'net zero energy', or 'carbon neutral' exclude embodied emissions. For example, the *Australian National Carbon Offset Standard for Buildings* only considers operational carbon emissions, and not embodied carbon—although this may be considered in future versions (Commonwealth of Australia 2017). A building that achieves carbon neutrality in operations will still have a significant carbon impact due to its embodied emissions; in fact, its embodied carbon will likely be much higher than a typical building due to the additional materials and systems needed to achieve such a high performance. It is therefore vital for the design team to holistically consider carbon emissions across the full *lifecycle* of a commercial building. For example, changing a building's structure from a concrete frame to mass timber at the design stage would likely significantly reduce its carbon footprint—but this would not contribute towards its ability to meet carbon neutrality under current definitions. On the other hand, installing building integrated wind turbines would contribute towards achieving carbon neutral status, even if only a little. Yet wind turbines would likely save far less carbon than the use of structural timber if considered holistically over a building's life (Oldfield 2019).

While there are very few building regulations that govern the reduction of embodied carbon emissions, standards and definitions are changing. In Norway proposals have emerged to consider embodied carbon emissions as part of a new framework for defining zero energy performance in buildings (Fufa et al. 2016). In Australia, *The Carbon Positive Roadmap* proposes that all new 6 Star Greenstar rated buildings will need to demonstrate a reduction of embodied carbon of 10% against a reference building by 2020, and 20% by 2023. The aim is for this to be expanded to all new buildings by 2030 and 2035 respectively (GBCA 2018b).

While figures of embodied carbon can vary significantly based on geography, building type, materials and calculation methodology, a new office building in Australia will likely have an initial embodied carbon in the order of 400–1200 $KgCO_2$-e/m^2GFA. One benefit of reducing this is that carbon savings would be instant, made prior to the building being built—as opposed to operational savings which can take years to accumulate. Some key strategies to reduce embodied carbon in commercial buildings include:

Structural Optimisation

Structural materials are the greatest contributor to embodied carbon in most commercial buildings. As such, strategies to optimise a building structure and dematerialise its concrete and steel can contribute to significant savings. A growing trend is the use of timber as a structural material in Australian commercial buildings, with examples including International House in Sydney and 25 King in Brisbane (see Fig. 9.5). This trend will likely accelerate with a 2016 change to the National Construction Code (NCC) allowing timber buildings up to eight storeys without the need for costly additional approvals. Timber has a benefit over steel and concrete given that wood sequests carbon during its lifecycle; a cubic metre of wood will absorb on average 787 kg of CO_2-e

Fig. 9.5 International House, Barangaroo. Timber as a low carbon structural material in multistorey commercial buildings (*Source* Tzannes Associates, with permission)

during its life. If sustainably sourced, timber can therefore significantly reduce building emissions. Research by Teh et al. (2016), found that if all new commercial buildings built in Australia used timber, by 2050 carbon savings would be in the order of 13 MtCO_2-e without sequestration, or 28 MtCO_2-e including sequestration.

Passive Design

Mechanical systems and services are often the second greatest contributor to embodied carbon in commercial buildings (Oldfield 2012). While embracing passive design can have an embodied carbon cost—i.e. through additional insulation, shading, layers of façade, etc.—passive design can reduce air conditioning and other servicing requirements, along with plant machinery and ducting. This can therefore reduce carbon intensive materials such as steel, copper and aluminium.

Cement Replacement

Given the large carbon impact of cement, strategies to replace this in commercial buildings are beneficial. Replacement products including the use of Fly Ash or Ground Granulated Blast Furnace Slag (GGBFS) are commonplace.

Adaptive Reuse

While 51% of the building stock standing in Australia in 2050 will be completed after 2019 (ASBEC 2018), existing buildings still need to be retrofitted and upcycled rather than demolished. A radical reimagining of the commercial building stock is possible, not only to improve operational carbon performance and thermal comfort, but to save embodied carbon too. The Quay Quarter Tower in Sydney, for example, will retain two-thirds of the existing AMP Tower, originally built in 1976. Floorplates will be extended to the north to create additional lettable area, but thousands of tonnes of concrete will also be saved by reusing the existing concrete core, columns and slabs over 50 storeys.

Low Carbon Finishes and Fittings

Finishes and fittings also contribute significantly to embodied carbon in commercial buildings, due to their high replacement rate (i.e. recurring embodied carbon). The use of low carbon finishes (i.e. timber, recycled material products, etc.) and durable materials with a longer lifespan can reduce carbon impacts in this category.

Low Carbon Retrofitting of CBD Precincts

Precincts are typified by physical proximity, diverse uses, similar key stakeholders, regulatory context, governance frameworks and service infrastructure. However, they are inherently complex and characterised by multilayered interactions between institutions, people, regulatory, financial and policy frameworks, and technological systems like water and energy. Precincts provide a unique opportunity for flexible, dynamic and local responses and value creation. Stakeholders can benefit from economies of scale to access technological innovations if they can enable collective action and recognise collective value. How we harness this opportunity is unlocked through an effective understanding of stakeholders' needs, existing assets and social and economic drivers as well as technical and physical drivers.

For this reason, to enable an existing precinct to consider collective action towards carbon reduction there is a need to understand the economic, stakeholder, governance, economic and financial barriers and drivers as well as the technical barriers and drivers. Due to the complexity of decision-making and value differentials at a precinct scale it is not a matter of identifying a single technology or project, but instead critical to think in terms of a program of collective actions that need to be taken. The challenge is how to break this down into manageable scales without losing sight of the need for the integrated system outcomes we desire.

Sydney's Broadway Precinct

The Empowering Broadway research (Swinbourne, Hilson & Yeomans 2016), developed with the CRC for Low Carbon Living, focused on an existing precinct to explore how a low carbon transition could be enabled at a precinct scale. The research focussed on the existing and emerging technical, governance, financial and policy frameworks both reviewing international best practice as well as setting up a Living Laboratory through stakeholder engagement, research and analysis of the Broadway study area.

The Broadway Study area is within Sydney's CBD and includes the Central Park development (a new mixed-use precinct), The University of Technology Sydney (university campus) and NSW TAFE (tertiary training campus)—see Fig. 9.6. The public domain is managed by City of Sydney (Local Government) and the energy distributor is Ausgrid (distribution network). The precinct was identified as each of

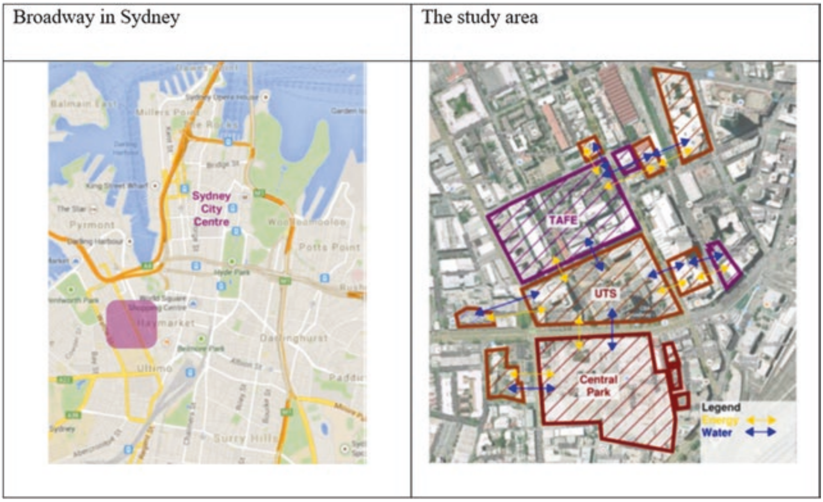

Fig. 9.6 Sydney Broadway precinct (*Source* Swinbourne, Hilson and Yeomans 2016; CRC for low carbon living, with permission)

the stakeholders were already operating precinct systems and all were motivated to become more sustainable and reduce carbon emissions. Between them, these stakeholders hold a range of assets of different ages and uses including retail, educational, residential, commercial and public domain.

Key Learning

The following points outline some of the key findings from the Empowering Broadway research that are important considerations when looking at transitioning precincts to a low carbon future.

Stakeholders

At a precinct level, a multitude of stakeholders control the short-, medium- and long-term decisions being made within the precinct which will collectively over the long-term impact its ability to transition towards a low carbon future. Therefore, at the outset, there needs to be an understanding and engagement with the key stakeholders, to understand their motivations and drivers as well as their level of control, influence or interest in energy and carbon outcomes. It was found that there are significant challenges in engaging with a diverse stakeholder group with wide-ranging levels of knowledge, values, engagement and perceptions on energy and carbon within a precinct. However, this phase of the process is important to realise a collective vision and effective governance to progress a precinct's transition. In a nutshell, the value of effective stakeholder engagement at a precinct level improves legitimacy, transparency, relevance and credibility, to support implementation.

Governance

Precincts have fragmented governance through a range of ownership, management, financial, policy and regulatory considerations. This creates the need for a shared vision and understanding of the governance mechanisms required to enable this vision to be realised. The study found that for precinct scale projects, business and governance models are innovating very quickly, often faster than the technologies. Put simply, a level of collective governance is required and emerging technologies are enabling this both at a social, financial, asset and utility level.

Existing Assets

Existing precincts have a varied asset mix with different maintenance and renewal strategies. These assets include the building envelopes, energy infrastructure, water infrastructure and fixtures and fittings. This creates challenges with timing and coordination as existing infrastructure and assets are at multiple stages of replacement and renewal. For example, for an air conditioner unit with a design life of 20 years on an asset register indicating 10 years since installation, the cost of replacing it 10 years early from an accounting perspective is effectively a loss of

10 years off the asset value and embodied carbon. The sunk cost of early replacement is an important consideration and therefore an understanding of the ownership, lifecycle and influence of these assets is important in enabling a precinct transition. For this reason, it is valuable to understand the relative and collective opportunities within the asset cycles as well as the current decision-making processes in asset replacement.

Risk/Resilience

Risk is a significant driver for decision-makers both in behavioural and economic decision-making. The perceived and actual risk of engaging with your neighbours at a precinct scale can be a significant barrier to enabling precinct level transition. In addition to this, there is risk in relation to the uncertainty of regulatory, political, economic, growth and technology change that needs to be considered and addressed if precinct scale initiatives are applied. However, collaborating at a precinct scale can break down those risk perceptions and can also create a sense of shared value and trust. Rapidly developing technologies and practices such as peer-to-peer energy trading, blockchain and offsite renewable energy are quickly changing the dynamics and investment risks for precinct action, collective action, collective risk and collective benefit.

Financing

In order to transition a precinct, investment or investment coordination is often needed. There is significant innovation occurring in financing models that can enable precinct energy and carbon transitions. There are several factors driving this innovation. One of these is the increasing ability to use technology and data to manage assets as well as to trade utilities, efficiencies, renewable energy, peak consumption or trade reduction in consumption. The emergence of blockchain and other crypto platforms also facilitate greater transparency and trade of services and risk. Another factor driving change in financial markets is identifying investments that have a positive environmental or social benefit as well as a positive financial return. This has been found to decrease risk and increase investment value. This is being realised in the emerging green bonds and ESG investment markets. Other financial opportunities exist where there are tax benefits, grants, low interest loans (green loans or environmental upgrade agreements) which can unlock capital or operational finance for precincts.

Data/Information

To manage a precinct scale carbon transition, it is critical to understand the nature of consumption, supply and distribution within the precinct as well as an appreciation of who or what can impact or influence carbon emissions. It is also important to understand what the decision-making processes are and what assets and building occupants are responsible for in terms of consumption. This can enable more effective decision-making to have the greatest impact and prioritise programs and projects to realise positive outcomes. One of the challenges of data gathering was found to be the diverse range of quality, quantity and data collection standards that exists across different assets. There were also significant challenges in the willingness to share this data due to privacy and commercial concerns. This requires effective understanding of what data is needed to enable precinct level decisions, data recording and sharing protocols as well as governance and privacy standards. In summary, precinct level data is critical to prioritise precinct level action and business cases; however, this needs to be carefully managed to ensure quality, quantity and privacy standards can be realised.

Change and Uncertainty

The declining cost of renewable technologies and energy storage in the face of rising network costs are creating significant opportunities for precincts to consider energy system supply optimisation. The current utility systems are also exposed to significant national and state regulatory controls, incentives and disincentives which creates a difficult investment environment.

Potential Model Typologies to Enable Transition

The following provides some examples of models that can help enable precinct transition:

Precinct Microgrid/Precinct Utility

This is where the precinct energy or utility infrastructure is owned by a third party who operates the distribution, and potentially some of the generation or storage within the precinct. This model will seek to drive system efficiencies and allow for renewable energy integration and bulk purchasing discount benefits to the community of building owners. One of the challenges with this model is to recognise the low carbon incentive in transition as the model can rely on selling utilities to achieve its financial commitments.

Energy Services Companies (ESCO)

This is a model where energy is provided as a service, selling the service benefit rather than the kWh. This can be commercial, not for profit or consumer owned. It comes with a level of service guarantee and lower cost profiles. Unlike a commercial microgrid it is also incentivised to drive efficiencies to reduce costs.

Bulk Precinct Retrofit Model

This may be through environmental upgrade agreements where the funding for the upgrades are borrowed off future rates/utilities. It could also include agreements to bulk purchase or upgrade physical infrastructure to reduce the cost and enable precinct initiatives to be optimised.

Centralised and Outsourcing Facilities Management

This provides for focussed precinct level asset coordination and management, allowing greater economies of scale and increasing the depth in experience across the facilities teams to drive efficiencies.

Membership Model

Building owners and managers receive assistance with energy efficiency retrofits in return for providing service providers with access to data or meeting council sustainability objectives. Friendly competition leads to greater uptake of energy savings projects. For example, the Better Buildings Partnership is a membership model where the building owners and managers receive assistance with energy efficiency retrofits in return for fees and shared experience. This can be realised within a precinct but in the case of the NSW Better Buildings Partnership, has been achieved across an asset class.

Conclusions

There are very few examples of carbon neutral office buildings in Australia of significant scale. The first was Pixel, in Melbourne, completed in 2010 with a floor area of 1136 m^2 (Fig. 9.7). The building is designed to dramatically reduce its energy demand through a shaded façade, water cooled exposed slabs facilitating radiant cooling, night purge ventilation, heat exchange and high levels of insulation. Onsite energy generation includes wind turbines, fixed and trackable PVs and an anerobic digester. The building's carbon impact is not only reduced at an operations level though; reusable façade panels provide future adaptability, while a specialised concrete mix called pixelcrete was used with almost half the embodied carbon of traditional concrete.

Since then other buildings and precincts have sought carbon neutrality through a mixture of efficient performance and carbon offsets or power purchase agreements that utilise offsite renewable generation

Fig. 9.7 Pixel building, Melbourne

such as large-scale wind or solar farms. Examples include Barangaroo by Lendlease at a precinct scale in Sydney (Barangaroo 2018) and the Australian Institute of Architects Headquarters (41 Exhibition Street) in Melbourne (Architecture 2018).

Recently Frasers Property obtained the first Certified Carbon Neutral Commercial Office building called Building F in Rhodes, Sydney. Building F achieved a NABERS Energy rating of 5.5 stars using a combination of energy efficiency measures, including building monitoring and tuning, along with a 100 kW solar system to minimise energy use onsite. The building also uses 20% GreenPower on its remaining energy demand (NABERS 2018b).

Building scale is important to consider when targeting carbon neutrality, and here commercial office buildings can be at a disadvantage. Some commercial buildings such as libraries and civic centres have large roof spaces relative to their total floor areas, thus ample space for integrated PV systems to offset energy demand. Larger scale offices though tend to have multiple storeys on tight urban sites, limiting the area available for integrated photovoltaic panels, or other onsite energy systems—which are more effective on the roof than vertically aligned on facades. At present, this means most office buildings aiming for carbon neutrality in Australia do so through a mix of energy efficiency and carbon offsetting. However, given developments in onsite energy generation technologies, and reducing costs, this could change in the future. As we move towards a greater decarbonisation of the commercial building sector, there are a number of areas where increased focus will accelerate this change. These include:

- Given the large commercial building footprint occupied by government at all levels, an increase in Government Office Accommodation Standards, particularly around existing buildings is important. This applies both to the tenancy space and how it is operated, but also the base buildings that government tenancies occupy.
- Increased awareness, information sharing and training of commercial tenants of various sizes to make more informed decisions when selecting tenancy space. But, also to inform tenants as to how they can continue to optimise and improve the energy efficiency of their space and improve awareness and behaviours on how they use the space.
- Dramatically enhancing the National Construction Code through lifting minimum standards and providing a clear trajectory of future three-yearly amendments towards carbon neutral performance, so that industry can respond and plan accordingly.
- With a decarbonised electricity grid alongside improved passive design and construction features of commercial buildings, large scale buildings will still need to rely on technological advances in buildings integrated photovoltaic (BIPV) renewables to achieve carbon neutrality along with precinct solutions, demand management and carbon offsetting.
- An evolution of the scope of ‘carbon neutral’ to not only include carbon emissions associated with building operations, but also to consider embodied carbon. This will allow for a holistic carbon performance of commercial buildings to be realised. It will also allow for greater consideration of the carbon impact of technologies and

strategies designed to reduce operational emissions, on building's embodied carbon performance, providing an understanding of trade-offs over time.

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10

The Trajectory to a Net Zero Emissions Built Environment: The Role of Policy and Regulation

Philip Harrington and Virginia Hoy

Introduction

The transition to a zero-carbon built environment is underway in Australia, but for the most part, the process is occurring in an unplanned and inconsistent manner, and despite rather than because of effective policy signals.

Households are leading the transition process primarily by investing in photovoltaic systems—one in five households, or more than 2 million households, now have rooftop PV.[1,2] More recently, but at an increasing rate, businesses are making similar investments, either in rooftop PV systems, or else making use of the recent contractual innovation known as power purchase agreements (PPAs) to secure long-term

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contracts from remote, utility-scale renewable facilities, often on favourable terms relative to the normal or 'black power' market. The duration of PPAs (up to 15 years) significantly exceeds contract terms available in the National Energy Market, offering a valuable source of price certainty for businesses that is not available through normal electricity contracts.

The strong drivers for this development have been the dramatic rises in energy prices in Australia since 2007. Depending upon the state and user class, electricity and gas prices have approximately doubled over the last decade (ACCC 2017, p. 10; Oakley Greenwood 2018). In addition, there have been equally dramatic falls in PV panel (and, to a lesser extent, system) costs over the same period (IRENA 2018). This has significantly increased the affordability and the value of these systems to households and businesses. From the consumer's perspective—and for those able to access the benefits of PV—this option is effective in reducing costs to a degree not rivalled by alternative approaches, which no doubt accounts for its popularity. There is policy support for such investments through the Small Technology Certificates scheme and through local subsidies in some states and local government areas.[3]

There are significant risks associated with the unplanned nature of the transition, however, including:

- unequal access to the financial benefits of solar systems
- little attention to energy efficiency improvement
- a lack of planning for electricity (or energy) system transition
- uncertain greenhouse gas emission outcomes.

These are considered briefly in turn.

First, the ability to access the financial benefits of PV systems is limited to those with a suitable housing type, tenure and solar access; and with sufficient income to finance the investment. A growing concern is that those energy users with access to PV will be largely insulated from policy and energy price fluctuations, while those without—which may include many low-income and disadvantaged Australians—will have no such protections.

Second, energy efficiency policy in Australia has stalled over the last 5–10 years, at least at the national level. There have been no changes to new building energy performance regulation since 2010, and no new standards for appliances and equipment for 5 years. Many programs have been terminated, including the successful Energy Efficiency Opportunities program, the Low-Income Energy Efficiency Program and others. Some jurisdictions choose to opt out of nationally agreed housing and building standards, often substituting them with less effective alternatives. In NSW, Australia's largest housing market, BASIX has delivered housing that, on average, rates 1.5 stars less than the 6 star national standard,[4] while in Queensland and the Northern Territory, apartments as low as 3.5 Stars can legally be built in 2018, due to the combined effect of the Queensland Development Code and special provisions in the National Construction Code providing for star ratings to be reduced by 1 star where outdoor living areas are provided.

For housing, no new national standards will be entertained until at least 2022, while for non-residential buildings, the 2019 National Construction Code will lift energy performance standards, but only to a degree marked by modest stringency (ABCB 2018). The National Energy Productivity Plan, launched in 2015, is yet to deliver any new efficiency policies, despite a work program covering 38 policy areas.

Despite this, energy efficiency is contributing to the transition in a modest way through market-led transitions to LED lighting, most importantly, and to steadily more efficient heat pumps, OLED televisions and computer monitors. In certain sectors, such as premium offices, the combination of the NABERS rating system, Commercial Building Disclosure and state/territory efficiency schemes—and property institutions motivated by sustainability rating systems such as the Global Real Estate Sustainability Benchmark (GRESB), Green Star and others—is proving very effective in lifting average efficiency. However, we estimate this sector to represent around 7.5% of all office space in Australia and 1.7% of all non-residential building space. Also, four states and territories operate energy efficiency targets and schemes—Victoria, New South Wales, South Australia and the Australian Capital Territory, and these continue to expand annually. Overall though, the inconsistent nature of efficiency programs from state to state means that households' and businesses' exposure to energy costs varies as a function of their location and the relevant state government's policy practices. In the presence of climate change, the thermal performance of buildings will need to be considered independently of the nature of their energy supply, due to health and mortality risks associated with heatwaves.

A third risk category from the unplanned transition is the consequences for efficient electricity and energy network planning and investment. The collective effect is such that new network investments—to correct for voltage fluctuations, or to provide distributed storage and ancillary services—are now required. That said, growth in demand (for example, for heat pumps) is equally unplanned and can have similar consequences for networks. Also, some households are investing in batteries, as well as PV systems, and this trend is likely to increase in future, and also to spread to businesses, as battery prices fall. To an extent, households and consumers are making upstream (generation and storage) investments that would previously have been made by electricity businesses, because doing so shelters them from rising and otherwise poorly controllable costs. In future, intelligent networks are expected to emerge—and indeed are required—to better deal with the variable nature of both supply and demand, and this may offer new opportunities for network businesses to create value for their customers.

From a national policy perspective, it is unclear what the net outcome of this bottom-up process will be in terms of future greenhouse gas emissions. Some households—that have sufficient North-facing and unshaded roof area, and the financial means to invest in large PV systems—are already likely to be at or beyond net zero at the building level, exporting more electricity over a year than they import from the grid. However, the potential to achieve similar outcomes elsewhere, or systematically, is not the target of any national policy, although some states, territories and cities are aiming much higher than Australia's national targets (CRCLCL 2017a). Many businesses operate from rented premises and may not be able to access the benefits PV systems except with the co-operation of the building owner. PPAs may be able to be accessed by smaller businesses if they operate in a building with an embedded network supplied by a PPA. The national renewable energy target remains in place until 2020, but the policy landscape after that date is undefined.

Against this backdrop, what is the role and opportunity for governments to use best practice policies and regulations to accelerate and better manage the transition to a zero emissions future?

Policy and Regulatory Opportunities—And Opportunity Costs

CRCLCL (2017b) maps best practice policy and regulatory models internationally and in Australia. If utilised to the maximum extent, these policies could reduce energy costs for households and businesses and accelerate the transition to a net zero emissions built environment.

Numerous studies indicate that there are excellent opportunities for using policy to move the built environment towards net zero energy and emissions. A recent study by the Australian Sustainable Built Environment Council and ClimateWorks indicates that it would be cost effective to lift energy performance requirements for housing by between 1 and 2.5 stars (depending upon the climate zone) or by over 50%. Three years delay in delivering this outcome would add $1.1 billion in unnecessary energy bills for the half-million homes built in that period (ASBEC 2018a). For non-residential buildings, ASBEC finds that even 'conservative' Code improvements would save up to 34% of commercial building energy use and up to 56% of public buildings energy use (ASBEC 2018b). Similarly, a new study finds that if Code standards were set to take advantage of cost-effective energy efficiency improvement and solar energy opportunities from 2022, this—along with modest enhancements of existing energy efficiency policy measures nationally and by states and territories—could see the non-residential building sector as a whole achieve net zero energy and emissions before 2050. Delaying cost-effective Code energy performance increases by 3 years (from 2022 to 2025) would forego $4.2 billion in lost economic welfare, while also leading to higher greenhouse gas emissions, future abatement costs, energy costs for businesses, and peak demands and associated infrastructure costs (EA/SPR 2018, p. 7).

Despite this potential, CRCLCL (2017b) also documents the increasing reticence on the part of governments, and particularly the national government, to use policy—and regulatory policy in particular—to influence outcomes in the domain of climate policy. It notes factors such as the significantly higher standards of evidence and process required of regulatory proposals when compared, for example, very large spending programs and subsidies. All major regulatory proposals by the Australian Government and COAG are required to comply with regulation impact assessment and regulatory burden processes, while Budget proposals and non-regulatory policy models face no such requirements.

Second, there appears to be a lack of agreement at the national level about how to manage the changing nature of electricity system security requirements as the grid decarbonises, as evidenced by the COAG Energy Council's inability to agree a new national energy policy in 2018. However, the private sector and market bodies such as AEMO appear to be getting on with the necessary investments and provisions despite this.[5] Australia's national government and most states and territories (with the notable exception of the ACT) appear to continue to harbour doubts about the need for genuine and urgent action to address climate change. This is despite surveys of the Australian population consistently showing strong majority support for action on climate change (The Australia Institute 2018). Also, there is a lack of agreement at the national level on how best to reduce emissions, with the two major policy levers—carbon pricing and regulation—largely dismissed.

More generally, the study notes that regulation, in particular, is increasingly regarded with suspicion by governments in Australia. The Australian Government's Guide to Regulation (Australian Government 2014, p. 16) offers the following advice[6]:

> As policy makers, we must balance the desired outcomes of regulation against the burden imposed on potentially large numbers of businesses, community organisations and individuals to achieve that outcome. Remember that regulatory action is not risk free; how confident are you that your proposed solution will work? What are the genuine consequences of no action? Analyse how the problem has been dealt with

> in the past or is currently regulated by Commonwealth, state, territory or local government regulations or by governments overseas. Are there deficiencies in the existing approach? Why does current regulation not properly address the identified problem? Is it a problem of design or implementation, or both? How can you be sure your policy options will succeed where others have failed?

While none of these or the Guide's other 39 pages of requirements and questions are individually unreasonable, the combined effect is to discourage and delay regulatory proposals. Indeed, they have the explicit aim of ensuring that regulation is 'introduced as a means of last resort' (p. 3), regardless of potential to increase net social welfare that often exists, at the same time as emissions are reduced. The requirement to measure 'regulatory burden'—that is, regulatory costs considered in the absence of the associated regulatory benefits—represents a significant deviation from evidence-based policy and encourages distorted public policy outcomes. This is particularly concerning when—ironically thanks to regulation impact statement and evaluation requirements—we have very considerable evidence of the effectiveness and cost-effectiveness of regulatory policy, but very little evidence of the effectiveness or cost-effectiveness of non-regulatory policy models, which can be introduced without a transparent process.

In part, because many policy and regulatory settings have fallen behind the pace of change in underlying market realities, the scope for cost-effective policy interventions to lift energy performance in Australia is currently greater than it would otherwise be. For example, non-residential building energy performance standards are proposed to be lifted by an average of 30% in 2019, but this outcome has an expected social benefit cost ratio of 9.5, strongly indicative of low stringency (ABCB 2018, p. 69). The large gap between policy potentials and outcomes reflects the long delay since the last stringency change in 2010 (and a lack of regular review processes in-between), the significant increase in energy prices during this period, and finally the practice of setting low rather than economically optimal standards.

While the balance of this chapter explores the potential for low-carbon policy innovation in the built environment, a prior requirement is that Australia pays greater attention to basic regulatory house-keeping: ensuring that standards at least keep pace with market realities; and undertaking regular and fully transparent review processes that are rules-based, and which therefore minimise the scope for discretion and special interests to take precedence over the public good.

Best Practice Policy and Regulatory Models

The CRC's *Best practice policy and regulation* project (CRCLCL 2017b) examines the key features of the policy and regulatory environments for the built environment in parts of Europe, North America and the Asia Pacific, and presents a series of case studies from particular countries and regions.

Europe represents best practice in mandating the core requirements of its member nations' policy packages at the supranational level through EU law. This includes mandating the policy approaches, setting standards and targets those policies are required to meet, setting out a rules-based approaches to updating/increasing stringency of policies, and providing a wide range of supporting mechanisms and an enabling environment. With this overarching structure member nations have developed ambitious individualised policies and policy packages to best suit their conditions/situations.

North America represents best practice in its institutional arrangements, enabling continuous, professional and expert policy and code development at a national level, which is then adopted by the states and cities, as mandated in some instances and voluntary in others. The system of national 'laboratories' is central to the development and maintenance of expertise and the performance of policy-relevant research. National programs include model codes, stretch codes, equipment minimum and high-performance standards and labelling, for which the federal government plays a central support role, providing technical assistance to state and local governments to help facilitate the adoption, implementation and compliance processes. Many North American states and cities are independently setting high targets and providing comprehensive financial and non-financial support to enable a transformation of building performance.

While it is hard to generalise given the sheer diversity of countries in the Asia Pacific region and their varying political, social, cultural and economic environments, it is notable that there are a number of countries in this region that are widely considered to be at the forefront of development and implementation of policies and policy packages designed to drive energy efficiency and decarbonisation of the built environment. What these countries seem to share is a political and societal willingness for decisive national action, and in many cases far-reaching regulation, which is not common in other areas.

Individual Policies

Through the review of regional policies and policy packages, best practice elements of each of the individual measures were drawn out.

- National targets, both long and short term, are ambitious and have underlying sector specific contributions established, and pathways to achieving targets set out.
- Building codes use rules-based processes and timelines to deliver ambitious but predictable changes, with coverage extended to require existing elements of a building meet minimum requirements when a renovation triggers the code and to include minimum requirements for onsite renewables or solar readiness.
- Mandatory disclosure is applicable to all building types, is triggered on an ongoing basis (rather than just point of sale or lease), capable of rating both asset and operational performance, leveraged by other complementary programs, and utilised for data collection to allow measurement, monitoring and reporting on energy performance of the building stock as a whole.
- Energy auditing is a requirement for mandatory disclosure and can be linked to a requirement to undertake certain upgrades where the building does not meet minimum requirements.

- High-energy performance assessment tools/labels are used to rate comparative building performance and acknowledge outstanding achievement, are integrated with rating tools required to establish code compliance and mandatory disclosure, and with complimentary incentive schemes as a requirement for eligibility.
- High-performance stretch codes, developed federally, for easy reference/uptake by state and local governments, that can be aligned with future updates to building codes, allowing buildings to be certified to future codes.
- Dedicated market transformation programs that use a combination of information, incentives and regulation to drive market change.
- Tax incentive programs used widely.
- Energy retailer/utility obligation schemes utilised broadly internationally, with mandated targets set at central level, specific targets set for low income and social housing sectors, and are linked to trading schemes targeting other sectors of the economy or carbon pricing schemes more generally.
- Minimum energy performance standards (MEPS) set for a broad range of products, equipment, building materials and systems, with methodology set for future increases to stringency over time, and extended to include high-energy performance (HEPS) labelling which can be leveraged by complementary programs/policies.
- Support for high performing technologies and practices through dedicated research institutions financed by federal governments but sufficiently independent to ensure stability and provision of independent expert analysis, demonstration projects and program trials used to test and demonstrate best practice and to test market capability to meet future requirements, and government sponsored competitions and award programs to incentivise development of high performing technologies.
- Innovative financing mechanisms designed and supported centrally, including on-bill and property-assessed financing, energy efficient mortgages/loans and public–private partnerships that encourage investment in energy performance of buildings and support investor recognition of high performing buildings as an investment asset class.

Policy Packages

In Europe, in particular, we see combinations of deliberately ambitious targets, Codes, mandatory disclosure (still an emerging policy approach), energy retailer obligations, energy audit programs and incentives for high/above-minimum performance including financial incentives, and high-performance standards and labelling. In both the United States and Europe, we see a willingness for governments to intervene in product and service markets with the explicit aim of changing existing market outcomes, in order to shift the balance in favour of high-efficiency and low-carbon solutions. This approach, known as market transformation, was pioneered by the United States in the 1980s and 1990s, with the Environmental Protection Agency running consumer-focused initiatives such as EnergyStar, while the Department of Energy placed (and continues to place) a strong emphasis on technical research. US DOE's funding is invariably linked to co-funding or other support by universities and companies, in order to facilitate commercialisation of research success. This approach is largely responsible for the commercial development of LED lighting, for example, and the commercialisation of sub-compact fluorescent lighting before that, among the many technologies targeted and supported for market transformation.[7]

We find that the *interaction* between complementary policies was a key feature of best practice policy packages:

- Policies were designed in combination to complement, leverage, strengthen and streamline.
- Common combinations included building codes, building rating/disclosure, beyond-Code incentives.
- Supporting tools designed for multiple functions, for example a rating tool that provides an asset rating used to evidence meeting code requirements, can also be used for purposes of mandatory disclosure and beyond code initiatives.
- Targeted market transformation initiatives use a combination of information, incentives and regulation to drive market change. This is done using labels, information, minimum standards, procurement, grants and rebates.

Conclusions

While the countries and regions surveyed have diverse political, social, cultural and economic environments and histories, what leading nations have in common includes:

- Setting high but achievable targets, short- and long-term, with 'trajectories' or pathways for their achievement.
- Clarity and transparency of objectives—reducing greenhouse gas emissions is commonly cited as a primary concern.
- The use of comprehensive and integrated policy packages, comprising a broad palette of complementary individual measures, rather than over-reliance on single instruments (or prohibitions on certain policy choices, such as regulation).
- Sustained and progressive efforts over long periods of time, including professional and transparent management of policy change over time.

CRCLCL (2017b) calls for a renewed focus in Australia on the use of evidence- and rules-based processes to determine the most effective and efficient policy instruments, while setting aside preconceived ideas about policy instrument choice. It argues that the distinction between 'market based' or 'economic' measures on the one hand, and regulatory measures on the other, is entirely false: policies known as economic measures, such as carbon trading/pricing schemes, make extensive use of regulation, while regulation can be used to create markets and to achieve market transformations.

The Report notes that many Australian policy practices relating to the carbon performance of the built environment lag behind international best practice by a large measure. While the factors noted above that distort the choice of policy instruments certainly contribute to this outcome, greater attention needs to be paid to the role of specific practices that contribute to sub-optimal outcomes. In particular, the timing of policy and regulatory reviews appear to be largely discretionary. This is leading to outdated standards being left in place long after economic conditions have changed, warranting review and (generally) updating to contemporary standards. Further, current review processes lack transparency and accountability. For example, regulation impact assessments require consultation, but if no RIS is triggered following an internal policy review, then the nature of that review and its outcomes may never be known, and the reasons for failing to proceed with policy or regulatory reforms will equally remain hidden, with no opportunity for stakeholder input into the process. We call for a renewed commitment to objective, rules-based and transparent processes for reviewing and renewing policies and regulations.

Finally, the CRC Report demonstrates that there are policy models and practices in use around the world that could be drawn upon in Australia to accelerate the transition to a net zero emissions built environment, and to do so in a managed, equitable and cost-effective manner. To this end, Australian policymakers would do well to recommit to:

- Setting ambitious but achievable targets, for both the short and longer terms, and identifying detailed and least-cost policy pathways for ensuring that those targets are met
- Taking urgent, effective but also cost-effective action to reduce greenhouse gas emissions
- Making use of the full palette of policy and regulatory policy models, in complementary and effective packages, with policy instrument choice being made on the basis of evidence rather than ideology
- Policy and regulatory practices, including review processes, that are objective, rules-based, transparent and accountable.

Notes

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Part III

Regenerating Urban Precincts and Cities

11

Sustainable Precincts: Transforming Australian Cities One Neighbourhood at a Time

Giles Thomson, Peter Newton and Peter Newman

Introduction

The majority of urban development in Australian cities in recent decades has been delivered in a piecemeal manner, resulting in suboptimal development outcomes in terms of both sustainability and liveability. Considerable attention has recently been given to the capacity of

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Australia's burgeoning cities to continue to support the high quality of life we are accustomed to, while at the same time concerns over the sustainability of Australian cities has come to light. These combined factors highlight the need for more strategic approaches for planning our cities to address future sustainability and liveability needs. In addition, the shifting international policy agenda has highlighted the increasingly urgent need for improved sustainability outcomes as the next section explains.

Australia has recently signed the following high-level international sustainability frameworks: the Sustainable Development Goals (SDGs, September 2015) (United Nations General Assembly 2015), the *New Urban Agenda* (NUA, October 2016) (United Nations 2017) and the Paris Agreement (COP21, December 2015; United Nations 2015).

The need to decarbonise is mandated in all three high-level agreements, foremost of these is the Paris Climate Change Agreement where Australia's commitment is to reduce greenhouse gas emissions across the economy from 26 to 28% below a 2005 benchmark, by 2030. In the absence of federal leadership, several state and territory governments have introduced ambitious greenhouse gas emissions reduction targets including net zero emissions by 2050 in South Australia, ACT, Victoria, NSW, Tasmania and Queensland (ASBEC 2018; Newton & Glackin 2018). The need to translate these goals into effective policy will require coordination between all parts of the economy including industry, agriculture, energy and the built environment.

This chapter considers planning aspects of the built environment and how this sector can best respond to the sustainability agenda. It starts from the premise that comprehensive, as opposed to piecemeal, planning approaches can optimise the scale and performance of built environment outcomes. It offers a high-level discussion of the influence of transport systems on urban form at the city scale (*urban fabrics*); the need for greater attention on *infill* (brownfield and greyfield) development to discourage urban sprawl at city fringe (greenfield) locations; and, finally describes some of the benefits resulting from *precinct-scale planning* approaches. Sustainable precincts are described in terms of 'why' precincts should be considered and 'where' precincts should be located.

As Australia's major cities continue to grow, movement across them has become increasingly dysfunctional. This has led to renewed interest in the historic way of building Australia's cities before the automobile, where transit such as trams and trains connected higher density walkable centres. The next section introduces the theory of urban fabrics as a way to think about various urban development patterns and the inseparable influence that dominant transport modes play upon urban fabrics and urban performance.

The Theory of Urban Fabrics

The tram, train and especially the car, which currently dominate urban transport are all essentially products of the nineteenth century and each have produced a different urban fabric around their respective infrastructures (Newman, Kosonen & Kenworthy 2016). While modern versions of these modes are more developed in relation to safety and comfort, they are little changed in the key characteristics (capacity, effective speed), which determine how they accommodate urban travel and also how they shape our cities (Newman & Kenworthy 1999, 2015). In contrast, all of these modes represented a major leap forward over previous transport technologies (walking, horse drawn vehicles) when they were first introduced.

The way that cities are shaped by transport can be explained in terms of the Marchetti Constant relating to the travel time budget in cities (Newman & Kenworthy 2015). This suggests that throughout history, no matter what mode, the average travel time budget for work in a city has been just over an hour. Hence in a walking city the urban fabric is densely packed within a 30 minute walk radius (for the journey there and back); a tram and train-based city could spread further out to 10 or 20 kms at medium densities along corridors and still keep within the travel time budget for most people; then, finally the automobile-based city could spread 40 to 50 kms at much lower densities.

Current transport systems have gone backwards in recent years as traffic has slowed down and hence there is a revival of people choosing to live in dense, centrally located and well serviced walking fabric as well as in medium density corridors with good transit systems that can actually go faster than traffic (Newman & Kenworthy 2015). This change has happened because cars on a freeway lane can only move around 2500 passengers per lane per hour whereas rail-based solutions can handle ten times the volume of passengers per hour in the same space (Table 11.1). The traffic is not just reducing the speeds of those in cars but any other vehicles (trucks, buses, trams, bicycles) caught up in the congestion. Thus urban efficiency as a whole has declined, notwithstanding the apparent improvement in personal mobility, suggesting that there is a need to regenerate cities using more efficient urban fabric as well as new technologies that can support this (Glazebrook & Newman 2018).

The theory of urban fabrics was developed by Newman, Kosonen and Kenworthy (2016) to help planners see that there are three main city types, not just one (automobile fabric), as has been suggested by modernist city planners since the 1940s. Urban fabric is shorthand for describing the urban environment (or urban morphology) that results from the different types of underlying infrastructure within a city as set out above. Urban fabric includes transport infrastructure, such as road or rail technology, building setbacks, road patterns and widths, which in turn shape the form of the more localised infrastructure of buildings, open space and utilities. The theory enables planners to create strategies for managing the different fabrics to highlight how some urban fabrics have inherently more sustainable properties that need to be optimised and extended to other parts of the city through infill strategies.

The three dominant city types from history that form the basis of urban fabric theory—walking cities, transit cities and automobile

Table 11.1 Calculations of transport patronage capacity per hour per kilometre of lane space

Transport mode	People per hour per km of lane space	Multiples of car capacity in a suburban street
Car in suburban street	1000	1
Car in freeway lane	2500	2.5
Bus in traffic	5000	5
Bus in freeway lane (BRT)	10,000	10
Light rail	10,000–20,000	10–20
Heavy rail	50,000	50

Source Based on data extracted from Newman and Kenworthy (1999, 2015)

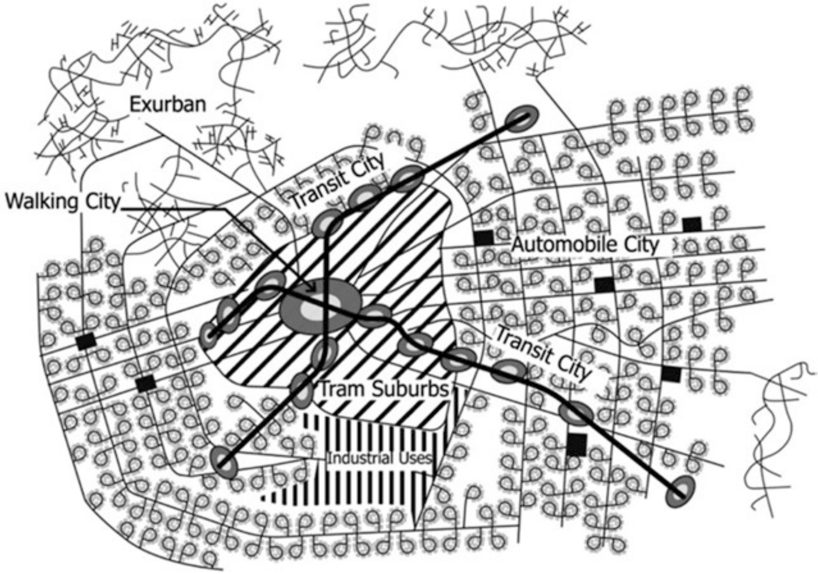

Fig. 11.1 Automobile city, transit city and walking city: a mix of three city types (*Source* Newman and Kenworthy 2015)

cities—are obvious in most cities today depending on the age when the city was developed. Figure 11.1 shows a typical Australian city with its various fabrics, now dominated by automobile fabric in the past 60 years or so.

Rediscovering Walking and Transit Urban Fabrics

Many modern cities are now attempting to reclaim the fine-grained street patterns associated with walkability (Gehl 2010) but often don't have the tools to do so, as modernist planning manuals rarely focus on pedestrian needs. However, this is slowly changing; for example, the new (US) National Association of City Transportation Officials (NACTO 2012, 2016) manuals and the work of Jan Gehl emphasise the importance of human-centred urban design (Gehl 1987, 2010) and the importance of pedestrian prioritisation to make successful urban environments.

Transit city fabric has had a considerable revival in recent decades and is the preferred location—along with walking city fabric—for knowledge economy jobs such as education, hospitals and health professionals, and consulting services, with the highly spatially confined jobs associated with financial services, government and high-end services keeping to the old walking cities (Newman & Kenworthy 2015).

There has been a slowdown in the building of automobile fabric as walking and transit fabric have been rediscovered, leading to the phenomenon of 'peak car use' (Newman & Kenworthy 2015). This is important for low carbon living and in particular the value of urban precinct regeneration as they will be far more popular and lower in carbon if they are more like walking or transit fabric and in areas where the infrastructure supports this. The variations in urban density versus per capita consumption of energy use and corresponding emissions show this very clearly (see Fig. 11.2).

However, decarbonising cities is not as straightforward as simply substituting cars with electric vehicles, because as major Australian cities continue to grow, there are other real issues associated with the dominance of automobile urban fabric, especially where it extinguishes the best features of walking and transit fabric (Newman, Kosonen & Kenworthy 2016). The low-density automobile city is the most resource-consumptive type of urban fabric, due to its inefficient use of land and associated increases in basic raw materials for building longer roads, pipes and wires to service an increasingly dispersed population (Thomson, Newton & Newman 2016). In addition, low densities have economic and social outcomes that are significantly worse than other city types (Glaeser 2011). It is this recognition of the economic agglomeration benefits and greater social qualities that is driving the previously mentioned strong re-urbanisation of Australia's cities. This demand is being led by the 'creative classes' who value the role of people and place as well as proximity to workplaces that can all be found in greater proportions in denser, walking and transit-oriented, urban environments (Florida 2014).

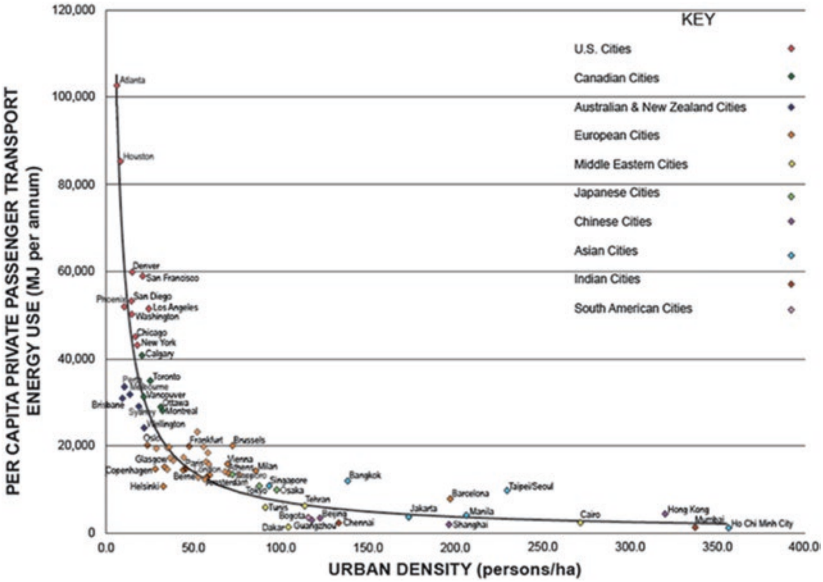

Fig. 11.2 Urban density and transport fuels in global cities (*Source* Newman and Kenworthy 1999)

The creative classes are attracted to vibrant locations near transit and often in more central locations, rarely will urban fringe locations offer these qualities, thus highlighting the importance of urban regeneration in existing inner and middle suburban areas rather than outer areas.

Urban Regeneration

This section looks at greenfields (outer peri-urban areas), brownfields (inner ex-industrial areas) and greyfields (established, ageing middle-ring suburban residential areas) and why urban regeneration needs to focus upon infill (greyfields plus brownfield) areas with a different model based on urban precincts.

Greenfields are those previously undeveloped sites, typically on the fringe of existing settlements. Greenfield development usually has the least constraints and the business models of most Australian bulk project home builders are geared towards greenfield development. But they have high government costs resulting from the provision of infrastructure services such as road, sewerage and other utilities (Trubka, Newman & Bilsborough 2010a, 2010c) and high societal costs due to fuel consumption, commute times and greenhouse gas emissions related to long travel distances that are due to low-density localities that are not well serviced by public transport (Dodson & Sipe 2006; Newton, Pears et al. 2012; OECD 2012; Trubka, Newman & Bilsborough 2010b).

The increasing geographical spread of urban areas into greenfields is known as 'urban sprawl' (OECD 2018; UN-Habitat 2011), sprawl negatively impacts upon the city fringe agricultural and ecological land that it displaces. As observed by Newton and Thomson (2016) sprawl has been a consistent challenge for urban planners in Australia's cities since the mid-1950s, and remains so, given that the dominant mode of new housing development continues to be detached low-density (78% of all residential stock in 1971, 74% in 2011). All of Australia's metropolitan planning agencies have now established targets for 'infill' housing development (i.e. new housing built on previously developed land, including both brownfield sites and greyfield sites), and many of Australia's major cities are now experiencing strong re-urbanisation. Australia's five largest capital cities have infill targets ranging from 47% in Perth to 85% in Adelaide, with Sydney and Melbourne at 70% (Newton, Meyer & Glackin 2017). However, much new development is resulting in suboptimal outcomes following the piecemeal redevelopment approach of 'knock down, rebuild' involving the demolition of an older structure and replacement with either a new detached dwelling or townhouses that can be accommodated within current restrictive residential zoning (Newton & Glackin 2015; Newton, Meyer & Glackin 2017; Newton & Thomson 2016). As a result, most of Australia's major cities are failing to achieve the infill targets for new housing established in their strategic plans with the majority of dwelling construction projects continuing to occur on greenfield sites in the outer suburbs (Newton & Glackin 2018; Newton, Murray et al. 2012). Suboptimal infill effectively increases the development footprint through built form, car parking and vehicle infrastructure, while only increasing densities slightly. The result has been the widespread erosion of those positive suburban qualities such as backyards, tree canopy and biodiversity (Hall 2007; Thomson & Newman 2017; Thomson, Newton & Newman 2016). There is a need for better models of infill development and this chapter suggests that urban precincts in well serviced, established middle suburban areas should be the focus of this.

The best urban regeneration outcomes result from a more complete recreation of an entire infill site at the block or precinct scale. This is because larger land parcels permit more integrated solutions to support distributed urban infrastructures such as energy, water and waste, while also optimising community facilities and shared open space arrangements (Newton et al. 2011). Urban regeneration may occur on infill sites in either brownfield or greyfield locations (Newton & Glackin 2014). Greyfields, unlike brownfields, usually have no need for site remediation. Greyfields in the Australian context have been defined as those ageing but *occupied* tracts of inner- and middle-ring suburbia that are physically, technologically and environmentally failing and which represent under-capitalised real estate assets (Newton 2010). They are predominantly located in the middle suburbs and as such provide greater access to employment, public transport and services than typical greenfield locations (Newton & Thomson 2016). There is significant potential for amalgamation of land parcels in greyfield locations to achieve precinct-scale lot consolidation. However, difficulties with site assembly, restrictive local planning schemes and NIMBY resistance represent considerable barriers, yet promising models have been proposed, some involving state and municipal government agencies as facilitators to engage with and build support amongst local communities (Newton, Meyer & Glackin 2017; Newton, Murray et al. 2012). Large infill parcels (i.e. brownfield or greyfield precincts) permit higher order urban regeneration responses. Larger sites offer the scale and flexibility to comprehensively plan sustainability and liveability enhancing opportunities, such as public transport, open space, distributed energy and integrated water infrastructures. Precincts and the opportunities they present are described in greater detail in the following section.

Precincts—A Neighbourhood Scale for Planning

Precincts are unified areas of urban land with a clearly defined geographic boundary (Huang, Xing & Pullen 2017). A precinct, with the exception of institutional precincts, will contain private and public land with shared infrastructure. At the larger scale, precincts may be described as synonymous with neighbourhood or district. Precinct size can vary considerably. For example, a precinct may be quite small, such as the internationally well-known sustainable precinct BedZED in London (1.7ha); compared to Hammarby Sjöstad in Stockholm (250ha). Efficiencies tend to have physical thresholds. Therefore, the size of the land parcel available or the desired technology will influence the approach to urban design from an eco-efficiency perspective. For example, the minimum size for economies of scale (to reduce cost per unit) or maximum size for physical efficiency (such as 'pedsheds' for transport or district heating networks for heating buildings). Distributed technologies require a clustering of participating properties to enable planning at precinct scale.

In this situation, defining a boundary is perhaps more important than the scale of a precinct.

A well-defined geographic boundary for a precinct, with a clear governance structure can allow for the precinct to be managed and monitored at the local level, potentially permitting it to trial new distributed localised infrastructures such as renewable energy as well as building efficiencies managed through smart technology and new shared urban transport systems.

Sustainable Precincts

Large sustainable precincts typically function as 'urban villages' in that they are optimise land with medium to high-density development; mixed-use zoning (residential uses mixed with retail, services and employment to reduce daily travel needs); and, the integration of high quality urban greenery and social infrastructure to create a 'village' feel in a city context (to enhance quality of life) (UNEP 2016).

The sustainability advantages of precinct-scale regeneration are numerous and have been identified by Newton et al. (2011) as including:

- Accessibility: where mixing dwelling types with other land uses reduces travel time and encourages active transport modes such as walking and cycling
- Energy: carbon neutrality or zero carbon status is enabled with the introduction of distributed (renewable) energy and storage and microgeneration technologies as new elements of hybrid buildings or precincts, capable of generating energy for local use as well as for the national grid (Newton & Tucker 2011)
- Water: integrated urban water systems involving water-sensitive urban design at the precinct scale, with an appropriate mix of technologies for local water capture, storage, treatment and end use (Kenway & Tjandraatmadja 2009)
- Waste: precinct-scale redevelopment can optimise reuse of demolished stock and minimise the waste stream from new construction, as well as automate waste disposal and maximise recycling from occupied dwellings, including food waste (Crocker & Lehmann 2013)
- Green infrastructure: where greenspace can be maintained or enhanced rather than lost as a result of redevelopment due to the capacity of precinct-scale urban design to accommodate innovative dwelling, green space and streetscape typologies.

These objectives need to be reflected in contemporary precinct design processes and be subject to performance assessment—a critical deficit in contemporary urban development that mitigates against transition to sustainable low carbon cities (see Newton chapter, this volume).

While every site will require a different response, adhering to the key principles of well designed, precinct scale, medium to high-density urban fabric linked active transport and transit-oriented development with green space and social infrastructure, will put in place robust infrastructural elements to maximise urban liveability, sustainability and desirability in Australian cities. In this sense, the principles run counter to some conventional planning approaches, born out of a post-WWII industrial modernism that specify single-use zoning, massive road construction and urban disinvestment to propagate 'suburban' monocultures. Suburban monocultures are typified by dormitory suburbs, bland shopping centres where ebb and flow activity is dependent upon opening hours, and car dependency. Well-designed, well-located mixed-use, medium density precincts can regenerate the urban fabric by creating urban villages. In a number of respects, this approach represents a return to traditional patterns of living seen in the early years of European settlement in Australia the remnants of which are still apparent in most Australian cities and particularly so in pre-WWII neighbourhoods, but with an overlay of high performance, life-enhancing, sustainable infrastructure. An example is the recent precinct scale, greyfield, urban regeneration White Gum Valley (WGV) project in Fremantle which has shown it can meet the objectives of the Paris Agreement as well as the UN Sustainable Development Goals (Wiktorowicz et al. 2018).

Conclusion

Actively thinking about *urban fabrics* and *urban regeneration* will assist the conscious delivery of the type of Australian cities we want, by choice not chance. Such thinking is necessary in order to enable the urban sustainability transition that Australia needs to successfully achieve its sustainability and liveability goals (SDGs, Paris, NUA). Delivering sustainable precincts comprising *transit* and *walking urban fabrics*, ideally in *infill* urban regeneration areas, and supported by distributed infrastructure, can help us meet these various international and national agendas, one neighbourhood at a time. Getting these big moves right will put in place beneficial urban structures to support attractive, sustainable and liveable places, for current and future generations of urban residents.

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12

Development of Low-Carbon Urban Forms—Concepts, Tools and Scenario Analysis

Ke Xing, Thomas Wiedmann, Peter Newton, Bin Huang and Stephen Pullen

Introduction

While cities are currently key sources of greenhouse gas emissions (GHG), there are already signs that cities can act as frontrunners of positive change in this respect towards 'low carbon' or 'decarbonisation' outcomes when aligned to regenerative urban development strategies (Girardet 2015; Wigginton et al. 2016). Given the complexity of the urban built environment in terms of forms, fabrics and spatial scales, strategies and measures devised to mitigate urban carbon emissions need to be targeted to the relevant urban settings. From a systems perspective, 'City' and 'Precinct' are two dominant and complex urban built

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forms, at the macro- and the meso-scales, respectively, representing embodiment of land, constructed facilities, transport, and physical and social infrastructures. These infrastructures support production and consumption activities in relation to particular social, economic, environmental and technological contexts. A city can be regarded as a 'system of systems' consisting of a cluster of different precincts interconnected with transport and essential service networks. Often referred to as 'neighbourhoods' or 'districts', precincts represent parts of an urban area that have defined geographical boundaries and serve certain functional or planning purpose(s). They can accommodate multiple uses such as residential, commercial, educational, health, administrative or their combinations (Huang, Xing & Pullen 2017a). They involve spatial, physical and functional interplays of landscape, zonings, buildings, infrastructures (energy, transport, water and waste), as well as occupants. A precinct can be treated as a single entity for specific analyses, planning and urban design, as well as recognising its interactions with surrounding urban features and fabrics and the sustainability implications thus incurred.

Based on such notions, 'City' and 'Precinct' present as two appropriate 'spatial lenses' for developing low-carbon urban forms. They enable urban planners and decision makers to examine and manage carbon signatures of urban settings in accordance with planning purposes at different scales and/or spatial levels. This requires keeping track of not only direct emission reductions instigated by one product, process, technology or activity, but also capturing all indirect changes in emissions instigated by the original change (Ness & Xing 2017). Therefore, a major challenge is with how life-cycle energy and carbon signatures of the fabric and metabolism of different urban forms are defined

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methodologically, quantitatively assessed, and effectively implemented in planning policies, guidelines and regulations for achieving and sustaining 'decarbonisation' outcomes in the long term (Newton et al. 2012). The carbon profiles of such multidimensional and multi-scale urban forms (buildings, infrastructures, precincts, etc.) need to be analysed through a nested, multi-scale assessment to provide urban designers and urban policymakers with an understanding of: (a) where embodied and operational carbon emissions reside, and (b) where intervention or substitution will have the biggest effect.

By drawing upon the research of the Integrated Carbon Metrics (ICM) Project funded by the CRC for Low-Carbon Living, this chapter presents two tools for interrogating and assessing the whole-of-life carbon emissions of built forms at city and precinct scale in order to map out their full carbon profiles, to identify the carbon 'hot-spots', and to analyse the potential pathways for transitions to low-carbon urban development. To this end, the next section introduces an analytical tool, the City Carbon Maps, designed to produce embodied carbon footprint estimates for transboundary emissions mapping and evaluation at the urban scale, whereby the carbon maps of Australian capital cities are also discussed. Then, the rationale and description of the Precinct Carbon Assessment method, a quantitative modelling and analysis instrument for precinct carbon accounting, are elaborated in the following section. A case study of a residential precinct retrofit with scenarios of carbon reduction options is undertaken to demonstrate its application for supporting low-carbon transformation at a precinct scale.

City Carbon Maps

As a basis for action on climate change, it is vital for cities to quantify and report their GHG emissions. It is important to have holistic and accurate carbon accounting for cities to inform the setting of meaningful targets, design successful policies and implement effective strategies for decarbonisation. In this regard, the City Carbon Maps developed under the ICM project aims to identify and manifest the complete flows of embodied carbon emissions for Australia's major capital cities.

Carbon Accounting Method

The City Carbon Map constitutes a consistent accounting framework aligned with national and regional accounting frameworks. To construct a comprehensive carbon map, territorial emissions, including those from transport, energy use, buildings and infrastructure, together with all emissions embodied in materials, goods and services imported into the boundary of a city all need to be accounted for. Following the Global Protocol for Community-Scale (GPC) Greenhouse Gas Emission standard (WRI, C40 & ICLEI 2014; WRI & WBCSD 2011), such emissions can be distinguished in forms of Scope 1 (from sources within the city boundary), Scope 2 (as the consequence of electricity use within the city boundary) and Scope 3 (occurring outside the city boundary, but as a result of activities inside the city boundary) emissions. In defining the carbon footprint of a city, Production-Based Carbon Footprint (PBCF) represents the sum of GHG emissions from all Scopes 1–3. It is important to note that this metric combines in-boundary and out-of-boundary emissions, which means that double counting of emissions may occur. Meanwhile, the Consumption-based Carbon Footprint (CBFC) methodology captures both the direct and the life-cycle GHG emissions, except those emissions embodied in goods and services exported from the city for external consumption by non-residents. Both PBCF and CBCF are covered by the carbon accounting method of the City Carbon Map to present a consistent and complete reconciliation of direct and indirect emissions of all different Scopes described in the standards.

The construct of a carbon map is simply a two-dimensional decomposition of the carbon footprint of a city's final demand. It splits up the total carbon footprint into the industry sectors from which the GHG emissions originate as well as into the product groups in which the emissions become embodied (Wiedmann, Chen & Barrett 2016). This is achieved through the derivation of specific city-scale, multi-region input-output data with environmental extensions using the Australian Industrial Ecology Virtual Laboratory (IELab http://www.ielab-aus.info) (Lenzen et al. 2014). This is a database that combines information on financial transactions between industry sectors and regions, derived from national IO tables published by the Australian Bureau of Statistics (ABS), with GHG data from the Australian Greenhouse Emissions Information System database (AGEIS 2017).

The industrial sectors are aggregated into nine categories: agriculture, construction, electricity, energy, food, goods, services, transport, and waste. The construction sector includes construction materials and services. The electricity sector is separated from other energy sectors to enable standard Scope 2 accounting. Industrial process emissions are allocated to industrial products. Direct household emissions (e.g. from heating or driving) are also included in the footprints.

Carbon Maps of Australian Cities

Based on the concept and the method of City Carbon Maps, the carbon footprints of the five largest capital cities in Australia are analysed. This sheds light on the relationship of the cities territorial GHG emissions, that is, direct emissions from within the geographical boundary of the city, and their out-of-boundary emissions. That is those that occur outside of the city but are related to the consumption of city residents (Wiedmann, Chen & Barrett 2016). The metropolitan area boundaries follow the greater capital city statistical areas (GCCSAs) published by the Australian Bureau of Statistics (ABS 2012). All data and results refer to the year 2009.

The analysis reveals several interesting aspects of embodied emission flows of cities. Perth has the highest per-capita CBCF (35 tCO_2e per capita) of the five cities studied, followed by Melbourne (25 tCO_2e per capita), Adelaide (22 tCO_2e per capita), Sydney (21 tCO_2e per capita) and Brisbane (16t CO_2e per capita). Figure 12.1 presents the relative breakdown of PBCF based on the emission scopes as well as their association with products produced within the city and those imported. Generally, Scope 1 and Scope 3 emissions make up the largest proportions of the carbon footprints of the cities. All cities, except Perth, rely more on GHG emissions from elsewhere in Australia and the world than from their own industries, to satisfy their final demand.

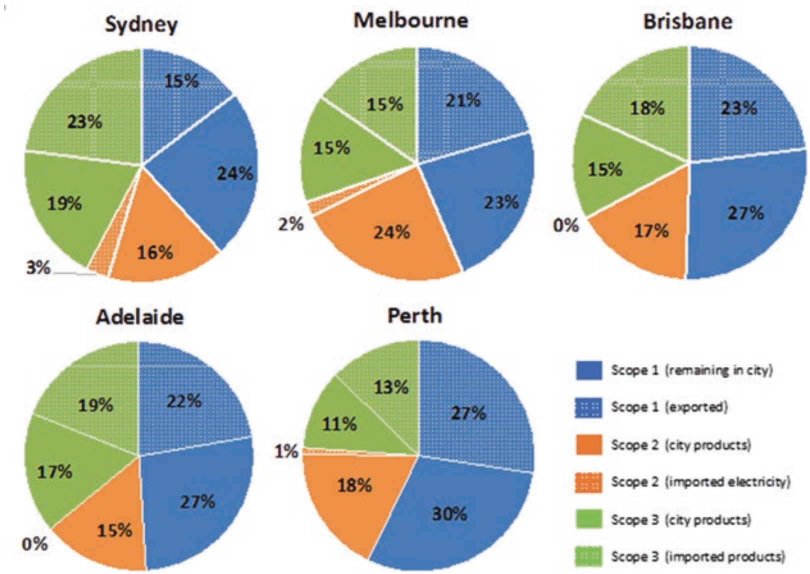

Fig. 12.1 Breakdown of city-related emissions (Production-based Carbon Footprints)

In addition, a breakdown by sectors, shown in Fig. 12.2, reveals that the majority of city carbon footprint emissions are generally attributable to three broad sectors: goods (e.g. clothing, furniture and pharmaceutical goods), construction (e.g. construction materials and services) and services (e.g. financial, legal and educational services). Electricity, food and transport rank second. The use of fossil fuels (energy) in homes and waste have only minor contributions to the overall embodied carbon footprints. Under the consumption perspective, a large proportion of Scope 1 emissions in all sectors, except transport, are exported as embodied emissions to consumption outside of the city. This means that consumers outside the city boundaries are buying goods and services that were produced or sold in the city (e.g. consumer goods or financial products). This reflects the demand for city products elsewhere and the general openness of cities to trade. Meanwhile, Scope 2 emissions are not only related to the direct use of electricity by households

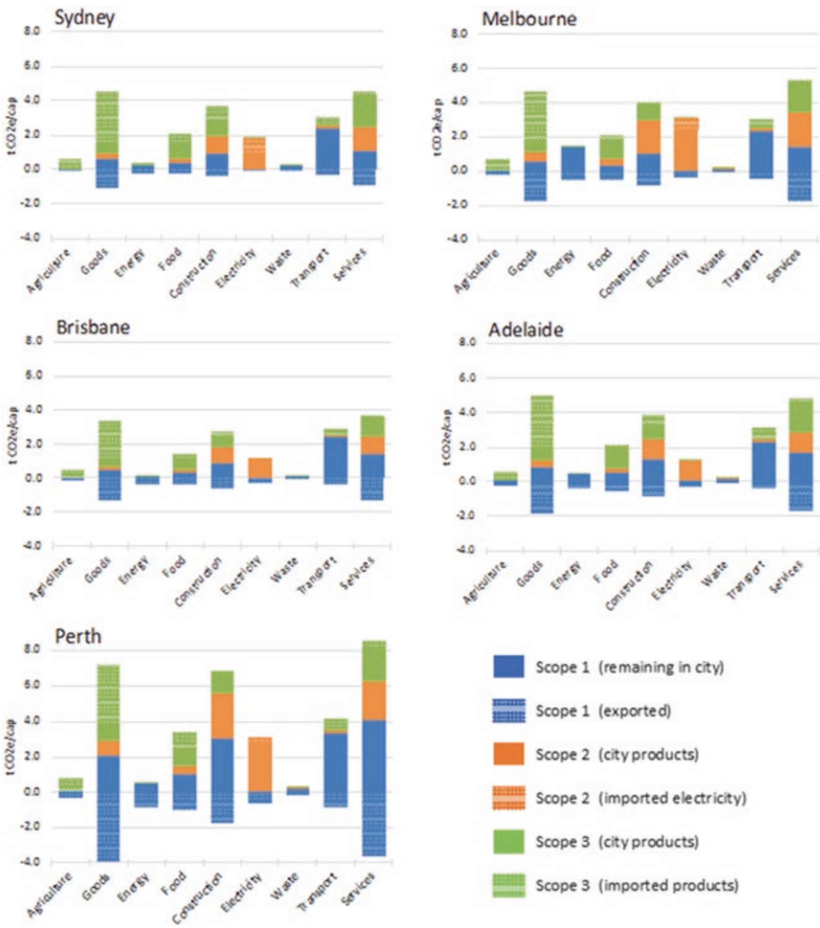

Fig. 12.2 Per-capita carbon footprints of five cities by product categories and scopes (Production-based Carbon Footprint = all values, Consumption-based Carbon Footprint = all values above the zero line)

and businesses (electricity category in Fig. 12.2), but also largely embodied in other sectors, most notably construction and services. Apart from the use of energy (fossil fuels), electricity and transport, Scope 3 emissions make up around one third to over half the carbon footprints of all sectors. There is a very high proportion of Scope 3 emissions from imported goods to Australian cities from overseas. Other sectors that contain significant proportions of Scope 3 emissions are food and agriculture, construction, transport and services.

Implications

For all five cities studied, the City Carbon Maps identify that the top 3 sectors driving carbon footprint emissions are services, goods and construction. While Scope 1 and 2 emissions contribute substantially, it is also the Scope 3 emissions in these sectors that need attention if full carbon neutrality is to be achieved defined here as balancing the total amount of GHG emissions emitted with the equal amount being either reduced or offset through carbon mitigation projects. Scope 2 emissions are certainly the easiest to reduce, by switching to 100% renewable electricity supply. Mitigating the emissions from the electricity sector will in particular benefit the service and construction sectors in all cities as they are all heavily reliant on electricity. Scope 1 emissions from buildings can be tackled with energy efficiency measures and incentives (related to envelope and built-in services and appliances) to a maximum possible extent, before further offsetting by renewable electricity (Newton & Tucker 2011).

Households are responsible for about two-thirds of the city CBCFs, while government and business drive the remaining one third (Wiedmann, Chen & Barrett 2016). More than half of the nation's CBCF is attributable to consumption in the five large cities, with many of those GHG emissions embodied in international imports of goods and services. This suggests that the current focus on territorial emissions would be ineffective at reducing city, national and even global emissions in the absence of mechanisms to monitor and report emissions embodied in trade of imported goods and services. Carbon footprinting should become part of the National Cities Performance Framework (Commonwealth of Australia 2017), with both the emissions embodied in imports and exports monitored, especially for embodied emissions of goods and services that have been shown to make up substantial parts of city carbon footprints. This would complement the approach currently focused solely on Scope 1 and 2 emissions, already implemented by most current city carbon accounting standards and Australia's National Carbon Offset Standards (http://www.environment.gov.au/climate-change/government/carbon-neutral/ncos).

Precinct Carbon Assessment Tool

Precinct Carbon Assessment (PCA) is a carbon modelling and analytics tool developed as part of the ICM Project to examine the whole life cycle of carbon of the urban built environment at a precinct scale. The PCA tool aims to provide both highly aggregated as well as more detailed assessment of *operational **and** embodied carbon* of precinct objects (residential buildings, commercial buildings, and infrastructure), building appliances, transport vehicles and discrete energy generation via solar PVs and storage units. With such functionality, the tool offers the capability to assess different low-carbon development options, including alternative travel modes and renewable energy systems. Figure 12.3 presents a schematic view of the functional features of the PCA tool.

Modelling and Key Parameters

To perform the carbon assessment, the PCA tool supports precinct carbon modelling at the building level, the product level, and the material level. Modelling can range from rapid assessments using highly aggregated data and standard/typical precinct object types (provided by the built-in database) to more detailed analysis using refined data and user-defined precinct object types. Such features can accommodate the needs of those users having different technical competence, resources and objectives.

To satisfy the requirements of different assessment scenarios, the input parameters, in relation to geographical attributes, demographic profiles, precinct morphology, infrastructure attributes, travel modes and energy and carbon intensities of building components, are structured for three

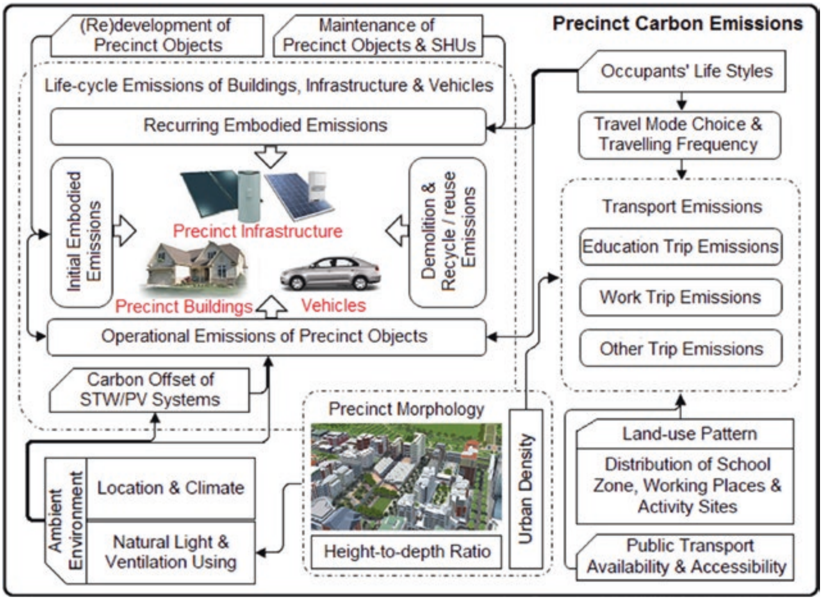

Fig. 12.3 A schematic representation of the PCA tool functions

levels of modelling as shown in Fig. 12.4. Level 1 is designed to suit urban planners and government agencies. It predominantly focuses on early-stage planning at a macro level. Therefore, highly aggregated data on energy/carbon intensity per square metre of each object type is used as the primary input for assessment. The Level 2 modelling is intended for the building and construction phase and associated practitioners. It aims to improve the carbon performance by material/components selection and optimal scheduling of operations for precinct objects. Hence, the data on MJ or tCO_2-e per square metre used in the modelling is built up from the product level, including detailed volumetric data of materials used, energy/carbon intensity of each material/product type, as well as units of use and the operating schedule of each appliance type (built-in and plug-in). For the Level 3 modelling, more detailed information about precinct object designs and travel mode selection is required as input data to support the examination of overall carbon performance from the perspective of design and development.

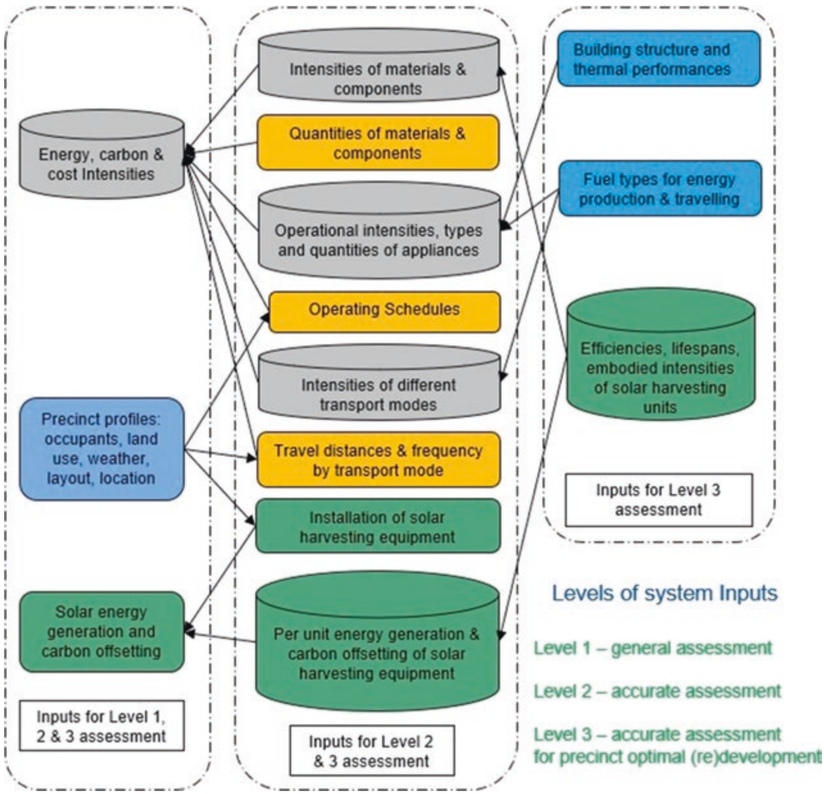

Fig. 12.4 Levels of modelling and input requirements for tool application

Carbon Assessment and Performance Metrics

To support scenario analysis and decision making, the PCA tool employs performance indicators that interrogate operational energy and embodied (both initial and recurrent) energy of buildings, appliances, and infrastructures for transport, energy, water, and waste; transport energy in relation to different transport modes and vehicle uses for commuting and lifestyle; as well as energy generation from deployment of Renewable Energy Harvesting Systems (such as solar PVs and solar thermal hot water units). Based on local power mix and fuel types, these indicators are converted from energy metrics (in MJ) to respective carbon metrics (in tCO_2-e), in terms of both life cycle and annual, for the whole precinct, for different building/object types, and for different types of occupant. Furthermore, Life-Cycle Cost (in dollar value), Cost-Carbon Intensity (in dollar per tCO_2e) and Payback Period (in years) can also be incorporated for analysis and decision making.

The precinct-scale carbon assessment is underpinned by an integrated model that consists of three key phases. At Phase 1, carbon intensities for embodied, operational and transport-related emissions are identified. The embodied carbon intensity of each precinct object type is determined by the life-cycle carbon intensities of main construction materials, the amount of each material required for construction, replacement and waste ratios of building components, as well as the carbon embodied in construction activities (e.g. material and equipment transportation, equipment use, onsite assembly, etc.). The recurrent embodied carbon is measured as the replacement ratios of major building components over the lifespan of precinct objects. As for operational carbon, operational energy intensities of precinct objects are firstly assessed and then emission factors (with the unit of $kgCO_2$-e/MJ) determined by local energy production are used to convert into operational carbon intensities. Transport-related carbon intensities are calculated from fuel consumption considering multiple fuel types, measured as $kgCO_2$-e/km/passenger. Phase 2 is designed for the evaluation of precinct baseline emissions associated with buildings, vehicles, as well as infrastructure services including energy, water and waste. In this stage, parameters interlinked with the environment, local climate, and occupant life-style preference (e.g. total floor area of each building type, schedule of appliances, travelling frequency and distance, etc.) are identified to support the calculation of precinct baseline emissions, together with the carbon offsetting contributed by renewable energy systems. Phase 3 is developed to improve the accuracy of precinct carbon evaluation. At this stage, precinct baseline emissions are moderated by morphological characteristics in relation to factors such as density, compactness, building orientation and obstruction angle. The occupants' life-style preferences are considered and integrated into the baseline carbon measurement by affecting operating hours of appliances, maintenance and refurbishment cycles of precinct building objects and transport mode selections. The impacts of actual precinct morphology or master planning of an urban precinct are analysed to identify the strength of characteristic influencing factors such as urban density and solar potential. Finally, these influencing factors are modified iteratively in order to improve the overall carbon profile of the precinct. More detailed information about the precinct carbon model and the assessment methods can be found in Huang, Xing and Pullen (2017b, 2017c).

A Case Study of Precinct Redevelopment

In this case study, the PCA tool is applied to explore and assess different scenarios associated with the densification of an established low-density residential precinct. This is a common challenge for infill associated with development in all major capital cities, given the rapid surge in population and housing demand. The objective is sustainable low-carbon regenerative redevelopment (Newton 2018). The precinct selected for this study, Andrews Farm, is located 30 kms to the north of Adelaide CBD in South Australia. It represents a typical outer established residential suburb that can be found in any Australian city. Based on 2011 Census data, the precinct had a population size of 7197, with 48.6% of the occupants being less than 25 years old. There were 2034 dwellings within the 273-hectare precinct, which were predominantly single-storey, detached houses. In this study, it is anticipated that the precinct will experience a population growth of 15%. This will require small lot subdivision of land, replacing some of the existing low-density dwellings with medium-density dwellings and introducing an additional 680 new townhouses (two-storey, semi-detached) as part of the densification process (Newton, Meyer & Glackin 2017). It will also lead to increased transport activity and infrastructure for essential services.

For planning purposes, the options for achieving low-carbon redevelopment are:

- Option 1: high energy-efficiency new buildings (i.e. 7-star rating equivalent assumed; current standard is 6 stars),
- Option 2: precinct scale renewable energy system deployment (i.e. increase of rooftop PV installation to 90% with an average of 5 kWp per household assumed), and

Table 12.1 Scenario analysis and comparisons

Carbon measure	Baseline (in tCO_2e)		Scenario 1 (in tCO_2e)		Scenario 2 (in tCO_2e)	
	per annum	per capita per annum	per annum	per capita per annum	per annum	per capita per annum
Embodied carbon	14.9×10^3	2.1	18.2×10^3	2.2	19.0×10^3	2.3
Operational carbon	21.7×10^3	3.0	25.7×10^3	3.1	25.7×10^3	3.1
Transport carbon	18.2×10^3	2.5	19.1×10^3	2.3	10.8×10^3	1.3
Carbon offsetting	−775.0	−0.1	−989.4	−0.1	-4.8×10^3	−0.6
Total carbon	54.1×10^3	7.5	62.1×10^3	7.5	50.8×10^3	6.1

- Option 3: change of occupants' travel mode choice to low-carbon transport for commuting (i.e. increased use of public transport by 35% with an average of 30 km per round trip per day assumed).

Three main scenarios, representing incremental changes, can be considered for the carbon reduction potential. In this analysis, two scenarios are examined and presented to compare with the current 'Baseline', that is, Scenario 1 (changes mainly to the dwelling types based on Option 1) and the Scenario 2 (changes with a combination of Options 1–3).

Table 12.1 summarises the comparison between different scenarios in relation to their carbon signatures. The total carbon of the current precinct (i.e. the 'Baseline' scenario) is assessed as 3243.1×10^3 tCO2e over 60 years or 54.1×10^3 tCO2e per annum, including 775 tCO2e per annum of onsite carbon offsetting from rooftop PV.

According to the results, the carbon signature of Scenario 1 goes up by 15% (i.e. 8.0×10^3 tCO_2e) from that of the 'Baseline', despite having new dwellings of much higher energy efficiency. This is mainly attributed to the increase of embodied carbon (i.e. more houses and expanded infrastructure) and operational carbon from total energy use (i.e. more occupants and more services required for water and waste management) by 22 and 18%, respectively. Consequently, these also lead to slight increase of carbon per capita. Since Scenario 1

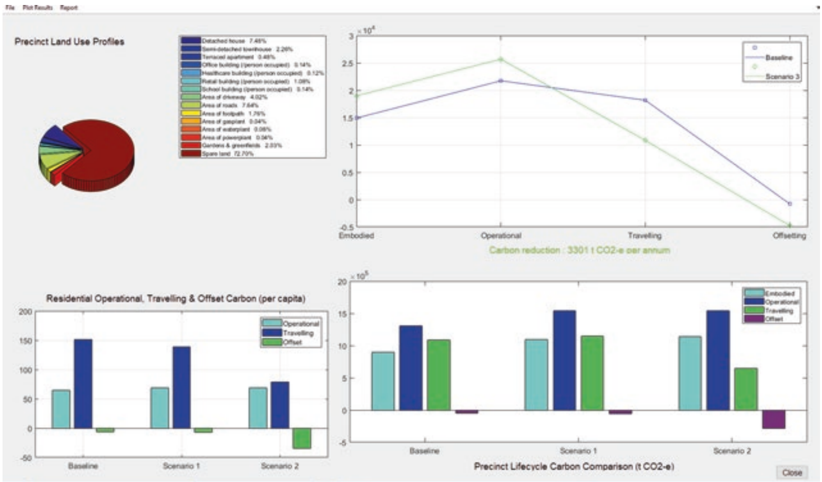

Fig. 12.5 Reporting of the PCA results

incorporates 15% population growth, with anticipated demographic changes related to more small households with young children, it contributes to a marginal increase of total transport carbon and slight decrease of transport carbon per capita. In comparison, Scenario 3 presents potential for achieving more reduction in total carbon, leading to 3.3×10^3 tCO2e (or 6%) less than that of the 'Baseline'. This is a result of having higher onsite carbon offsets generated from a large increase of precinct-scale PV deployment and more uptake of public transport for commuting, as shown in Fig. 12.5.

Implications

The results from applying the PCA tool can provide insights capable of informing planning and policy decision making for low-carbon urban renewal of residential precincts. Firstly, it is clear that population increase will have a major impact on a precinct's carbon signature due to increased housing, transport activities, and consumption of services. Secondly, increasing provision of high energy-efficient houses to reduce operational energy alone has a limited effect on carbon reduction, especially when used as infill in redevelopment and urban densification. In the meantime, the contribution of embodied carbon to the total carbon can rise significantly when infrastructure, especially transport infrastructure (e.g. roads, driveways, paths and pavements), is considered in the assessment. Thirdly, transport carbon represents a very large part of a precinct's carbon signature, particularly for outer suburbs (as shown in this study). Encouraging and facilitating occupants to adopt carbon-efficient travel modes for commuting can be the most effective way for reducing transport carbon, which underscores the importance of Transit-Oriented Development (TOD) and more incentives for the uptake of electric vehicles in urban planning—more so if they are shared (Dia 2019). Furthermore, the effect of solar PV on carbon abatement may not be as strong as what was expected. In this analysis, the implementation of community-scale PV contributes to 8.5% carbon reduction on the basis of an uptake rate of 90%. A precinct-scale deployment of renewable energy harvesting systems (with and without energy storage) needs to be strategically planned and analysed for both carbon offsetting and economic effectiveness. A combination of solutions for housing, infrastructure, travel and renewable energy is required to address all carbon measures holistically for developing precincts capable of achieving low-carbon targets.

Conclusion

A major challenge with 'decarbonising' urban development is how life-cycle carbon signatures of different urban forms are defined and quantitatively assessed in the context of twenty-first century built environments. In this chapter, two assessment tools developed from the ICM project are applied to the assessment of carbon footprints of built forms at the city scale and at the precinct scale.

The City Carbon Maps aim to examine the embodied carbon emissions of cities from the perspective of production and consumption, as well as from the import and export of goods and services both within and across city boundaries. The complete carbon flows of the five major

Australian metropolitan areas are analysed as examples to inform possible decarbonisation strategies and policies by different urban stakeholders—especially Federal governments, where embodied carbon in international trade flows have been ignored to date.

While the City Carbon Maps tool provides a 'whole-of-system' view of the carbon profile of a city, the Precinct Carbon Assessment (PCA) tool adopts a bottom-up approach to model and analyse the life-cycle carbon metrics of a precinct, in the context of its built environment objects and morphological features. It provides users with flexibility to adjust precinct design settings, renewable energy system options and carbon intensity data of precinct building material objects in order to conduct quantitative analysis in the pursuit of finding best-practice solutions. By doing so, it can help to identify carbon 'hot-spots' and to assess different design and development options directed towards 'decarbonisation' outcomes for the built environment.

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13

Health and the Compact City

Mark Stevenson and Jason Thompson

Introduction

From the early writings of Graunt (1662), cities have been linked to poor health. As populations migrated from rural to urban areas the challenges associated with poor sanitation, contaminated water, overcrowding, poor or no housing and exposure to pathogens particularly in port cities, led to widespread infectious diseases (Grob 2009). The challenges faced by cities in the sixteenth century are not too dissimilar to those confronting cities in the twenty-first century. Urban migration and growth continue today, with more than one half of the world's rapidly growing population now living in cities, and projections this will rise to 75% by 2050 (Montgomery 2007). Associated with the urban

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population growth, cities are confronting an array of problems: fossil fuel depletion, climate change, ageing and insufficient urban infrastructure, housing affordability, food and water shortages, social isolation, and a rising burden of non-communicable disease, road injury and mental ill-health.

Urbanisation and Health

Over history, urbanisation has been driven by industrialisation. This is best illustrated, recently, in China where over the 10 years to 2010, 226 million Chinese residents migrated from rural areas to cities for employment (Yang et al. 2018) and during this same period, the country's Gross Domestic Product, a measure of the country's productivity, grew by 40% (National Bureau of Statistics 2015). Living in a city offers opportunities that are not available elsewhere; including opportunities related to access to health systems. In contrast, living in a city also results in exposure to an array of health risks.

As purported by the World Health Organisation (WHO 2016a), the leading health risks associated with urbanisation relate to access to clean water, the environment, violence, injury, NCDs (including cardiovascular diseases, cancers, diabetes and respiratory diseases such as asthma), poor diets, physical inactivity, alcohol abuse and infectious diseases. Many of these health risks are a consequence of increased population densities, exposure to air pollution, greater levels of car dependency (hence reduced physical activity), noise and heat, increased access to unhealthy food choices and a lack of green space (Nieuwenhuijsen 2016).

The array of health risks prevalent in urban areas are unevenly distributed throughout cities resulting in considerable health inequalities. In Australia for example, the health inequalities are exhibited between residents in the peri-urban compared to residents in inner-city areas. The prevalence of health risks such as obesity for example, is 2.3 times higher in peri-urban areas of the Melbourne metropolitan area compared to the inner-city Melbourne area (North Western Melbourne Primary Health Network 2017). Since 2000, health inequalities in the United States have moved from being predominantly an inner-city challenge to one that is increasingly experienced in the suburbs (Allard 2018). In China the health inequalities are greatest among the spatially segregated urban poor who are confined to certain old neighbourhoods (Yang et al. 2018). Inequalities between neighbourhoods and their built environments are an ongoing challenge. Socioeconomically disadvantaged neighbourhoods experience considerably more negative health impacts compared to less disadvantaged neighbourhoods (Gray, Edwards & Miranda 2013). Much of the health inequalities observed across cities are a consequence of social inequalities along with poverty and both risk factors need to be targeted if efforts to reduce the health inequalities are to occur (Harpham 1997). Urbanisation and rising health inequalities are just one of many sets of indicators that highlight the need to begin to understand how the multiple urban systems interact and contribute to the health of city residents.

Cities, Complexity and Health

A healthy city is only healthy for its time; it may become unhealthy as the world changes around it. No greater example of this comes from the advent of the motor vehicle, which has facilitated substantial change in urban design and the consequent understanding of what contributes to healthy and desirable locations.

Motor vehicles radically changed the shape and size of cities and were originally considered a great benefit to those with means to afford them. Car ownership created opportunities for people to escape beyond what were often polluted, crime-ridden, high-density city centres to suburbs that promised sunlight, ventilation and enhanced health (Lopez 2012). Trends towards rapid motorisation in the post-World War 2 period were witnessed particularly in countries such as the United States, Canada, Australia and New Zealand (Bell 1956). These countries shared common features at the time of expanding economies, large tracts of unoccupied land in which to enlarge city footprints, democratic and individualistic cultures, and urban infrastructure that was largely unaffected by the tragedy war. In this early post-motorisation era, the suburbs, not the city, offered the greatest opportunities for health.

However, as motor vehicles became more affordable, both their numbers and consequences grew. The move to the suburbs facilitated the expansion of city boundaries (Bell 1956; Bhatta, Saraswati & Bandyopadhyay 2010), introduced low-density sprawl, and divided cities into discrete areas linked by emerging and extensive arterial roads and highway systems (Dargay & Gately 1999; Giuliano & Dargay 2006). Cars, originally designed for a select few, were suddenly becoming 'mass transit' (Noland 2001) and the negative externalities of motor-vehicle-oriented transport systems in terms of road injuries, pollution, and congestion (i.e. productivity) grew. Today, the *solution* that was motor vehicles, kill 1.35 million people each year in road transport crashes and contribute 25% of particulate pollution that accounts for 4.2 million deaths per year through lung cancer, cardiovascular and respiratory disease (Gorz 1973; WHO 2018). Cars are no longer a transport solution but rather, an increasing health and planetary challenge.

Given these issues, cities are now looking towards alternative transport systems that do not rely entirely on the private car and are re-imagining the benefits of what is deemed 'a compact city' namely, one that negates the need for motorised private transport. Transport policies that embrace new urban mobility (i.e. those that focus on sustainability and take account of urban change, provide alternatives to private motor vehicle use and utilise advances in digital technologies that deliver innovation) are taking hold as they promise not only population health gains but important environmental gains (WHO 2016b). For example, widespread electrification of motor vehicles, greater shared vehicle trips and enhanced active transport infrastructure that facilitate walking and cycling trips in cities are predicted contribute to reductions in global energy use and CO_2 emissions by 70 and 80%, respectively (Mason, Fulton & McDonald 2015; Replogle & Fulton 2014). As well, there is much focus on the preservation and extension of urban green space not only for potential physical and mental health gains and also to mitigate the negative externalities of urbanisation such as urban heat island effects (Feyisa, Dons & Meilby 2014), and motor vehicle-related air pollution (Selmi et al. 2016).

What we have alluded to above highlights that cities are dynamic sociotechnical systems. The study of cities needs to be undertaken from this perspective. Methods that do not or cannot appreciate the dynamism of cities may fail to capture the breadth of factors that contribute to city performance and therefore the health co-benefits.

Multiple urban systems namely, water, transport, housing, the economy and the social environment, contribute to the health of city residents. Despite this understanding, there is limited research on how the various urban systems interact to enhance or negatively impact, the health of city residents. The paucity of research is due, in part, to the complexity of cities. Cities are dynamic environmental, technological, population and economic systems which makes it difficult to understand or even predict the likely urban transitions contributing to the health of city residents. Consequently, to understand dynamic urban systems and to derive policies that target the health of city residents, there is a need to develop and utilise integrated models that include the relevant inputs, outputs and urban system related outcomes.

Galea and colleagues (2005) advocate for researchers, urban planners and policymakers to re-focus their attention from disease outcomes and to better understand the multi-level risk exposures in cities (exposures such as the risk per vehicle kilometre travelled, exposure to particulate matter in the air, levels of green space) that influence the health and wellbeing of city residents. Researchers are beginning to embrace such approaches using large data sources which include important exposure and outcome measures at a global scale (Thompson et al. 2019). These transdisciplinary approaches to understanding the health determinants of cities are key to developing sustainable policies that support population health.

Unique approaches to understanding complexity and our cities is well illustrated by Bettencourt and colleagues (Bettencourt et al. 2007). They applied the universal scaling laws applied in biology (West & Brown 2004) to the study of cities. Their research has highlighted that many characteristics of cities such as patent production, elements of a city's infrastructure (such as the length of electrical cable) are power law functions linked to a city's population size and an exponent β. Exponents reflecting '…wealth creation and innovation have $\beta \approx 1.2 > 1$ (increasing returns), whereas those accounting for infrastructure display $\beta \approx 0.8 < 1$ (economies of scale)' (Bettencourt et al. 2007, p. 7301).

Recent research applied social connectedness (measured by accessing mobile phone data) along with the social determinants as an extension to these universal scaling laws. Pan et al. (2013) found that the universal scaling laws increased super-linearly. Research such as that by Bettencourt et al. (2007) and Pan et al. (2013) is providing unique insights in relation to how cities might operate and what role various urban systems independently, or in combination, could contribute to health outcomes of city residents.

New methods along with varied applications of existing analytical methods, in association with unique data, will increasingly provide insights on the health of city residents. There is considerable value in integrating real-time data gleaned from analytics obtained from cars, public transit, energy providers and or personal smartphones for example, with complex systems models such as life-course and or agent-based models in ways that will guide how best to intervene to reduce the considerable health inequalities (Bettencourt 2018). Unique analytical approaches capable of exploring the complexity of cities will be valuable in determining whether policies such as those advocating compactness (compact city models) will deliver safe, sustainable and healthy urban environments.

Compact Cities and Health

Currently at just over 7.3 billion people, the world has added a massive 1 billion people since 2005 and 2 billion since 1993 (United Nations 2017), most of whom have been added to city populations. Managing the exponentially increasing city populations in both high, middle and low-income countries has become a significant global challenge. City residents require a constant supply of resources to ensure productivity and viability of the city and yet consumption of these resources has both positive and negative ramifications. Safe and healthy food, clean water, clean air, safe housing and safe transport are among the most basic of urban amenities and yet locations of extraordinary economic dynamism and progress, locations such as Eastern China, are experiencing levels of airborne pollution due to increases in motor vehicles, energy production and industrial processes that are equivalent to smoking up to 25 cigarettes a day (Rohde & Muller 2015). The fact that the City of Cape Town, South Africa, a city of nearly 4 million, is fast running out of water due to an unprecedented drought while residents in cities in California and Northern Europe are now facing regular threats from a new generation of wildfires, fuelled by global climate change, highlights the complexity of the urban challenge. As does the city of Lagos, Nigeria where its population has increased 100-fold since 1960 and shows little sign of slowing. While Lagos' levels of waste, air pollution and road trauma soar (Onyemaechi & Ofoma 2016), its levels of formal planning, governance and infrastructure capable of tackling the challenges remains limited.

In both Australasia and North America, rates of being overweight and obesity leading to the development of Type 2 diabetes, cancers and associated metabolic diseases are hovering between 60 and 70% (Ng et al. 2014). The combined effect of poor diet, high sugar intake, low levels of physical activity, smoking, and other modifiable lifestyle factors driven in part by the reinforcing influence of low-density, car-dependent cities provide little avenue for change.

As global rates of infectious disease rates have declined, the rates of other non-communicable diseases (NCDs) have moved to take their place. Some of these illnesses are the likely and arguably natural result of an ageing population (e.g. Alzheimer's disease, some cancers, cardiovascular disease, pneumonia: Heath 2010). However, most are a result of the current urban-age (Horton & Lo 2015). Road trauma, Type 2 diabetes, heart disease, respiratory disease, heat exposure and cancer; combined, these illnesses now account for 70% of the global morbidity. They are all, in part, attributable to the way our cities have been purposefully designed (Roux 2013).

Attempts to optimise city design for the promotion of population health are not new. Looking historically, at the peak of Spain's international conquests (during the late 1500s), a set of 148 ordinances known as '*Leyes de Indias*' (The Law of the Indies) were handed down by then King Phillip II to ensure the colonial power's new towns met criteria for promoting population health, recreation, commerce, microclimate, security, beauty and social order. These laws stipulated city planning rules that were explicit in relation to the health of city/town residents. City planning emphasised starting with a central, public plaza that was to 'be square or rectangular…of no less than 200 feet wide and 300 feet long'. The configuration of streets surrounding the plaza required, 'four principal streets: One from the middle of each side and two streets from each corner of the plaza' (Mundigo & Crouch 1977, pp. 254–255). Elsewhere, 'smaller plazas of good proportion', were also to be laid out, creating a characteristic chequerboard pattern in the city (see Fig. 13.1).

Influenced by Graeco-Roman planning before it and combined with the collective Spanish experience of instigating hundreds of new settlements from the late 1400s onward, *Leyas de Indias* formalised the construction of a city typology that could be repeated time and again by Spanish settlers in regions across the Americas and beyond. The template set out a comfortable, recognisable, and compact urban form for Spaniards travelling and emigrating to the 'new world' (Mundigo & Crouch 1977).

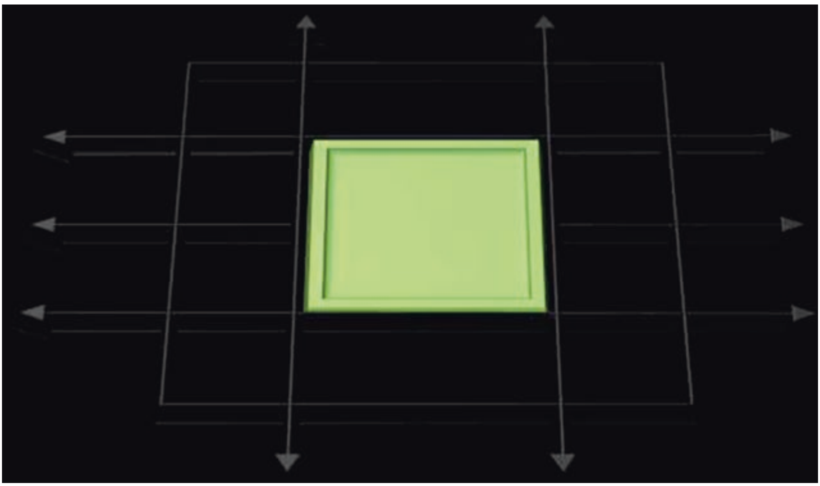

Fig. 13.1 Illustration of ordinance 112–114 from the Leves de Indias, demonstrating characteristic design principles set out for central plazas, which were the starting point for new settlements initiated during the period of Spanish colonialisation

There is much discussion in the research literature with respect to the opportunities (or otherwise) that a compact city model or approach may deliver with respect to health outcomes (OECD 2012). There are a number of definitions of what compact cities comprise, but the overriding component is that compact cities embrace a mixed land-use along with considerable residential and population densification across the entire city (Badland et al. 2014). As a consequence, by achieving what some term 'compactness', the opportunity for reduced distances between place of residence and employment for example, and the potential for integrated public transit to facilitate movement around the city is greatly enhanced; it is these attributes that are espoused as ones that create healthy and more sustainable cities (Forster 2006).

Recent research (Stevenson et al. 2016) assessed the health implications, particularly reductions in non-communicable disease and injury, of a compact city scenario. Stevenson et al. (2016) modelled land-use densities in 6 selected cities (Melbourne, Australia; London, United Kingdom; Copenhagen, Denmark; Delhi, India; Sao Paulo, Brazil; and Boston, United States of America) whereby land-use was increased by 30% (from city-densities described in 2014), the diversity of land-use was enhanced by 30% (from mixed-use ratios based on 2014 city estimates), and average distances to public transit were also reduced by 30%. As a consequence of increasing the compactness of the cities, opportunities for changing transport mode choices were also assessed namely, supporting a 10% modal shift away from private motor vehicle use to active transport modes namely, walking and cycling.

The approach to increasing these land-use elements to reflect a compact city resulted in considerable reductions (between 13 and 19% in cardiovascular disease alone) in the burden of disease (Stevenson et al. 2016) highlighting what could be achieved if cities were able to plan or enhance current land-use such that it reflected a city of short distances, greater mixed use and at the same time, increased public transit and presided over a population transition to active transport using safe infrastructure. This study, the first to highlight that a compact city influences the health of its citizens, points to the need for increased efforts to understand the implications of compact cities not only in relation to health, but other urban systems including, housing, transport, energy and water.

Despite this recent study, and the considerable environmental benefit including up to 30% reduction in energy consumption and the carbon footprint associated with compact cities (Williams, Burton & Jenks 2000), the research is not unequivocally supportive of compact cities approaches in relation to the potential health co-benefits (Giles-Corti, Ryan & Foster 2012). These contrasting views are central to current debates concerning the relationship between city design and health. While designs, measures and mechanisms are argued, and competent researchers from medicine and a spectrum of social sciences attempt to distil the 'true' nature of relationship between urban design and health, there is still surprisingly little that is agreed upon. This may be in part, a reflection of the methods that have been used until now are too narrowly focused.

Increasingly, cities are being appreciated for their complex, dynamic nature that resist being harnessed by the typically linear methodological frameworks that have served the health sciences for generations (Roux 2013). Cities are dynamic. Their infrastructure and people change, grow, adapt and develop habits and cultures, healthy or otherwise. Technologies advance and are displaced; creating efficiencies, solutions, bottlenecks, demands and instigating new challenges. In short, there is no ideal healthy city that is impervious to change nor invulnerable to future, unforeseen, sociotechnical changes that come to surround it. It is therefore not surprising that the empirical research methods from the last half of the twentieth century may be inadequate for grappling with such complexity (Pongsiri et al. 2017).

Conclusion

As highlighted in this chapter, there is an array of health risks associated with increased urbanisation including air pollution, greater levels of car dependency (and therefore reduced levels of physical activity), noise and heat, to name a few. The potential to adopt a compact city model namely, a city of greater population and residential densities, a model that supports integrated public transit designed around short distances and thereby optimising the opportunity for walking and cycling as part of the transport journey is integral to enhancing the population health of twenty-first-century residents. Research is beginning to quantify the health benefits associated with compact cities. However, these benefits need to be evaluated in the context of problems that may also be associated with densification of our cities. What this points to, and alluded to briefly in this chapter, is the urgency to embrace a complex systems approach to understanding and managing our cities. As Diez Roux (2013, p. 12) highlights, '…the use of systems approaches will allow us to see and understand patterns and trends that researchers, communities, and policymakers may not otherwise be aware of'. Embracing new complex systems methods and approaches will ensure the potential co-benefits of implementing policies that support compact city approaches are considered across multiple urban systems domains thereby ensuring planning and policies relevant to twenty-first-century cities, are productive, environmentally sustainable and importantly, enhance the health of city residents.

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14

Low Carbon Urban Mobility

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Introduction

The reform of urban mobility remains one of the biggest challenges confronting policy-makers around the globe (Wilson 2012; Winston & Mannering 2014). The key challenges facing our cities include rapid urbanisation, road safety, congestion, environmental emissions, the growing infrastructure investment gap, fiscal pressures and declining

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revenues,, and the increasing need to provide resilient urban transport systems that promote accessibility to jobs and opportunities.

The global urban population is increasing rapidly. Today, more people live in urban areas than in rural areas. Around 200 years ago, only 3% of the world's population lived in urban centres (Armstrong et al. 2015). The urban population of the world grew from 746 million people in 1950 to 3.9 billion in 2014 (United Nations 2014). In 2007, for the first time in history, the global urban population exceeded the global rural population. Since then, the world population has predominantly remained urban. In 2014, 54% of the world's population was urban and the trend is expected to continue so that by 2050, the world will be 66% urban and roughly one-third rural (United Nations 2014).

Road traffic also continues to account for around 80% of transport CO_2 emissions and is expected to reach 9000 Mt per year by 2030 if the current mobility trends are not curbed (International Transport Forum 2010). Emissions from transport have been shown to be growing more rapidly than those from other anthropogenic activities (Righi, Hendricks & Sausen 2015). In the time period 1990–2007, the EU-15 CO_2-equivalent emissions from land transport increased by 24%. In the year 2000, emissions from land transport comprised 74% of the global CO_2 emissions from all transport activities (Eyring et al. 2009; Uherek et al. 2010). This growth is expected to continue in the future, due to increasing world population, economic activities and related mobility (Righi, Hendricks & Sausen 2015). In the year 2000, there were roughly 625 million passenger light-duty vehicles (PLDVs) around the world (IEA 2013). By 2010, that number had reached nearly 850 million

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PLDVs. Modelling by the International Council on Clean Transportation (2012) predicts a doubling of the world's motor vehicle population over the next twenty years. Modelling by the International Transport Forum (2010), using Carbon Dioxide Equivalent (CDE) measures, projects that transport emissions would grow by 9 $GtCO_2$ eq by 2030 and increase by a further 110% above 2010 emissions levels by the year 2050. These forecasts underscore the importance of current and future policies that target reductions in oil consumption and GHG emissions from the transport sector.

In addition, it has also been estimated that the social, economic and environmental costs of avoidable congestion account for a large percentage of a country's GDP. At the international level, the avoidable cost of congestion is estimated to account for more than 1% of the GDP across the European Union, and currently cost the United States more than $115 billion each year (European Commission 2011). For the Australian capital cities, the cost was estimated to be around $16.5 billion in 2015 and forecast to grow to around $30 billion by 2030 (BITRE 2015).

Finally, inadequate or poorly performing infrastructure impedes economic growth and presents major challenges for governments around the world. Without well-maintained and resilient transport infrastructure—roads, rail and public transport—cities cannot meet their full growth potential and economic targets. At the same time, investment in new infrastructure and urgent maintenance of existing assets comes at a time when many governments operate in constrained budgetary environments and have competing demands on their scarce resources. This issue affects developing countries and also many nations in the developed world. From the US through Europe to the emerging world, the backlog of projects includes upgrade of existing assets and proposals for new projects to drive economic growth. One of the pressing issues in both developed and emerging markets is the need to invest in transport infrastructure that provides connectivity and ease of access to jobs and opportunities. Although technology has a big role to play in asset optimisation and making better use of existing assets, many cities still suffer from a lack of integrated and connected networks of transport systems.

The Opportunities

There is increasing wide recognition and acceptance that addressing transport issues through building additional road capacity is not sustainable, and does not solve traffic congestion or improve mobility in cities.

Sustainable transport policies and intervention measures provide opportunities to meet the needs and demands of citizens and businesses in urban environments. Setting a city on a course towards sustainable transport requires a roadmap and a holistic vision which incorporates different strategies to meet the demand for travel, including public transport and active transport policies. In recent years, technology has also been playing a big part in enhancing the performance of existing assets and thereby reducing the need for building additional infrastructure.

Low carbon mobility is defined as 'mobility that results in substantially lower levels of carbon' (Giovani & Banister 2013). There are four key strategies to achieve this. The first one is the 'Avoid' strategy which implies the need to change the social norms and travel behaviour to ones that require less mobility (e.g. telecommuting and living nearer to shops and services). The second is to 'Shift' travel from energy-intensive modes to different forms of transport (e.g. from car to train or cycling or walking). The third is to 'Share' transport and mobility resources (e.g. ride-sharing or car-sharing). The fourth is the 'Improve' strategy which calls for improving the fuel efficiency and emissions of vehicles (e.g. the use of hybrids and electric vehicles) and also maximising the efficiency of the physical infrastructure that is required for the movement of people and goods.

The topic of low carbon mobility is not new. Researchers and policy think tanks have tried to advance this agenda before but it has met with limited success. The renewed interest and opportunity today stems from the new interpretations that have begun to focus on both the supply and demand sides of travel, and a better understanding for traveller behaviour and the inputs and contributions to the topic from multidisciplinary teams. This has also been facilitated through the convergence of a number of forces such as shared mobility, digital innovations and disruptive mobility models which are introducing new options for travellers through ride-sharing and car-sharing through easy to use and reliable technology platforms. The proliferation of Intelligent Transport Systems (ITS) throughout transport infrastructure also means that disruptions and incidents are detected quickly. This information is then provided to travellers with more ease and speed than ever before, providing them with options to change mode of travel or time of departure.

Integrated Land-Use and Transport Planning

A low carbon urban mobility transition requires consideration of the relationships between transport planning and land-use planning. Land use-transport integration (LUTI) is concerned with the development, management and operation of urban transport systems that provide for sustainable outcomes for our cities. It is primarily concerned with the optimal distribution of facilities and services in an urban area so that these are available to all of its inhabitants in ways that minimise adverse environmental impacts while maximising opportunities for sustainable economic development and social interaction.

Given the traditional trade-off between housing type and location, with resulting impacts on demand for transport which have been largely met by the private car in suburban locations, strategies to reduce urban carbon emissions need to be directed at providing substantial alternatives to that mode, based around greater use of the active modes and public transport. To make this transition feasible requires in-depth consideration of built form, relationships between transport modes and land-use development, land-use mixes, the location and intensity for services and facilities and the supporting infrastructure and precinct planning and design including the relationships between neighbouring precincts and between precincts and major activity centres such as the CBD. A consideration of these planning issues combination may be collectively described in terms of LUTI, with policies for and implementation of LUTI offering the pathway to urban sustainability.

Sustainable cities require land-use planning decisions that support the use of public transport and the active transport modes of walking and cycling. Active transport is very suitable for short distance trips, and is flexible and timely. Most trips involving public transport usage include active transport access to the transit services, even if this is only walking to a bus stop. It is also vulnerable and erratic. It has also been largely neglected in conventional transport planning, and indeed in urban design—urban spaces and corridors for pedestrian movement need to be (and be seen as) safe, attractive and efficient places to be in and to move through. Encouraging active transport—for example by locating destinations closer to origins and so reducing trip lengths—may not only be the key to reducing environmental impacts but also lead to improved public health, through increased physical activity and fitness, and improved productivity, through reduced congestion and time spent on the roads and reduced stress among commuters.

The key concept behind LUTI lies in what may be taken as the basic driver of urban development: accessibility. In broad terms, accessibility is concerned with the ability of people, households and enterprises to engage in everyday life. The notion of accessibility in transportation planning can be illustrated through a basic definition: accessibility is 'the ease with which desired destinations may be reached' (Niemeier 1997). In particular circumstances such as those pertaining to low carbon mobility and the availability and use of alternative transport modes, this broad definition may be refined to explicitly include other relevant factors, such as time dependency which may be an issue in, for instance, assessing accessibility levels for public transport users where the level of service of public transport provision varies widely over hours of the day or days of the week. Thus Primerano and Taylor (2005a, b) defined accessibility as 'the ease for people to participate in activities from specific locations to a destination using a mode of transport at a specific time'. This is an appropriate definition for use in urban studies where different regions within a metropolis have different levels of access to public transport services. 'Wegener's Wagon Wheel' model (Wegener 1996) of the urban development process (and the interaction between the land-use and transport systems) illustrates the primary role of accessibility in the key decisions that underpin urban development and urban activity.

Figure 14.1 shows this model. Urban development is a continuous process in the figure. Its central part—the 'wheel'—comprises the

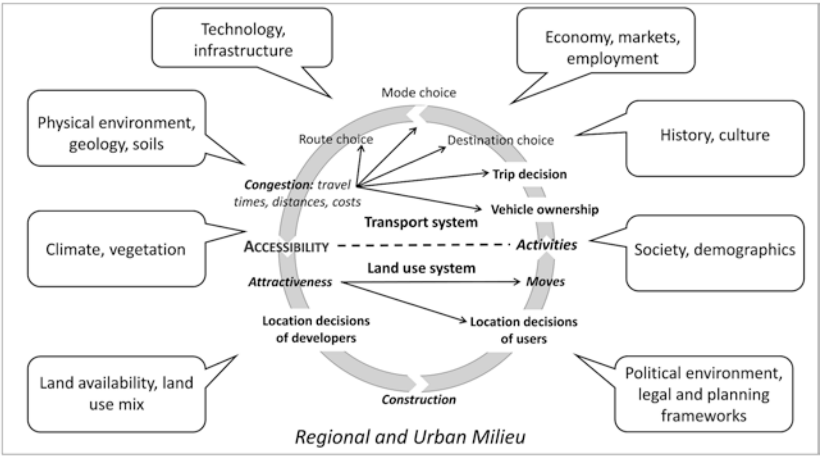

Fig. 14.1 Wegener's 'Wagon Wheel' conceptual model of urban development, land use-transport interaction and the role of accessibility (*Source* Adapted by author from Wegener 1996)

land-use system and the transport system, connected through accessibility and the activities undertaken in the urban area. The wheel includes a number of decisions made by different players and a number of outcomes stemming from those decisions. The outcomes are indicated in italics in Fig. 14.1. The basic outcome is the set of activities. Location decisions of developers and consumers are made on the basis of the relative accessibility of different areas—outcome 'attractiveness'—including their suitability for different activities (services and facilities). The accessibility of a given location is affected by the travel choices of the consumers (when, where and how to travel, and of course a basic decision about private vehicle ownership and use), which lead to the development of congestion and hence the actual (time, distance and cost) separations between localities. These separations affect the accessibility actually experienced by people, hence the ongoing evolution of the system. Choices of location, vehicle ownership and travel depend on (or are influenced by) broader characteristics and influences of the urban area, including its physical environment, history and culture, social and economic environment and available technology. These factors in the urban milieu serve to influence the choices of players in the urban development system, at macro, meso and micro levels. While subject to external shocks (such as geo-politics, energy prices and overall economic conditions, including competition between regions and cities, and climate change) the system is effectively closed and is evolutionary.

LUTI policies and planning practices may be used to influence location and travel decisions in a city towards achieving goals of sustainability and low carbon mobility, by facilitating use of active transport and public transport and by location of services and facilities close to residences, so that travel distances are reduced for some trip purposes and high capacity public transport is widely available for longer distance travel. Issues concerning the roles of public transport and the active modes are highlighted in the next sections of this chapter.

Public Transport

Significance of Public Transport in Achieving Low Carbon Mobility Outcomes

The environmental and social costs of current urban transport systems are huge in Australia where carbon pollution from transport is second only to the generation of electricity, and the scale of emissions is increasing.

Electric and autonomous vehicles, powered by renewables, are a necessary part of the solution. But, for many reasons, we cannot continue to build our cities around the demands of single-occupancy vehicles. In developed cities, roads and carparks typically alienate 30% or more of the land area encroaching on space which is more valuable for essential social and economic interaction as well as removing the carbon sinks embodied in natural environments and agricultural land. Further, the health costs of sedentary lifestyles will force a re-assessment of the value of active travel.

To meet the challenges of creating an effective carbon-constrained city that also tackles the complex and inter-related requirements for healthy and happy citizens, we must encourage greater use of mass transit and active travel. No urban region has been entirely successful in creating the conditions in which public and active transport systems offer access to urban life with speed and convenience approaching that of the private car, but some have done much better than others. The key is the extent to which a city rejects the idea that more roads will solve the problem of crowded roads. The endless repetition of attempts to build a way out of congestion is often justified by the assertion that there is no alternative: many argue that low population density and dispersed trip patterns in the suburbs where most people live are insurmountable obstacles to competitive public transport at an affordable cost. Fortunately, however, this is not the case.

The possibilities for creating effective and efficient public transport systems even in dispersed suburbia rest on the existence of the 'network effect'. This is a synergistic effect of organising transit services (usually in a multimodal system) in a way that increases demand at a faster rate than that at which new financial resources are added. This approach challenges the traditional 'diminishing returns' argument used by transport economists and is fundamental to understanding how public transport planners can do much more with their available budgets than most transport economists predict. Traditional public transport planning approaches take users' dislike of transfers as evidence that it is necessary to eliminate them wherever possible, thus creating service patterns in which each individual line is used to connect a multiplicity of origins and destinations. This is self-defeating unless huge financial resources are available.

Emerging Trends, Best Practices and Elements of Success

A public transport network can be designed and operated in a hierarchy of interconnected multi-directional nodes. Transfers are essential to the ability of such system to operate both efficiently and effectively. So, the task of transport planners and urban designers is to remove obstacles to 'seamless' transfer such as poor physical design, uncoordinated timetables and financial penalties imposed by fare systems that, for example, charge separately for bus and train travel within a single journey.

The success of a network also relies on maintaining a universally high level of service through cross-subsidies from busy radial trunk lines to the less patronised, but essential, feeder and cross-town services. This observation supports the notion that the creation and maintenance of an effective network requires planning and management by a public agency. A further requirement for success is to ensure that coordination of a public transport network is done within a framework for land-use planning that recognises the relationship between transport policy choices and objectives for economic development, population health, the maintenance of good air quality and the protection of the environment. With such relationships established, often through community engagement to identify common values and visions, it is possible to set clear targets for desired changes in mode share.

Elements of a successful 'networked' public transport systems can be found in many cities, but the exemplars are in German-speaking Europe. The most progress in a 'new world' city can be seen in Vancouver. These cities have won their success through skilful action by planners, communities and politicians to maintain a consistent approach to transport and land-use policy over many years. This is not to say that there is unanimity or an absence of contention over these policies, particularly in the suburbs. Instead, past success is used to build the political constituency to weather attempts to turn back the clock.

These real-world achievements show the way to a low carbon transport future for other cities.

Active Transport

Active transport—walking and cycling—is an integral part of sustainable transport and the quest for low carbon mobility (Giovani & Banister 2013), as well as offering health and social benefits. Besides environmental improvement, reduced energy consumption and carbon emissions, active transport can reduce demand for other modes of transport and provide more human scale activity 'on the street', enhancing safety and security for all. Opportunities for increased usage of active transport modes should result from initiatives in low carbon planning and design, both at the local level and broader urban scale. Assessment of changes in usage of active transport modes from low carbon mobility policies and implementations requires the establishment of baseline data on present levels of usage.

While there is a current policy impetus for the uptake of active transport for both environmental and human health benefits, reflected in an increasing understanding of how to plan and design for active transport (Giles-Corti et al. 2016), in Australia rates of active travel across the population are generally low. Nevertheless, there has been an increase since 2011, especially in inner-suburban areas where home-to-work distances are shorter than in the outer suburbs (DIRD 2015). The *State of Australian Cities* report (DIRD 2015) saw active transport as a potential antidote to traffic congestion, which is increasing in Australia's cities, particularly Sydney. Ogilvie et al. (2004) provided a systematic review of research from Europe, the USA and Australia regarding interventions to promote active transport usage. They found consistent evidence that transport policies increasingly seek to reduce traffic congestion by discouraging car use and encouraging the take-up of active modes.

Policies and initiatives to increase active transport usage are generally predicated on two grounds: (i) improved environmental sustainability and (ii) enhanced health outcomes. For the latter, walking and cycling may be undertaken expressly for the purpose of recreation and exercise, but this activity is also undertaken for utilitarian transport purposes. This can include access to public transport or for local trips to specific destinations. Some researchers have considered the ability of active transport, either for recreation/exercise or for transport, to meet health supportive targets for physical activity. International data provides strong evidence for the population level health benefits of active travel (Pucher et al. 2010). Tudor-Locke et al. (2005) used Australian Bureau of Statistics (ABS) Time Use Survey data to consider representative patterns of walking for transport and exercise. They found that although walking for transport was often undertaken in multiple brief episodes, the accumulated durations approximated the desired levels of recommended activity in public health guidelines. Cole et al. (2006) also considered walking activity with respect to these guidelines. They found that walking for transport was less likely to meet the guidelines when compared to walking for recreation and exercise. There were also socio-demographic differences. Men over 60 years were less likely to walk for transport, while men 45–59 years were more likely to walk for recreation and exercise. Women were more likely to meet public health guidelines than men. Wasfi, Ross & El-Geneidy (2013) studied daily walking activity in Montreal. They confirmed the important role of public transport in supporting active transport, indicating that suburban rail users could achieve much of the recommended activity for health benefits by commuting to work or school.

A useful descriptor of travel behaviour is the trip length frequency distribution (TLFD). This is a statistical distribution showing the relative spread of travel by distance or time. One representation of the TLFD is the cumulative distribution function (CDF), which indicates the probability of trip lengths equal to or less than a given value. Developing sets of TLFD for different travel modes, varying trip purposes and for different socio-economic groups, provides a broad picture of travel behaviour in a region. Taylor and Thompson (2018) analysed active travel behaviour in Melbourne, Australia using the VISTA household travel database (DEJTR 2018), including the development of TLFD for walking and cycling in terms of a range of socio-economic factors.

Travel behaviour was considered in three dimensions: travel decisions (number of trips), transport load (travel distance) and travel exposure (time spent travelling). Travel in Melbourne was dominated by the private car. This accounted for nearly half of all trip numbers, more than 60% of travel distance, and just over half of travel time. Vehicle driver was the most popular mode for all dimensions (46% trip numbers, 60% distance and 52% time). In terms of trip numbers, walking was the second most popular mode (22%). Vehicle passenger was the second most used mode in terms of distance and time. Walking accounted for 2.0% of travel distance, and for 12.7% of travel time. Distances travelled on foot were much less than those for wheeled modes, as expected, but walking was the third highest mode in terms of travel time. Public transport (train, tram, school bus and public bus) accounted for 8.2% of trip numbers, 10.7% of travel distance and 10.6% of travel time. Train was the dominant public transport mode in Melbourne, especially for distance travelled. In an overall context, bicycle use was small, constituting 1.5% of trip numbers, 1.0% of distance travelled and 2.1% of travel time.

There were interesting variations to the overall modal split statistics in terms of trip purpose for the active modes. Walking was the most popular mode for education trips accounting for just over 40% of total trip numbers and 26.5% of travel time (and 6.3% of travel distance). Cycling accounted for about 2% of education travel by trip numbers and travel time, and 1% by travel distance. Recreation trips include both travel to a place to take part in recreational activities and any travel that is the recreation itself. Cycling accounted for 5.7% of trip numbers, 4.6% of travel distance and 8.8% of travel time, the highest percentages for that mode under any trip purpose. Walking was the second highest mode for trip numbers and third highest for travel time for recreation trips.

In terms of general usage, the analysis of trip length frequencies by mode and socio-economic characteristics suggest that walking is a universal activity. It is undertaken by many people at similar activity levels across the community. Cycling, on the other hand, is very much an activity undertaken by a small minority with different rates between diverse groups, especially in terms of age and income (although household bicycle ownership is comparable to household car ownership). An indication of these factors is given by Fig. 14.2, which shows the TLFD for walking and cycling trip distances, by gender. Walking activity for males and females is effectively identical, but there are large differences for cycling, with males riding longer distances.

A full discussion of active travel in Melbourne is given in Taylor and Thompson (2018). They concluded that there is significant potential for increased use of active transport modes. For walking, policy and urban design measures, especially at the precinct scale, to offer more destination alternatives that can be easily accessed on foot could be particularly useful. Travel on foot is an activity available for most people and trip purposes, provided suitable destinations are available. Mixed-use developments at the precinct scale—LUTI—can provide these, and when coupled with frequent and high-quality public transport services, can offer a wider set of alternatives still. Walking is a fundamental travel mode, inexpensive and providing health and social benefits. The median

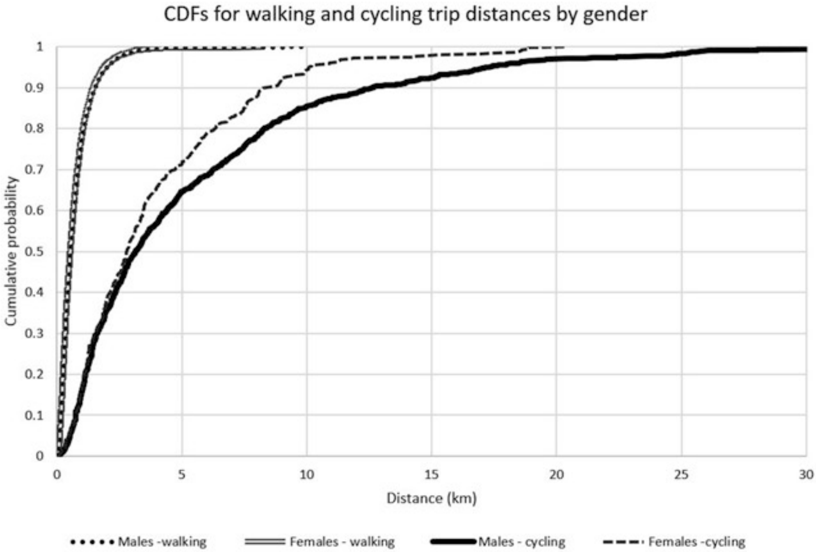

Fig. 14.2 Walking and cycling trip length frequency distributions (TLFD) as cumulative distribution functions of travel distances by gender in Melbourne

walking distance for single episode walking trip segments in Melbourne was found to be 540 m, while the 85th percentile distance was 1.24 km.

Planning and urban design measures could increase walking opportunities and activity, but this will require a paradigm shift. As noted by Negron-Poblete, Séguin and Apparicio (2014), pedestrian activity is not dependent on distance alone, but can also be adversely affected by obstacles to movement, particularly for seniors in suburban locations. Urban design sympathetic to travel on foot is therefore a key consideration for low carbon mobility.

Urban Mobility and the Sharing Economy

Significance of Car-Sharing and Bike-Sharing

Earlier studies (Böcker & Meelen 2017; Firth 2012; Möhlmann 2015) have shown that people's lives improve from the responsible expansion of shared transportation options. The shared mobility paradigm prioritizes people over vehicles, promotes equity and encourages information sharing. Shared fleets also enable significant reductions of CO_2 emissions as intensive per-vehicle use will lead to an accelerated fleet replacement, and thus newer technology vehicles will penetrate the market faster, further reducing CO_2 emissions.

Car-sharing provides short-term access to motor vehicles for personal and business uses without the costs and responsibilities of ownership and operation. As private car usage rarely exceeds 10% of the day, shared mobility is helping to increase low levels of private vehicle use in both space and time (OECD 2016). The idea of sharing a car is no longer new with companies like GoGet offering vehicles for timeshare among a local population, or those like Uber allowing cars to be shared by multiple people at the same time. However, there is still a resistance to share space in a large vehicle with members of the public, and public transport agencies need to be more aggressive in their attempt to attract riders. Car share services are at a crossroads in Australia due to waning enthusiasm from local councils that reflects a strategic uncertainty by this level of government about the relevance, importance and value of the service (Phillip Boyle & Associates 2017). The scale and growth of this service is not significant in many Australian cities and this leads to a situation where no existing (business as usual) policies, practices or paradigms are challenged. Bike-sharing is a pro-environmental, cheap and healthy mode of transport. In Australia, safety concerns (more specifically mandatory use of a helmet) and a lack of cycling infrastructure (dedicated bike lanes) were found to affect uptake. From the local authorities' perspective, dock-less share bikes have created huge headaches due to levels of abandonment. Table 14.1 documents worldwide issues and barriers to the provision of sharing economy mobility services and provides a comparison with the initial findings from a CRC LCL study being conducted in Adelaide.

Emerging Trends and Best Practices

Vehicle sharing is attracting significant investments from start-ups and venture capitalists from both business-to-business (B2B) and

Table 14.1 Key issues and barriers to the provision of sharing economy mobility services

No	Key issue	Worldwide barriers	Adelaide specific barriers
1	Car-sharing	• Lack of public policy implementation campaign in public policy • Lack of enough on-street parking spaces • Car-sharing insurance requires approval by governmental policies • Lack of privacy for personal travel	• Low accessibility • Lack of user's acceptability • Lack of strong policy support, e.g. a parking levy, registration cost
	Shared autonomous vehicles	• Fragmented politics and government inexperience • Social and moral dilemmas present a challenge in automation programming • Absence of vehicle-to-vehicle (V2V) and vehicle to infrastructure (V2I) communication • difficulties in insurance liability • Substantially increase synergies between autos and transit	• Lack of public awareness • Lack of infrastructure communication • Fragmented Politics and government inexperience
2	Bike-sharing	• Rebalancing bikes across the network over time • Lack of optimal routes that facilitate rebalance • Limited cycling infrastructure • Challenge of rider safety and poor safety perceptions • Requirement for strong entrepreneurs • Lack of joint partnership • Lack of financial funding	• Lack of adequate funding • Limited cycling infrastructure • Safety concerns • Vandalism of dock-less bikes
	Shared electric bicycles	• Electric charging infrastructure in public places is lacking	• Lack of public preference • Concerns such as theft vandalism

(continued)

Table 14.1 (continued)

No	Key issue	Worldwide barriers	Adelaide specific barriers
3	First/last mile multimodal sharing	• Require support to promote consumer mobility behaviour • Low quality of transport infrastructure • Require an integrated ticketing system across all modes • Lack of intermodal traffic information • Require an improved collaborative relationship between service providers and the local governments	• Low quality of transport infrastructure • Require an integrated ticketing system across all modes • Lack of intermodal traffic information • Require an improved collaborative relationship between service providers and the local governments
4	The technology of IoT, Big Data, cybersecurity and blockchain	• Loss of privacy • Past data lacked the capacity to explore scenarios and limited in its application to network planning, design and evaluation • Constraints posed by legislation, infrastructure and sufficient supply of transport services	• Loss of privacy • Past data lacked the capacity to explore scenarios and limited in its application to network planning, design and evaluation • Constraints posed by legislation, infrastructure and sufficient supply of transport services
5	Policies	• Taxation challenges • Lack of quality and trustworthiness in current evidence-based research • Difficult in establishing peer–peer exchange networks • Difficulties in utilising social media tools	• Lack of leadership and collaboration • Lack of quality and trustworthiness in current evidence-based research • Difficulties in utilising social media tools

business-to-consumer (B2C) market's funding (Wallenstein & Shelat 2017). Car-sharing and bike-sharing have also given rise to peer-to-peer (P2P) systems that enable vehicle and bicycle owners to rent their vehicles and bicycles when they are not in use. Last year more dock-less, app-unlocked versions began to appear in Australia, where start-ups such as Ofo, oBike and ReddyGo have entered the local market.

From a user's perspective, the density of stations and availability both of bikes and spaces to park the bikes will be the main considerations (ITDP 2018). The best practice is to aim and achieve a good station density within the catchment area so that it ensures that no matter where a user is, there will be a station within a convenient walking distance to both the origin and destination of his or her trip. Technology is fast changing, and some entrepreneurs are introducing shared economy mobility schemes which are against the local laws. However, they believe that they become so popular that local or state authorities will be forced to change the laws to accommodate them and eventually these schemes will become legal.

Future Outlook

The role and extent of Smartphones, internet connectivity and Cloud will expand, allowing consumers to efficiently search for their desired services, understand the terms of use and ensure timely logistics. Going forward, the transaction costs will continue to decrease as more friction is removed from sharing platforms. Blockchain, which is a digital ledger of economic transactions is gradually maturing and will play an important role in popularising shared services using P2P networking. Internet ubiquity will make sharing the products and services more accessible. Moreover, the expense of transferring goods will be significantly reduced due to better access to self-driving cars, drones and delivery robots; all of which will facilitate a more extensive geographic expansion of the potential market for shareable goods. Though the sharing economy is in its infancy stage now, when the sharing of transportation assets becomes the norm, the situation will change, and there will be a new transportation network. However, each city is unique, and there will be a wide array of services that will fit within the existing transportation network with scope for further evolution. Technology is making P2P, services more accessible and more convenient but more importantly in future, the most significant disruption would come from autonomous vehicles, as the technology is on its way (OECD 2015).

Digital Innovations for Smart Urban Mobility

The Role of Digital Innovations in Improving the Performance and Efficiency of Urban Mobility

The convergence of physical and digital worlds is creating unprecedented opportunities to enhance the travel experience for millions of people and businesses every day. Disruptive and emerging forces—including on-demand shared mobility, big data analytics and autonomous vehicles are expected to change the mobility landscape and provide travellers with more choices to meet their travel needs while reducing reliance on building additional infrastructure. The coming together of these trends is providing new opportunities to 'sense the city' and unlock operational innovations and open up access to high-quality urban mobility. Through data mining, artificial intelligence and predictive analytics, smart mobility systems can help city managers monitor the performance of vital infrastructure, identify key areas where city services are lagging, and inform decision-makers on how to manage city growth.

Decision-makers and leaders who run our complex cities are increasingly recognising the role of smart technologies in improving the efficiency of existing infrastructure and sweating of assets through better utilisation of available infrastructure (Hobbs & Hanley 2014). These systems can significantly improve operations, reliability, safety and meet consumer demand for better services with relatively small levels of investment (Batty 2013).

The smart infrastructure paradigm includes applications of information technology, data mining, sensors, smart algorithms and predictive analytics to improve the performance of infrastructure systems and asset management in the buildings, energy, health, water and communications fields as shown in Fig. 14.3. Smart cities of the future will therefore include advanced network operations management and control systems that utilise field sensors to detect and respond quickly to equipment and infrastructure faults. This will reduce downtime in vital city services by using these sensors to monitor the health of critical

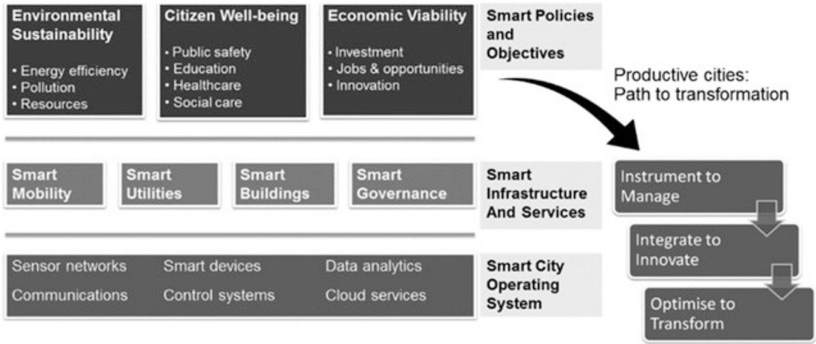

Fig. 14.3 Smart cities model (*Source* Dia 2015)

infrastructure, collect data on system function and identify potential breakdowns before they occur and when necessary alert operators inside an integrated urban control centre to the need for predictive maintenance (Batty 2013).

Figure 14.3 clearly suggests that technology should be viewed and used only as an enabler to achieve a city's desired objectives. These objectives include, but are not limited to, environmental sustainability (energy efficiency and improved air quality), citizen well-being (public safety, education, social care) and economic viability through providing access to jobs, services and opportunities. To achieve the desired transformation, cities would need to harness the increasingly available amounts of data that is crowd sourced as well as from smart urban infrastructure. To develop insights into this information, the data needs to be integrated, fused and mined to establish patterns and trends which can be used to optimise city services and transform cities to meet the desired policies and objectives.

Smart Mobility

The impacts of digital innovation have already started to be felt in cities around the world. Technology has brought with it smartphones, connected devices and infrastructure, highly automated vehicles and access to large amounts of real-time traffic data. For the first time, road users have access to increasingly more sophisticated applications to help them plan their journeys and meet the demands of their travel. This fundamental shift offers consumers a real choice based on real-time and in some cases predictive information that allows users to plan ahead and anticipate delays and disruptions to their commute. New technologies also offer consumers mode choices based on comparative pricing and current network status. As transport operators change their business models, and new start-ups and technology providers enter the urban mobility landscape, new business models will continue to transform the use of information, payment, integration and automation (Deloitte 2015).

Providing access to high-quality urban mobility services requires a variety of planning and operational innovations, as well as better understanding of travel behaviour, operational processes and the factors which affect these issues. The last five years, in particular, have seen rapid developments in technology and a marked shift in the thinking towards the provision of mobility solutions to meet people's demand for travel in urban areas.

Smart mobility essentially includes systems that are used to provide seamless, efficient and flexible travel across all modes of transport. This includes a number of elements which make up smart mobility including instrumented smart infrastructure, ITS, operational and strategic modelling. In addition, it also includes some of the emerging disruptive mobility solutions including mobility-as-a-service and the anticipated autonomous shared mobility-on-demand services.

In practice, this should translate into smarter connected vehicles, trains and public transport systems which would increasingly sense their surrounding environments and enhance safety in situations where driver error is most common (Winston & Mannering 2014). For example, on-board public transport, a range of GPS, position fixing, video surveillance and communications equipment are increasingly providing more accurate and reliable multimodal real-time passenger information, resulting in better-informed travellers and ensuring a smoother, safer and more reliable experience for customers (Neumann 2015). Back-office systems that leverage sensors, web, mobile and GPS technologies are increasingly utilising smarter algorithms, data mining and predictive modelling tools to reduce delays to passengers by optimising schedules and capacities in real time. Electric vehicle charging infrastructure will also increasingly be integrated into smart grid networks, providing consumers with access to sustainable and equitable forms of connected mobility (Yi & Kandukuri 2012).

Conclusions

Cities are a complex network of interconnected systems. The challenges facing transport in our cities—rapid urban growth, dependence on motorised transport, reduced access to services and activities etcetera—are structural in nature and must be framed as part of a holistic approach to improve urban form in cities. Solutions and interventions which recognise this complexity will have a strong potential for charting a course towards sustainable urban mobility.

In planning and designing urban mobility solutions, it is essential to recognise travel as a 'derived demand' but also a 'valued activity'. Travel originates from the need for people to access places, jobs, opportunities, services and activities. The purpose of most travel is to earn income, purchase goods, attend schools etcetera. The transport infrastructure and the vehicles, cars, trains, buses and bikes that move on it are simply the means to achieve these ends. From a practical perspective, this implies planning and designing compact, mixed-use communities that reduces the need for travel while improving pedestrian and bicycling infrastructure. This in turn would lead to less reliance on private cars.

Reframing the primary objective of urban transport as one for improving access to jobs and opportunities gives priority to policies and strategies which promote transit-oriented developments, improved public transport services, active transport infrastructure and less reliance on policies that encourage private vehicle usage. The concept of accessibility should apply to all segments of society to ensure that the poor and disadvantaged have good access goods and services within the city.

Ten key principles from the 'Avoid, Shift, Share, Improve' framework presented in this chapter include: Planning dense and human scale cities; Developing transit-oriented cities; Optimising the road network and its use; Improving public transport; Encouraging walking and cycling; Controlling vehicle use; Parking management; Promoting clean vehicles; Stakeholder consultation and engagement; and Creating pathways and adapting regulations to comprehensive deployment.

Also, the connection between land-use and transport needs to be rebuilt and strengthened to achieve sustainable urban mobility. An integrated approach to land-use and transport shifts the focus of planning from placement of structures and designation of land-use to that of enabling the realisation of people's needs and everyday functions in the most efficient and sustainable manner. Within this approach, the key challenge is therefore to foster an integration of multimodal mobility within a holistic and sustainable land-use system.

Finally, a strong link exists between transport supply and demand, and urban form. Mixed-land use developments reduce the need for travel and promote active transport. Quality transport connections between functional places and facilities improves access and increases functionality of each place, leading to a reduction in the distances and number of trips between origins and destinations. This can be achieved through creative planning and urban designs, combined with innovative infrastructure and transport engineering designs. Also, achieving low carbon mobility requires prioritisation in the choices of infrastructure investments. The current imbalance in funding and investments between private and public modes of transport needs to be corrected. This applies equally to developed and emerging countries. It is not sufficient to pursue policies that 'balance' investments between different modes of transport. More initial funding should be allocated to developing and expanding non-motorised and high-capacity public transport infrastructure. The option of value capture to complement public funding should be examined to generate sustainable funding streams. Besides being a politically appealing option, this funding model also reinforces the link between land-use and transport.

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15

Integrated Urban Water Systems

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Introduction

This chapter provides information on the potential role of *Integrated Urban Water Systems* in sustainable urban development. It considers how water management can help improve not only water resource management, but also energy use, greenhouse gas emissions and liveability.

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Low carbon cities and net energy positive buildings are rapidly becoming a reality. However, significant water challenges remain to be solved in the urban environment. Connecting rooftop solar PV to the centralised grid, for example, is far less problematic than, say connecting a decentralised rainwater or stormwater harvesting scheme into the mains distributions system due to supply and quality issues. Effectively integrating sustainable water systems into cities, using cities as *water supply catchments*, delivering *water sensitive urban design* and using water to aid liveability (such as mitigating urban heat), in low-energy and affordable ways, are generational challenges.

The chapter considers frameworks for accounting for water's role in cities, understanding the broader role that water can play in energy and greenhouse gas management, and liveability. We particularly use and draw on the concept of *urban metabolism* as a framework for understanding and managing water and related energy in cities. This framework has long been viewed as relevant to water and energy management in urban systems (Tambo 2002; Wolman 1965).

Integrated Urban Water Systems considers all water flows, including both *natural* and *anthropogenic* flows. Flows that are part of the *natural* water cycle are the precipitation that falls on an urban area, and flows of runoff, infiltration and evapotranspiration. Flows that are part of the *anthropogenic* cycle are the centralised and decentralised water supplies and the resulting wastewater.

Urbanisation alters these flows, with knock-on adverse effects to the quality of the environment. Of particular significance is the impact that increasing densification and urban infill is having on the loss of greenspace, canopy trees and ground surface permeability (Fig. 15.1). *Integrated Urban Water Management* considers management of all flows of water to minimise impact and maximise environmental, social, economic values.

There are also virtual flows of water into urban areas, which are embodied in the goods and services consumed by urban inhabitants. This is discussed in Wiedmann et al. (this volume).

Mitigating the adverse effects of urbanisation on water will require a transition towards *water sensitive cities*, which takes an integrated approach to water management using adaptive multi-functional

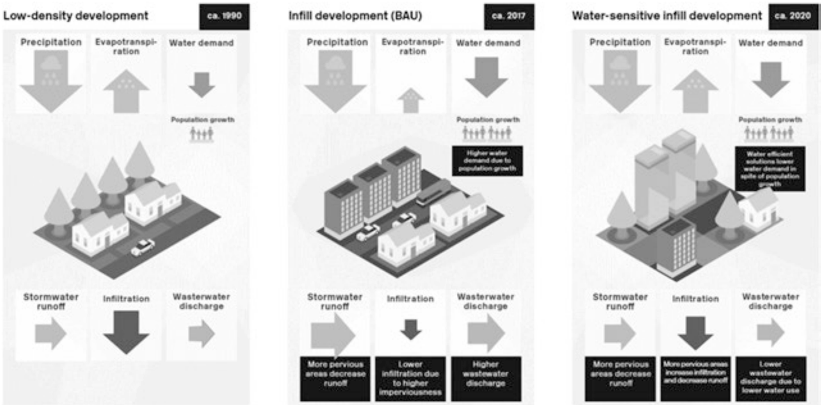

Fig. 15.1 The influence of urbanisation on urban water balance (*Source* CRC for Water Sensitive Cities 2018, with permission)

infrastructure. The challenges of this include managing a diversified and diffuse range of fit-for-purpose water sources, changing urban design, achieving high levels of end-use efficiency, restoring waterway health and reinforcing water sensitive values and behaviours in the community (Wong & Brown 2009).

Urban Metabolism Evaluation Framework for Water

Integrated management of urban water necessitates an integrated assessment of these flows, which is surprisingly absent in contemporary metropolitan planning strategies. One evaluation method that can assist is urban water metabolism evaluation (Renouf & Kenway 2016), after (Wolman 1965). The urban metabolism concept considers how an urban area consumes and transform resources, with the intent of replicating the metabolic efficiencies of natural systems (Fig. 15.2). As an evaluation approach for urban water, it quantifies the exchanges of water between a defined urban area and its supporting environment, to generate a comprehensive and integrated urban water mass balance (Fig. 15.3).

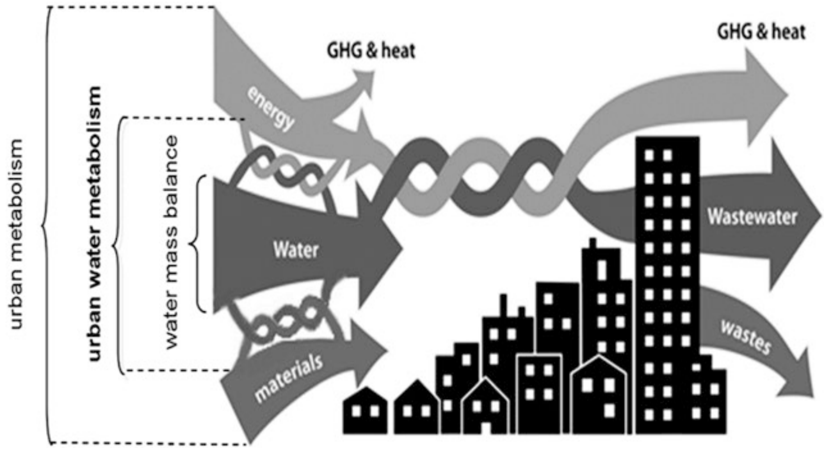

Fig. 15.2 Urban metabolism, water metabolism and mass balance as nested concepts (*Source* Adapted from Renouf et al. 2017, with permission)

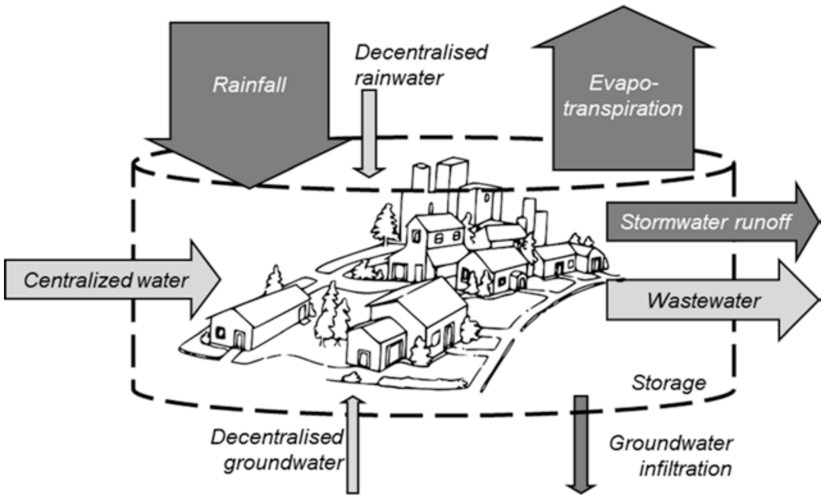

Fig. 15.3 Urban water mass balance in an evaluation framework (*Source* Adapted from Renouf et al. 2016, with permission)

Urban water metabolism as a conceptual framework shifts the way we conceptualise urban water management. It forces us to consider a city as *an entity*, as a three-dimensional system boundary. It uses mass balance to quantify all flows of water between the environment and the entity, including changes in storage. In so doing we can quantify how the entity *interacts* with the environment. This *mass balance* is a paradigm shift from the traditional *water balance* used by most utilities which is founded on *supply* must equal *demand*. This *urban water metabolism evaluation framework* enables performance indicators to be established, guided by the principles of an efficient metabolism:

- hydrological naturalness, reflecting the extent to which runoff, infiltration and evapotranspiration are altered relative to a pre-urbanised reference state;
- water supply internalisation, in terms of the proportion of urban water demand met by harvested precipitation and/or wastewater recycling;
- urban water efficiency, in terms of the volume water sourced externally from the environment (vs internally from the city), per capita per year;
- water-related energy efficiency, in terms of energy used for treating and pumping all the urban water flows, per capita per year.

At the *city-region* scale, it was used to understand the type and scale of water sensitive interventions that may be needed to improve the water metabolism of three rapidly growing Australian *city regions* (Renouf et al. 2018). The interventions considered included water demand reductions, harvesting and use of rainwater and stormwater, wastewater recycling and increasing the perviousness of hard surfaces, all implementable across the city-region. It found that the benefits from each initiative on their own were very modest, and that combined implementation of all would be necessary to effect a noticeable improvement. Evaluation at this large urban scale provided a screening of the broad opportunities and interventions, and showed the relative significance of benefits from each. It also provided quantified justification for the different priorities for the different cities based on region-specific conditions. It can inform strategic regional planning by promoting dialogue about what the desired performance for the city-region as a whole, and by screening the type and scale of initiatives that may be needed to achieve it.

At *precinct* scale, the framework was used to compare the relative water metabolism performance of water servicing alternatives for a new urban development, considering not just the water flows but also water-related energy (Farooqui, Renouf & Kenway 2016). The water servicing options considered were harvesting and use of rainwater and stormwater, wastewater recycling (both within and outside the urban system) and greywater recycling (both within the household and within the appliance). It found that use of harvested rainwater/stormwater offers dual benefits of improving urban water efficiency and reducing stormwater flow, compared with wastewater recycling that only helps the former. Energy trade-offs occur when the alternatives supplies are used at household scale due to the low pumping efficiencies, but energy benefits are possible for precinct-scale implementation. Interestingly, significant energy savings were found to be possible for greywater recycling within the appliance (e.g. recirculating shower) due to heat recovery. Evaluation at this urban scale enables consideration of the appropriate scales for decentralised water supplies, and optimisation for both water and energy efficiencies. It can inform local government priorities for local decentralised water schemes.

At *site* scale, the framework was used to evaluate the water sensitive performance of different housing designs, in the context infill development in Australian cities (Renouf et al. 2019). It tested whether good infill design that embraces water sensitive principles can mitigate the adverse effects of intensified urban densification. The hydrological naturalness of three dwelling design scenarios were quantified and compared. It found that a water sensitive dwelling typology can mitigate the adverse hydrological effects of infill densification, such that dwellings for additional residents can be accommodated without substantially changing the current hydrology. Evaluations at this scale can show how the physical urban design (residential buildings, road reserves and public spaces) can influence environmental performance, especially in relation to hydrological flows. It can inform local and state government programmes aimed at guiding, regulating or incentivising better outcomes by developers.

Urban metabolism forces us to think differently about water supplies in terms of those sourced from the environment (*external*) and those sourced from within the urban system (*internal*). This approach is different to the conventional distinction been centralised versus decentralised supplies, which refer to the way water supplies are managed rather than where they come from. The *external* versus *internal* distinction allows for performance indicators that reflect a desire to reduce reliance on *external* water, and to incentivise *internal* water.

The framework also provides a perspective on the whole urban area to give water managers and urban planners a more comprehensive picture for the purpose of setting objectives and targets that are regionally relevant. It could also consider all the diverse functions of water in the urban landscape, such as water use that facilitates recreation, urban heat mitigation and amenity. These are currently not well accounted for, and tend to be the first to be switched-off in times of drought. Having a better account of the water needed to service these will help with better planning and budgeting even in times of drought.

Energy Influences of Urban Water Systems

Urban water systems have large direct, and even larger indirect influence on energy use, and greenhouse gas emissions. Multiple studies demonstrate that the energy use of water and wastewater utilities is substantial, typically accounting for 1–2% of regional primary energy use (Liu et al. 2016; Olsson 2015; Sanders & Webber 2012). Many authors also show that water use by residents, industry, commerce and agriculture routinely accounts for over five-fold the energy use of water utilities (Elías-Maxil et al. 2014; Gerbens-Leenes 2016; Klein et al. 2005), and up to ten-fold when all components are included (Kenway et al. 2015; Sanders & Webber 2012). Collectively, this means that approximately 10% of regional primary energy use is influenced by urban water systems.

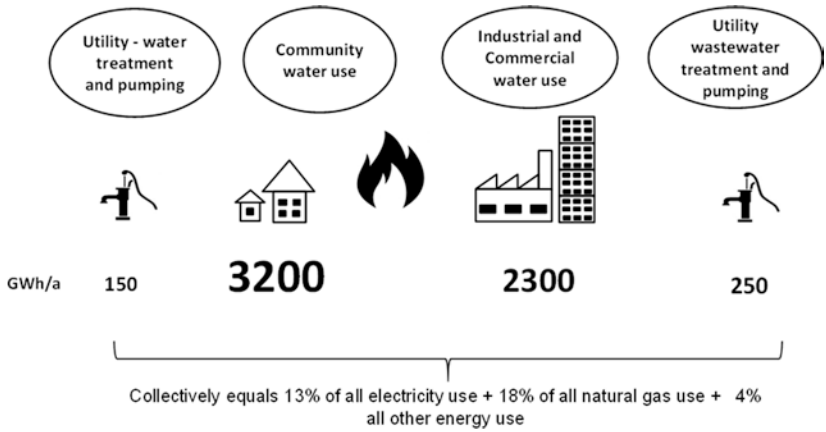

Fig. 15.4 Water-related energy in South East Queensland in 2012

Understanding the energy intensity through the urban water cycle is valuable because it helps shape understanding where greatest savings of energy and greenhouse gas emissions can be achieved. To illustrate the significance of these differences, Fig. 15.4 summarises water-related energy in South East Queensland, Australia. This demonstrates that in 2012 water and wastewater pumping by utilities accounted for some 400 GWh of energy use, primarily as electricity. In contrast, community and industry water users consumed around 5500 GhW energy, primarily as heat (gas and electric heating of water for showering, bathing, clothes-washing and taps). In industry and commerce, *water-related energy* can include, for example, steam production, air-conditioning and cooking.

GHG Emissions Implications of Urban Water Systems

Quantitative tools are available to help us understand the potential for integrated urban water systems to assist in decarbonising cities—life-cycle assessment and marginal abatement cost curves.

Life-cycle assessment has been widely applied to evaluate environmental impacts of urban water systems, including the life-cycle energy use and greenhouse gas (GHG) emissions. This technique considers all the life-cycle phases of an urban water system including the impacts of operation (Scope 1), the inputs to the system, especially energy (Scope 2) and sometimes the embodied impacts of the infrastructure construction materials (Scope 3).

Early studies on life-cycle GHG impacts of urban water systems focused on centralised water supply and wastewater treatment systems (Lundie, Peters & Beavis 2004; Poussade, Vince & Robillot 2011; Shrestha et al. 2011; Stokes & Horvath 2009). In these, scenario analysis was usually performed to quantify the GHG implications of implementing alternative water management approaches, such as supply augmentation with seawater desalination, water recycling and imported water. Seawater desalination has been consistently found to have the highest carbon footprint per unit of water supplied.

More recently there has been a growing interest in decentralised systems such as rainwater harvesting and greywater recycling involving on-site treatment. The comparison of *decentralised* systems compared with *centralised systems* (Hendrickson et al. 2015; Kavvada et al. 2016), and combined *integrated systems performance* is a current theme of research (Lam et al. 2017; Lane, de Haas & Lant 2015). In general, work has found that decentralised systems are more carbon intensive (per unit of water supplied or wastewater treated) than their centralised counterparts. Typically, it is because decentralised systems have higher operational energy use (i.e. kWh/m^3).

Marginal abatement cost curves can be used to inform least-cost GHG abatement planning and design. It assesses and visualises the relative cost-effectiveness of GHG abatement options by ranking their cost-effectiveness (\$/tCO_2eq) against their potential GHG savings (tCO_2eq/year potentially saved) (Fig. 15.5). Each box in the cost curve represents an individual abatement option, such as reducing water loss, installing new low-energy supplies, incorporating renewable energy generation options etcetera. The height of each box is the unit abatement cost, so options below

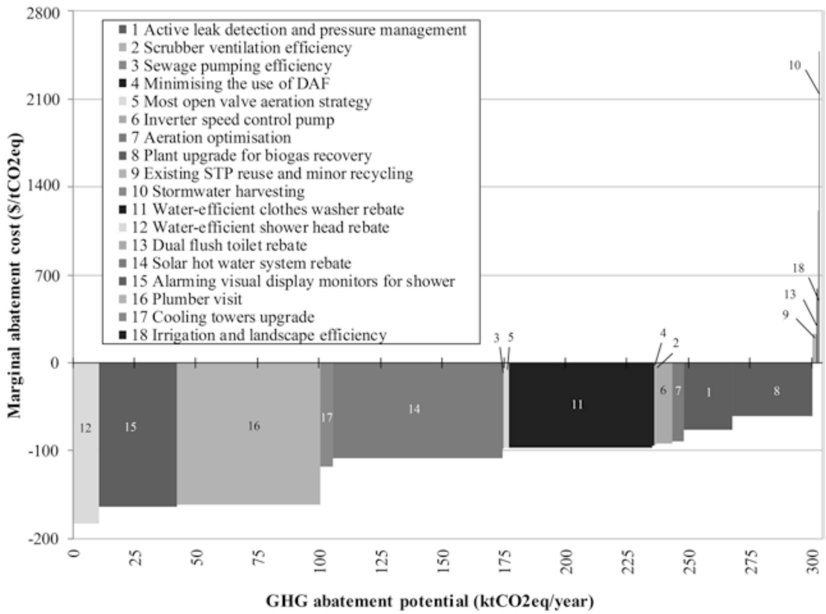

Fig. 15.5 An example of a marginal abatement cost curve for GHG abatement (*Source* Adapted from Lam, Kenway & Lant 2017 with permission)

the central line are hence financial beneficial. The width of each box is the abatement potential in tonnes of CO_2 equivalent savings.

In the water sector, this approach was first used to assess abatement opportunities for water utilities (Stokes, Hendrickson & Horvath 2014; WSAA 2012). In general, it has been found that energy efficiency measures and leakage reduction are quite cost-effective, while renewable energy use by water-utility are less cost-effective but offer greater abatement potential. This least-cost assessment approach has been used to examine abatement opportunities for the water end-use phase as well the utilities (Chini et al. 2016; Lam, Kenway & Lant 2017). With this integrated perspective of urban water systems, water-related energy management by water end-users can be seen to have better cost-effectiveness and abatement potential than most utility opportunities (Fig. 15.5).

Social and Liveability Implications of Urban Water Systems

Reducing urban water and energy intensity is a goal that needs to be considered alongside the broader objectives of cities, such as liveability and well-being. There is an emerging understanding that water management and urban design needs to change to maximalise liveability benefits without compromising water supply and security.

Holistic Water-Themed City Visions and Liveability

There have been attempts to integrate water management with more holistic city visions through concepts such as Water Sensitive Cities, Water Wise Cities, Sponge Cities and City Blueprint (Wang et al. 2018; IWA 2016; Van Leeuwen 2013; Wong & Brown 2009). Taking a more comprehensive approach on how water should be managed, these visions often seek to strike a balance between water efficiency and broader city performance, often encompassing attributes of liveability. Although liveability is difficult to define or measure (Balsas 2004), a number of studies map relevant attributes (Badland et al. 2014; Leby & Hashim 2010; Namazi-Rad et al. 2012). The most commonly addressed water aspects of liveable city living are those related to flooding, greenspace (blue-green corridors and multi-purpose spaces), quality of water infrastructure, and resource efficiency (Table 15.1).

Resource efficiency refers not only to water use efficiency, but also to optimisation of energy, nutrient and waste management. Resource efficiency stresses the need to: replenish water resources, reduce water and energy use, recover energy from wastewater and "recycle" nutrients and organic matter (IWA 2016). Other common attributes relate to urban heat mitigation, business opportunities and climate change mitigation and adaptation. Urban heat mitigation is addressed within the context of cooling benefits provided by (usually irrigated) open space. Opportunities for business innovation and improved productivity are mentioned in the context of costs of water provision and infrastructure maintenance, and are often seen as emerging from cross-sector

Table 15.1 Liveability attributes mentioned water city visions

Liveability attributes	Water Sensitive Cities (WSC Index)	Water Wise Cities	Sponge City	City Blueprint
Disaster preparedness, flooding and extreme weather	✓	✓	✓	✓
Green and public space	✓	✓	✓	✓
Quality of infrastructure	✓	✓	✓	✓
Resource efficiency	✓	✓	✓	✓
Urban heat mitigation	✓	✓		✓
Productivity, business opportunities and innovation potential	✓	✓	✓	
Climate change mitigation and adaptation	✓	✓		✓

cooperation and transdisciplinary workforce (Chesterfield et al. 2016; IWA 2016).

Water-Liveability Frameworks

Several authors conceptualise the link between water and liveability. The CRCWSC Societal Needs framework (de Haan et al. 2014; Johnstone et al. 2012) is one example. The framework provides examples of the role water can play through provision of drinking water, protection from polluted water, microclimate benefits, creating spaces for social interaction, enabling jobs that rely on water, etcetera. Another example of a systematic conceptualisation of water-liveability relationship is the

WSAA report on liveability (WSAA 2016). The report provides a conceptual map linking water to mental, physical and public health, safety, active transport, recreation, etcetera. Both frameworks share a comprehensive recognition of lifestyle opportunities granted by water and a focus on individual well-being.

There are a number of liveability attributes that are less explored, but that nevertheless involve urban water systems where the water sector could be involved. These include the role water can play in mitigation of localised environmental impacts related to air quality and noise pollution. This also includes water-related energy efficiency for the end-users (rather than utilities) and its impact on housing affordability (Binks et al. 2016). For example, some water efficient appliances may have a higher energy footprint than conventional ones (e.g. waterless incinerating toilets, steam closets used as an alternative to washing machines), and hence may have a greater energy cost.

Liveability attributes often span physical and functional including urban form issues such as greenspace, transportation modes and corridors (Mouratidis 2017). Changes to urban form, while not often recognised in liveability-water frameworks, have significant implications for design management of integrated water systems. For example, greyfield re-development and densification change the hydrological performance of the sites as land cover imperviousness increases and more stormwater runoff is generated (Renouf et al. 2019). This is likely to exacerbate problems related to stormwater management and flooding that is additionally impacted by climate change. There is also the question of how water can improve amenity in more compact neighbourhoods. For example, can water sensitive urban design (WSUD) features, such as stormwater wetlands and raingardens, be used to compensate loss of private greenspace? Can urban waterways corridors be adapted to connect neighbourhoods through blue-green corridors?

In the Australian water industry, there have been consistent attempts to make a strong association between WSUD and liveability benefits. However, some authors question these claims, pointing out the need for more rigorous assessment of both benefits and disbenefits that WSUD features actually provides (Furlong et al. 2017).

Conclusion

Water has long been understood to play a central role in creating sustainable cities. Historically this has been from the perspective of water supply and/or transport (e.g. shipping and freight). Increasingly as global temperatures warm and city density continues to grow, water is expected to play a fundamental role in shaping the form, function and design of cities. Cities of the future are expected to harvest more water from within—*cities as catchments*. They are expected to discharge less wastewater and stormwater and be more in sympathy with *pre-development* conditions. They are expected to store more water within their boundaries. And they are expected to use these features collectively to create low-energy, low-carbon, highly liveable, secure and resilient forms of settlement. These significant challenges will require new conceptual frameworks and new methods of assessment, and above all new forms of design, governance and management in order to become a reality.

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16

Energy Benchmarking for Efficient, Lower Carbon Wastewater Treatment Operations in Australia

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Introduction

Due to the progressive development and implementation of ever more stringent human and environmental health regulations throughout the second half of the twentieth century, the water industry has largely been focused on meeting wastewater treatment and effluent quality criteria

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for regulatory compliance (Jenkins & Wanner 2014), with less emphasis placed on efficiency and innovation in its operations until quite recently. The same is largely true of energy use for wastewater treatment.

Historically, energy has been relatively inexpensive internationally and many wastewater treatment facilities were not designed or operated with energy use efficiency in mind (NYSERDA 2010). Moreover, the gradual progression from simple low-cost treatment processes to more advanced highly engineered processes in order to meet increasingly stringent regulatory criteria has led to a progressive increase in the energy intensity of wastewater treatment over time (Chang et al. 2008). This progressive intensification of energy demands for wastewater treatment has been brought sharply into focus in recent years by dramatic increases in the cost of energy, including electricity (AEMO 2016), as well as increasing volatility in energy tariffs linked to deregulation and structural changes to energy markets (Escribano, Ignacio Peña & Villaplana 2011). Increased environmental awareness and the relevance of energy use and greenhouse gas emissions has also progressively driven the need for energy efficiency and process optimisation in wastewater operations. In combination, these factors have increased the pressure on energy-intensive industries and facilities like wastewater treatment plants (WWTPs) to look for ways to minimise operational energy use.

Energy Use and Efficiency in Wastewater Treatment

While energy required for wastewater treatment on a per capita basis is some 10-fold lower than that of domestic water heating for example (Kenway et al. 2015), WWTPs as industrial facilities are typically among the largest single energy users within municipalities (Krampe 2013; Müller et al. 2010), thereby presenting important opportunities for energy optimisation and efficiency gains. WWTPs can represent one seventh (1/7th) of the total energy consumption of municipal public structures and facilities, with energy also constituting some 20–40% of total WWTP operating costs (US EPA 2013).

Inefficiencies in WWTPs are due to various factors, including: use of inefficient equipment, usually from the over design of pumps and processes; incorrect operational practices and/or lack of proper controls; and a lack of operator understanding of energy conservation measures (Chang et al. 2008; Ragazzo et al. 2015). Also, the recent adoption of energy-hungry 'state-of-the-art' technologies such as membrane bioreactors and UV disinfection has become increasingly common, in some cases without proper justification for such advanced technologies (Ragazzo et al. 2015). Practically all WWTPs present opportunities for energy savings, including—or perhaps especially—new plants (Müller et al. 2010). To improve energy efficiency in the water sector, energy benchmarking has been applied internationally with the broad goal of helping the sector identify and adopt best practice efficiency in the pursuit of better industry performance (Cabrera et al. 2011).

ISO 50001: Energy Management Systems

Energy benchmarking in the water sector is a sub-set of the broader benchmarking approach and falls under the International Standard ISO 50001:2011 Energy Management Systems (ISO 2011). Energy benchmarking enables different water utilities to equate their operational energy performance with other water utilities and comparatively measure their performance, as well as identifying the source of differences for targeted implementation of energy efficiency improvement measures (GHD 2014b; Krampe & Trautvetter 2012). Once best practices are identified, the water industry then sets the best practice values (so-called Target Values) for ongoing improvement and efficiency gains (de Haas et al. 2015).

One of the key activities in energy benchmarking involves the undertaking of an initial energy review to establish an energy performance baseline. This baseline is then used for ongoing performance monitoring and setting improvement targets in relation to future energy performance. Adjustments to this baseline may be made if the performance indicators no longer reflect the industry energy consumption (ISO 2011). Under ISO 50001:2011, the industry is required to develop, record and maintain an energy review, and document the process. Energy consumption should be analysed based on industry data, with identification of the areas where energy use is significant throughout the facility to determine current energy performance.

While ISO 50001 provides the overall framework for energy auditing and identifying areas for optimisation, it does not prescribe the energy performance indicators (benchmarks) nor does it prescribe or recommend a standard/best practice approach to develop them. This leaves the water industry to determine the best approach for energy benchmarking and the setting of energy performance benchmarks. The first European energy benchmarking manual was developed in Switzerland in the mid-1990s and since then, considerable effort has gone into developing and refining these methods, with European methodology now considered world's best practice (Crawford 2010) and today embraced and replicated in many other countries, including Australia.

Australian Energy Benchmarking in Wastewater Treatment

In 2006, the Commonwealth Government of Australia established an Energy Efficiency Opportunities (EEO) programme (enacted by the EEO Act 2006) to encourage industry and commercial sectors to pursue cost-effective energy efficiency initiatives. An essential function of the EEO programme was the undertaking of a comprehensive assessment of energy use, the purpose being to identify cost-effective energy savings with a payback period of up to four years. Participation in the programme was compulsory for businesses that individually, or as part of a corporate group, had energy use exceeding 0.5 PJ/year. As at June 2013, EEO member corporations accounted for 56% of Australia's total energy use (Australian Government 2006, 2010); however, the EEO program was closed in 2014 with the repeal of the EEO Act.

Following on from its first EEO report and energy baseline in 2009 (SA Water 2009), the South Australian water utility SA Water undertook the first ever Australian energy benchmarking assessment of its wastewater treatment operations in 2012, with 24 WWTPs subject to detailed assessments (Krampe & Trautvetter 2012). The study followed the German methodology (Müller et al. 1999), incorporating benchmark optimisation values from Baumann and Roth (2008) and Haberkern, Maier and Schneider (2008) to enable a wider variety of treatment processes and WWTP sizes to be captured (Krampe & Trautvetter 2012). The methodology followed the same WWTP size classifications as determined in German benchmarking methodology for consistency with the benchmarks of Baumann and Roth (2008) and Haberkern, Maier and Schneider (2008).

This pioneering benchmarking work from South Australia recognised that the European benchmarks may not be fully applicable to Australian contexts; for example, due to higher nitrogen loads in Australian wastewater (Krampe 2013). The energy requirements of nutrient-removing WWTPs is strongly dependent on the nitrogen-to-organic carbon (N:COD) ratio in the raw wastewater, due to the oxygen consumption for nitrification and also because of the need for reduced COD removal by primary sedimentation in the case of a high N:COD ratio (Nowak 2003). Nevertheless, the effluent targets between Europe and Australia were considered to be comparable (Krampe 2013). Despite some issues with data coverage quality, this initial energy benchmarking work was extremely useful and helped to identify significant potential for energy efficiency optimisation, whilst also identifying data gaps for future such assessments (Krampe 2013).

Following South Australia's lead, in 2012 the Australian water industry peak body (the Water Services Association of Australia; WSAA) conducted an energy survey with the participation of 16 water utilities. This first national energy survey captured 134 WWTPs, recording a total energy consumption of approximately 16 GWh/y (Krampe 2012). Based on this initial survey, the first national Australian energy benchmarking assessment commenced in 2013. The study involved the collection of data from 17 water utilities spread across seven states and territories, including in total 142 WWTPs (GHD 2014a, 2014b). The study applied the same approach of SA Water (Krampe 2013; Krampe & Trautvetter 2012) and based its evaluation on 2013–2014 financial year data.

Results showed that 10% of assessed WWTPs had energy efficiency performance close to the best practice Target Values (GHD 2014a; as specified by Baumann and Roth (2008) and Haberkern, Maier and Schneider (2008))—a good outcome given that Target Values represent 10th percentile energy performance in category. When referring to Guide Value performance (50th percentile), Australian WWTPs performed significantly below expectations, with only 16% approaching these values (GHD 2014a, 2014b), highlighting the substantial future scope for energy efficiency improvements. Usefully, this initial study identified the minimum requirements for data collection, serving as a useful guide to water utilities in future energy optimisation efforts. It also provided a good baseline for understanding and improving future energy benchmarking and performance assessments by providing a reference manual for water utilities on to how identify WWTPs that represent best opportunity for energy efficiency improvements.

In 2017 a second study was commissioned by WSAA, this time evaluating 245 WWTPs across Australia and New Zealand. The results showed that although there had been improvement in data recording and collection and overall WWTPs showed improvement in energy efficiency (when compared to 2014 data), there was still much more to be done to improve energy performance and refine energy benchmarks (de Haas et al. 2018; GHD 2017).

Overview of National WWTP Energy Performance Assessments

The 2016–2017 survey by WSAA gathered information relevant to energy benchmarking analysis, including: general information (name, location and design capacity of WWTP expressed as megalitres (ML)/d and kg BOD_5/d, overall process description, pumping head); secondary effluent quality (chemical oxygen demand (COD), ammonia- and oxidised-nitrogen—all in mg/L); influent loads (flow in ML/d, COD in kg/d, total nitrogen (TN) load in kg/d); biogas production and on site power generation (biogas volume produced in ML/y or m^3/y, amount of biogas wasted/flared in ML/y, electricity generated from biogas in MWh/y, analysis data of the heat value of biogas or the percentage methane content); energy consumption of the plant (total electricity consumed, total external fuel source consumed, electricity consumption for the aeration of the secondary treatment stage). These data were assessed and a results summary of energy performance for the Australian state and territories, considering WWTP size and operational configuration, is presented below.

Some 87% of the Australian population is connected to sewage systems (UNSTAT 2011), or approximately 21.8 million people. There are 74 Australian urban water utilities with a combined 673 municipal WWTPs (Bureau of Meteorology 2018) collecting a combined wastewater volume of 1,896,641 ML during the 2015–2016 period (ABS 2017). The WSAA benchmarking study captured data from 245 WWTPs, 243 of which were Australian and the remainder from New Zealand. This chapter deals only with the performance of Australian WWTPs. These 243 WWTPs have a total annual operational capacity of 24,659,180 PE_{COD},[1] with a total treated wastewater volume of 1,528,210 ML, or some 4185 ML/d. Though representing some 36% of all WWTPs nationally, the 243 Australian WWTPs surveyed include the largest metropolitan plants and so collect and treat around 81% of the total national sewage flow (ABS 2017).

The assessment of WWTPs was carried out according to predefined WWTPs size classes (SC) and the distribution of WWTPs per SC is shown in Fig. 16.1. Notably, plants in SC 5 (>100,000 population equivalents; PE), while representing only 16% of the surveyed WWTPs, are responsible for 81.6% of WSAA surveyed wastewater flow treated (1,209,151 ML) or some 63.8% of the total treated wastewater flow nationally. In addition to size class, the WWTPs were assessed according to the plant's process configuration typology, being plant Types 1–5 (GHD 2014b, 2017). When assessed according to WWTP process configuration or type, 133 of the total 243 WWTPs (≈55% of total) were classified as Type 3 extended aeration activated sludge systems. The next most common process types were Type 5 aerated lagoons with 52 WWTPs (21.3% of total), Type 2 activated sludge systems with separate sludge stabilisation but without on-site biogas co-generation with 24 WWTPs (9.8% of total), Type 1 activated sludge systems with separate

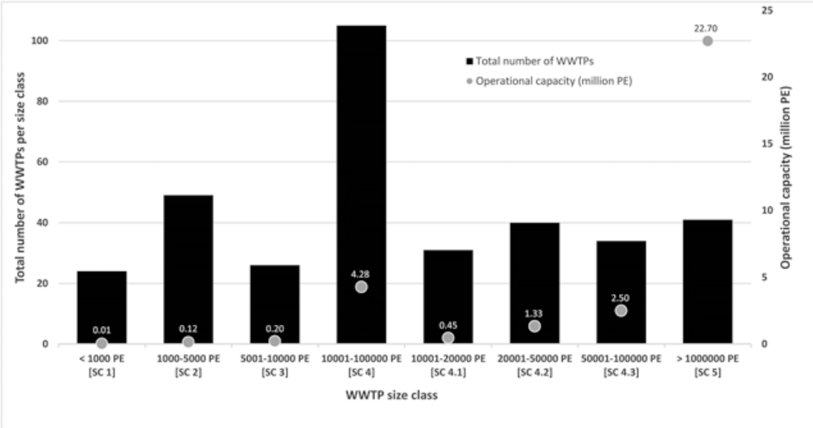

Fig. 16.1 Breakdown of WWTPs surveyed in 2016 benchmarking analysis according to size classification

sludge stabilisation and on-site biogas co-generation with 22 WWTPs (9% of total) and Type 4 trickling filters with 13 WWTPs (5.3% of total surveyed plants).

Wastewater Treatment Performance Results

Table 16.1 summarises the 2016 national WWTP load and performance characteristics by Australian state and territory, including population equivalent-normalised wastewater volumes, pollutant loads, electricity use performance, and related carbon dioxide-equivalent (CO_2-e) emissions.

Type 3 extended aeration activated sludge systems were shown to have the lowest effluent COD discharge values on average, achieving COD removal ratios of 66.1–99.2% (median 95.5%), followed by Type 1 activated sludge systems with COD removals of 88.8–97.7% (median 93.85%), Type 2 activated sludge systems with COD removals of 90–98.2% (median 93.37%), and Type 5 aerated lagoons with the poorest COD removals at 46.9–93% (median 87.2%).

Table 16.1 Summary of 2016 national performance data for all 243 Australian WWTPs surveyed

	ACT[a]	QLD	NSW	SA	TAS	VIC	WA	Australia
WWTPs surveyed	2	61	48	12	10	89	21	243
Wastewater flow (million m^3/y)	33.12	261.9	583.0	54.88	23.89	427.2	144.2	1528
Operational capacity (million PE)	0.49	4.36	7.75	0.93	0.45	8.37	2.31	24.66
Specific wastewater flow [m^3/(PE/y)]	66.9	67.29	74.3	76.61	55.29	73.08	86.77	73.08[2]
Influent COD (mg/l)	655.2	726.3	572.6	752.6	771.3	648.4	800.4	726.3[b]
Effluent COD (mg/l)	12.16	35.55	156.7	67.93	–	40.99	29.11	38.27[b]
COD removed (%)	98.14	94.73	91.8	89.42	–	95.06	95.23	94.89[b]
Influent TN (mg/l)	81.97	62.27	58.68	87.76	58.63	64.23	68.43	64.23[b]
Effluent TN (mg/l)	14.95	3.78	7.38	8.82	28.84	7.05	14.10	8.82[b]
TN removed (%)	78.32	93.39	86.58	84.93	51.95	88.40	74.45	84.93[b]
Specific energy consumption [kWh/(PE/y)]	317.1[c]	59.06	56.10	48.80	41.80	51.91	57.36	56.10[b]
Flow-specific energy consumption (kWh/m^3)	4.76[c]	0.84	0.78	0.75	0.68	0.78	0.83	0.78[b]
Nutrient-specific energy consumption (kWh/kg TN removed)	137.8[c]	16.51	16.80	11.64	27.19	15.94	18.08	16.80[b]
Carbon dioxide equivalent emissions [kg CO_2-e/(PE/y)][d]	298.5[c]	54.34	52.73	27.77	7.52	60.22	43.59	51.05[b]

[a]Australian States and Territories: *ACT* Australian Capital Territory; *QLD* Queensland; *NSW* New South Wales; *SA* South Australia; *TAS* Tasmania; *VIC* Victoria; *WA* Western Australia; [b]Average data; [c]Data considered non-representative of true performance due to very small sample size ($n=2$); [d]State-based grid electricity emission factors (kg CO_2-e/kWh; full fuel cycle scope 2+3) sourced from Australian Government (2018)

In the case of total nitrogen, the Type 3 activated sludge systems achieved the best results with a median effluent value of 5.3 mg/l (range 1–30.16 mg/l) followed by Type 2 activated sludge systems with a median effluent value of 8.15 mg/l (range 2.39–40.69 mg/l). Type 5 aerated lagoon WWTPs achieved median effluent TN levels of 11.72 mg/l (range 2.10–76.25 mg/l), followed by Type 1 activated sludge systems with median effluent TN of 16.02 mg/l (range 3.70–57.62 mg/l) and lastly Type 4 trickling filters which achieved a median effluent TN of 30.04 mg/l (range 3.77–44.12 mg/l).

Regarding energy use efficiency, trickling filters displayed the best energy performance with a median of 30.7 kWh/(PE/y) and associated carbon emissions 27.9 kg CO_2-e/(PE/y), with Type 3 extended aeration activated sludge systems having the highest median specific electricity use of 62.5 kWh/(PE/y) and associated carbon emissions intensity of 56.8 kg CO_2-e/(PE/y).

WWTP Energy Efficiency and Carbon Emissions Trends

Referring to 2016 national WWTP performance data (Table 16.1), Australian national average specific energy performance was 56.1 kWh/(PE/y) and per capita equivalent greenhouse gas emissions were 51.1 kg CO_2-e/(PE/y). Total WWTP annual energy use in both 2014 and 2016 survey years and total associated carbon emissions is shown in Fig. 16.2. The energy use patterns for wastewater treatment operations largely reflect state population sizes, with the performance of NSW disproportionately lower than its relative population size due to several large capacity primary-only treatment WWTPs (combined PE of these primary-only plants is some 4 million). Overall, total WWTP energy use and carbon emissions were relatively consistent between 2014 and 2016 survey years, with the exception of South Australia which achieved an approximately 50% reduction in both total annual energy use and carbon emissions due to significant investment in WWTP process efficiencies and optimisation.

Figure 16.3 gives the per capita equivalent specific energy use and associated carbon emissions intensity of WWTPs in both 2014 and

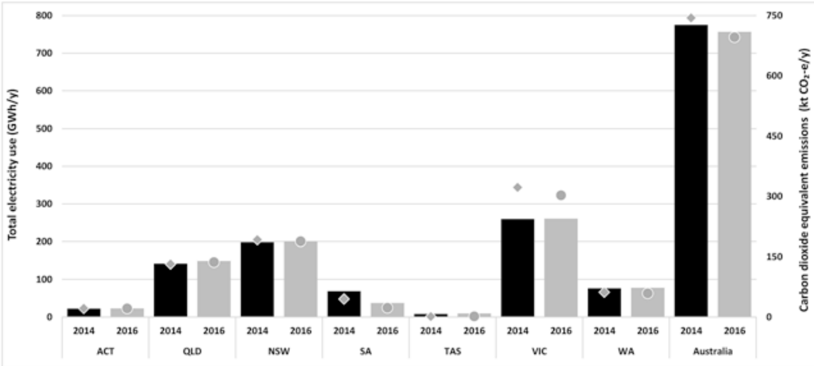

Fig. 16.2 Australian WWTP total annual electricity use (GWh; histogram bars) and carbon dioxide equivalent emissions (kt CO_2-e; ◆, ●) per state for survey years 2014 and 2016 respectively. Data derived only from those 121 WWTPs participating in both survey years

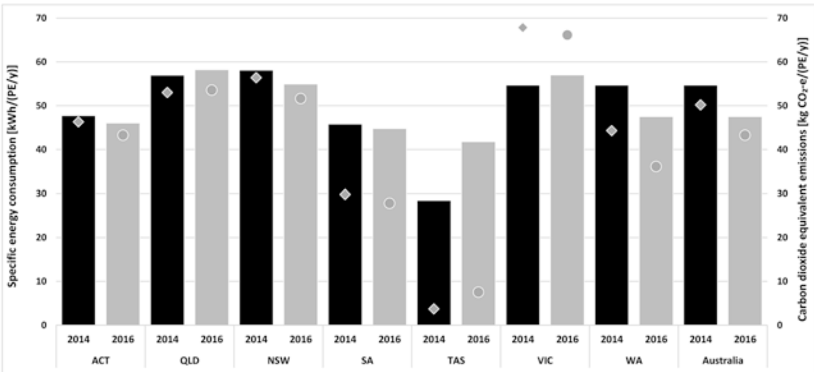

Fig. 16.3 Australian WWTP specific electricity use (kWh/PE/y; histogram bars) and carbon dioxide equivalent emissions (CO_2-e/PE/y; ◆, ●) per state for survey years 2014 and 2016 respectively. Data derived only from those 121 WWTPs participating in both survey years

2016 survey years according to state. At the national level, specific energy use efficiency of these plants improved overall by some 13% from 54.7 kWh/(PE/y) in 2014 to 47.5 kWh/(PE/y) in 2016. At the state level, most states performed similarly to the national average values. Notable exceptions were Tasmania which performed best in terms of both specific energy consumption (41.8 kWh/(PE/y)) and per capita equivalent greenhouse gas emissions (7.52 kg CO_2-e/(PE/y)), with the very low carbon emissions intensity there due to the predominance of hydroelectricity in this state. South Australia was the next best performer for both specific energy consumption (44.8 kWh/(PE/y)) and per capita equivalent greenhouse gas emissions (27.8 kg CO_2-e/(PE/y)). Large differences in carbon emissions intensity performance between states are a reflection of differing WWTP specific energy performance combined with variable state-based emission factors for grid electricity.

Future Outlook for Energy Efficiency and Low Carbon Wastewater Treatment

The Australian water industry has invested considerable resources toward energy efficiency initiatives in recent years and many water authorities now recognise the important role of optimising wastewater treatment operations in achieving their corporate energy and carbon neutrality objectives. This chapter has presented a summary of WWTP energy benchmarking work to date, with WWTP energy use and carbon emissions intensity performance data given for wastewater treatment operations covering the majority of the Australian population. National median per capita equivalent specific energy consumption was some 56 kWh/(PE/y), with an associated average per capita equivalent carbon emission intensity of 51 kg CO_2-e/(PE/y). While wastewater treatment operations are a dominant source of greenhouse gas emissions for the water industry, greenhouse gas emissions from WWTPs are a relatively minor component of the total national CO_2-e emissions inventory, contributing less than 1% to the total inventory.

The undertaking of energy benchmarking and subsequent WWTP energy efficiency optimisations have delivered measurable gains for some state water authorities in recent years; however, considerable scope exists to further optimise WWTP processes for future energy and carbon reductions. Participation in national energy benchmarking projects is currently voluntary, but international experience has demonstrated the importance of comprehensive industry participation in benchmarking exercises to develop robust performance metrics and ensure industry gets the most from benchmarking efforts. Regular and consistent updates of energy benchmarks are also required to ensure that they reflect current industry best practice, technological advancements and regulated environmental performance criteria.

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Note

1. Number of connected population equivalents is expressed as the sum of population pollution load in domestic wastewater (served inhabitants) and the measured pollution (organic) load from commercial sources entering a sewage treatment plant. A standard population-specific COD load of 120 g/PE/d was applied.

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17

Towards Low-Carbon Urban Metabolism—The Impact of Eliminating Food Waste

Peter Graham, Viv Waller and Belinda Christie

Introduction

In order to achieve sustainable development and climate goals, urban domestic material consumption must be reduced by 50% to 2000 levels, while providing for the needs of a global urban population that is predicted to double by 2050 (IRP 2016). More specifically, meeting the Paris Climate Agreement Goal of limiting global warming to

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1.5 °C above pre-industrial levels requires 'upscaling and acceleration of far-reaching, multilevel and cross-sectoral climate mitigation, and by both incremental and transformational adaptation' (IPCC 2018, p. 9).

We are currently not on track to meet these goals, and even if we succeed the impacts of climate changes already taking place on urban populations will be significant. One key area of concern is the resilience of urban food systems. Based on current global warming trajectories by 2050 approximately 2.5 billion people will be living in over 1600 cities where national food supplies will be threatened (UCCRN 2018).

Actions to reduce the greenhouse gas (GHG) emissions associated with food production and consumption are therefore critical. Agriculture for food supply accounted directly for between 10 and 12% of anthropogenic GHG emissions in 2010. Consequentially, limiting global warming to 1.5 °C requires significant supply-side mitigation actions be taken by the agricultural, forestry and other land-use (AFOLU) sector, while managing trade-offs between decarbonisation and food security (Frank et al. 2017). The per-capita GHG emissions from food production embodied in food waste is estimated to have increased by 44% between 1961 and 2011 adding a total of 68 Gt CO_2^{-e} over that period, leading to calls for transitions to low-carbon food supply chains (Porter et al. 2016).

Decarbonising the agriculture sector also requires mitigating GHG emissions associated with the consumption side of food systems (Smith et al. 2015). While supply-side emissions are strongly influenced by land-use and farming practices, demand side emissions are strongly influenced by life-style choice and the social practices around food in daily life, which are now predominantly taking place in urban contexts. According to the IPCC, consumption related emissions can be mitigated by reducing food waste, minimising '… demand for greenhouse-gas intensive foods through shifts to healthier and more sustainable diets' and by 'buying more local and seasonal food' (IPCC 2018, p. 23).

Food waste is the particular concern of this chapter. Estimates are that each year approximately 1 billion tonnes of food—that is, one-third of the food that is produced world wide—is wasted (FAO 2013). This costs the global economy around US$940 billion, and produces 8% of global GHG emissions.

The more than 5.3 million tonnes of food waste in Australia each year is estimated to cost the national economy about AU$20 billion annually. The decomposition of this waste in land-fill is estimated to have emitted 7.6 $MtCO_2^{-e}$ of GHG emissions in one year between 2014 and 2015. In addition to the environmental impact, this wasted food could have fed an estimated 7.8 million Australians seeking food assistance (Commonwealth of Australia 2017). This level of waste also represents significant consumption of energy and water required for food production, transport, storage, packaging and preparation. In addition to undermining the resilience of economies to climate change impacts, food waste also undermines urban food security (OECD/IEA/NEA/ITF 2015; Peterson & Dyball 2013).

In recognition, some countries have included actions to reduce food waste on both supply and demand sides into their international climate commitments under the United Nations Framework Convention on Climate Change (UNFCCC: https://unfccc.int/process/the-paris-agreement/nationally-determined-contributions/ndc-registry). Eliminating food waste is clearly a global concern and requires a holistic systems-based approach.

Circular Economy, Cities and Food

The circular economy (CE) is an economic concept that aims to decouple economic growth from material consumption and which supports the transition to systems of sustainable production and consumption that are restorative and regenerative (GI-REC 2018; WEF 2014). As an applied model, CE looks for opportunities to reduce consumption, eliminate waste by keeping resources in productive use longer, and returning by-products of consumption as inputs for further production (Petit-Boix & Leipold 2018). It has therefore found application as an approach to mapping and redesigning urban food systems in order to identify ways of eliminating waste and return nutrients to support food production (MacArthur Foundation 2017a). Returning nutrients to soils through composting is considered critical as a means of stemming land degradation, estimated to cost the global economy US$40 billion annually (WEF 2014).

Approximately 50% of the urban solid waste stream is organic and the total volume is expected to double by 2025 unless action is taken (MacArthur Foundation 2017b). Food waste and the nutrients it contains are therefore rarely returned to replenish rural soil. However, there are large potential economic and environmental benefits to closing this nutrient loop, and a number of cities are applying a CE approach to try to capture these.

In Amsterdam for example, a project to develop a CE strategy for the city estimated that processing rather than dumping of organic waste could create about EU30 million in added value, create about 450 jobs, reduce 750,000 tonnes of waste, and reduce 300,000 tonnes of associated CO_2 emissions annually (TNO et al. 2015). Cities such as London, Paris, Minneapolis, and New York have introduced curb-side collection of food waste, and a number of neighbourhood and community composting programmes have been working with households to collect and compost food waste for urban farms. The city of Auckland is also trialling curb-side food waste collection to help achieve its target of zero waste by 2040 (Jain et al. 2018).

An important consideration for cities in addressing the collection and re-use of food waste is how to create the *infrastructure* and encourage the *social practices* that works best in medium and high-density urban environments. In many OECD countries the challenge is how to retrofit new processes and infrastructure to existing built environments. A trial of food-waste collection in Copenhagen, Denmark in 2017 for example, involved 280,000 multi-family houses and 20,000 detached homes covering a population of 600,000 people. In the trial, households were given kitchen caddies, which were emptied into 'bio-waste' bins that were collected weekly from multi-family apartments and bi-weekly from detached homes. The waste material was treated via anaerobic digestion, and then finally refined as bio-gas. The trial produced 7.5 million m^3 of bio-gas per year which was used to produce electricity and district heating for a village of 450 houses (Jain et al. 2018). Copenhagen now included this in their 2018 waste management strategy, including the provision to 'better ensure nutrients remain in circulation' (CoC 2018, p. 12).

Different challenges are faced by rapidly urbanising cities. Over the next 40 years more than 230 billion m^2 of new buildings are projected to be constructed, the equivalent of adding a city the size of Paris every week (UNEP & IEA 2017). This offers a significant opportunity to redesign buildings and urban infrastructure to enable circular economies, and make sustainable practices such as collecting and composting food waste much easier than it is today.

One way to achieve this transition is to include design and planning requirements for food-waste collection and composting into standards for new building construction. India is currently experiencing the world's fastest rate of new construction, and has introduced performance criteria for site sufficiency, including provision for organic solid waste treatment, into the national green building rating scheme for large developments—the 'Green Rating for Integrated Habitat Assessment – Large Developments' (GRIHA-LD). This requirement applies to new townships, campuses and special economic zone developments (Kaur & Garg 2019). On a more modest scale the State Government of Victoria, Australia has included a requirement for the provision of 'on-site management of food waste through composting or other waste-recovery as appropriate' in their New Apartment Design Standards (DELWP 2016, p. 38).

Making provisions for infrastructure, design, and standards for catalysing a CE in urban food systems is important. However, actually making the transition requires changes in behaviours and social practice around food preparation, and separation of food scraps by people. Policy makers can help to ensure that there are socio-technical systems supporting diverse groups of people to do 'the right thing'; and to recognise the importance of the emotions that people experience when engaging in a practice. These emotions will vary according to the meaning that people give to what they do. Hence, another entry point for policy makers is in the creation of meanings around particular practices. The next section looks in more detail at how city residents can be encouraged to compost.

Demystifying Composting: How Households Can Be Resource Productive by Eliminating Food-Waste

A key objective of the CE is to avoid waste in the first place. Notwithstanding this, innovative systems for both on-site and off-site composting of unavoidable food scraps provides an illustration of the CE. In contrast to the recycling of many manufactured products, making use of natural biological processes to transform food scraps into compost that is then used to grow food can be a truly closed loop, continuing indefinitely.

In most developed countries, the majority of food scraps still go as waste to landfill (Hoornweg & Bhada-Tata 2012). In Victoria, 832,000 tonnes of food waste was disposed of in landfill during the 2010–2011 period, costing roughly AU$50 million in annual landfill levies. The amount of food waste in Australia is increasing due to population growth and the increase in single person households. In landfills, food waste slowly rots to produce methane, a GHG 72 times more potent than carbon dioxide (Sustainability Victoria 2013).

For every tonne of municipal waste stored in a landfill, just under one tonne of CO_2^{-e} is released (Morrigan 2011). Composting a city's food waste provides an opportunity to return the carbon from food waste to the soil, rather than release it into the atmosphere as methane.

Food scraps are also a rich source of nitrogen, phosphorus, and potassium, all essential for food production. Hence, compost is an important way of returning to the soil these nutrients that are lost when food is harvested (Lehmann 2012). Applying compost to the soil also improves the health of soil and its ability to retain water. It reduces or eliminates the need for chemical fertilisers, herbicide and fungicide, binds heavy metals in the soil, reduces erosion and promotes higher yields of crops (Department of Primary Industries 2004; Lal 2010). All of these benefits also translate to economic value (Adhikari, Barrington & Martinez 2009).

Although composting has been practiced for thousands of years, in the twenty-first century a significant conversion of a city's food scraps into compost requires a supportive regulatory environment, innovative recycling systems, odour-free in-vessel composters, and that residents and businesses actually separate their food scraps. Whether food scraps are composted on-site or off-site, the system works best when it is driven by demand for the resulting compost and this requires that the resulting compost be accessible to and acceptable to growers.

Kerbside collection of food scraps for off-site composting and subsequent use for growing food has proven successful in hundreds of cities across the world. It may not, however, be the best option for apartment blocks, or café precincts or other areas with a high density of food waste. On-site composting has the advantage that there is no need to transport food scraps and there is no issue with vermin or odour from bins awaiting collection.

As described in Waller, Blackall and Newton (2018), medium size aerobic in-vessel composters mimic natural composting and require minimal electricity, usually just to turn an augur or pump air. They are well suited to café precincts or shopping centres as, in addition to food scraps, they can be fed shredded compostable coffee cups and lids, bamboo cutlery, cardboard, paper and wooden chopsticks. Considerable effort is needed in the set-up phase to ensure that the human systems involved are seamless. A person skilled in achieving the right balance of inputs is needed for about 2 hours a day to initiate activation. The resulting compost is immature and needs to be cured for several weeks before use. With on-site composting still a niche activity, the mature compost can bypass the usual market mechanisms either by being used on-site, or going to local community gardens, local rooftop farms or community-supported agriculture (Smaje 2014).

Arrays of continuous flow worm farms have also successfully been managed by apartment residents or café staff with only minimal training. In this case, anyone on-site can be involved directly in the composting process and, in return, obtain the benefit of worm castings and worm juice. Christie and Waller (2018a) have shown that resident or office staff involvement in feeding their food scraps to worm farms, directly or indirectly, can also increase the sense of community.

Whatever technology is used for on-site composting, there is no one size fits all. However, whether on- or off-site composting, the most successful systems appear to be those where people can eat, or are aware of the food that is ultimately grown from their food scraps, in other words, where the CE is made visible.

Composting in Apartment Buildings

Because apartment buildings are becoming more prevalent in Australian cities, it is important to understand how on-site composting can be effectively introduced effectively into more densely populated and higher-rise buildings. Recent research funded by the CRC for Low-Carbon Living, investigated this question as part of a larger study into the social dimensions of food separation and composting across a range of urban sites (Waller, Blackall & Newton 2018).

An empirical study of the experience of on-site food composting of 38 apartment residents in 5 different locations in Melbourne, Australia was conducted and involved observation, semi-structured interviews, and focus groups with residents during field trials of two types of on-site composting: worm farms or in-vessel processor (Table 17.1)

Table 17.1 Composting site descriptions

Building	Council area	No. apartments	Composting technology (*n*=)	Location of technology	Trial or permanent
CBD	City	150*	Worm farm (14)	Car-park (far end)	Trial
North	City	85	In-vessel processor	Car-park (next to the waste facilities)	Trial
River	South-East	12	Worm farms (2)	Garden, ground level (next to amenities)	Permanent
Garden	South-East	40	Worm farm (1)	Garden, ground level (near entrance)	Permanent
Brick	South-East	11	Worm farm (1)	Garden, ground level (near entrance)	Permanent

Source Christie and Waller (2018a, p. 4); CRC for Low Carbon Living, with permission
*One-third of CBD building's apartments were serviced apartments

(Christie & Waller 2018a). The methodology was designed not only to determine the efficacy of different approaches to on-site composting for apartment residents, but to also 'draw-out' the wider influences that the trial had on the resident's lives.

The results indicate that on-site composting can be both effective in reducing food waste from the residents of apartment buildings, and offer wider benefits. These include community building, developing a connection with nature, and developing greater knowledge and awareness of how to affect positive environmental change through food choices and consumption behaviour. More specifically, the results suggest that apartment residents benefit from on-site composting in several distinct but related ways:

- Changed consumption habits leading to less waste
- Increased desire to grow green space
- Increased desire to create broader environmental change.

And, for sites where residents participated directly in feeding worm farms,

- Building connections to nature and their residential community.

This last point was a distinguishing difference between the City 'North' apartments which used an in-vessel processor to which residents' access was restricted, and the other sited that deployed worm-farm systems. In the 'North', building residents placed food scraps in bins located next to the waste facilities on each car-park level. They therefore had no direct involvement in the composting process, nor any opportunity to meet other residents participating in the project (Table 17.2).

Notwithstanding the small sample size, insights for on-site composting in apartment buildings can be offered. Key to the success of on-site composting is engaging the residents in a learning process to create lasting change in behaviour and social practices around food consumption and waste. Providing worm farms in convenient communal locations (more convenient than landfill bins) and engaging residents in workshops on how to worm-farm seems can build a community of practice

Table 17.2 Findings: benefits related to composting technology and type of community engagement

	Awareness of waste	Extending green thinking	Creating broader environ-mental change	Connection with nature	Community building
In-vessel processor, foyer stall	• ✓	• ✓	• ✓	•	•
Worm farm, foyer stall	• ✓	• ✓	• ✓	• ✓	• ✓[a]
Worm farm, Workshop	• ✓	• ✓	• ✓	• ✓	• ✓

[a]Somewhat evident

that can sustain on-site composting activities. Increasing signage and educational displays associated with composting technologies also helps to normalise the act of separating and composting food waste.

Composting in Offices

Food consumption and waste is not restricted to domestic settings, and measures to encourage on-site composting such as worm farms have also been shown to be beneficial in office buildings. Another study conducted under the same CRC for Low Carbon Living programme surveyed office workers at the City of Melbourne Council House 2 (CH2) office in Melbourne, about their experiences with using the building's array of worm farms, which have operated since 2015 (Christie & Waller 2018b). An online questionnaire was completed by 179 staff (43% response rate). The results showed that almost 50% of staff separate food waste for the worm farms every day and that they are less likely to put food scraps in a general waste bin if the food waste bins are provided. Most respondents reported being pleased with, and supportive of the worm farms, and aware of the wider benefits including diverting waste from landfill.

The study also identified some actions that could improve the effectiveness of on-site composting using warm farms in office buildings. These include:

- Ensuring food scrap bins are available wherever food is being consumed
- Ensuring food scrap bins are emptied regularly
- Involving a number of people on each floor in managing the food waste separation, and worm farm management
- Ensuring staff are educated about the kinds of food that can and cannot be put in food waste bins—including large posters with dos and don'ts clearly displayed
- Messaging regarding the wider environmental benefits of on-site composting
- Ensuring food-scrap separation and worm farm information is included in new staff inductions.

Conclusions

Making the transition to circular economies in urban food systems is critically important for limiting global warming to 1.5 °C, and achieving UN Sustainable Development Goal 12.3 of halving food waste by 2050 (UN 2015). This chapter has described the international significance of actions to reduce food waste in food systems with an emphasis on eliminating waste from the consumption of food. Steps are already being taken to apply CE approaches to make this transition.

A range of composting technologies are also available to suit different urban contexts. Single-family homes are beginning to be effectively served by curb-side collection of food waste for centralised composting or bio-gas production. Medium size aerobic in-vessel composters have been found to be well suited to café precincts and shopping centres because they can process paper cups, plates and organic utensils in addition to food scraps. Batteries of continuous flow worm farms have also been found to be effective for encouraging food-waste separation among residents of apartment buildings. Whichever technology is selected, people must participate effectively. The most successful systems make the link between the compost and the food people grow, purchase and eat visible. This is all promising, but not yet sufficient to achieve climate and sustainable development goals.

However comprehensive the transition in infrastructure is, it is people's actions that are the most critical factor in whether or the change we need towards a CE is achieved. People become more motivated to separate food scraps for composting or other forms of reprocessing when the CE of their food system is made visible to them. Ensuring there is awareness of the food that is being grown with their compost, perhaps even making it available to eat, and enjoying looking after worm farms as a community have all been found to be effective motivators. These strategies can also be effective offices. It seems fitting then, to conclude that enabling the eventual elimination of urban food waste through a CE approach, rests on providing people with the appropriate 'feedback' they need to motivate action.

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18

Urban Heat Island Mitigation

Mattheos Santamouris, Lan Ding and Paul Osmond

Introduction

The urban heat island (UHI) is the most documented phenomenon of climate change. It refers to an increase of the ambient temperature in dense urban zones compared to the surrounding suburban or rural areas. Urban overheating is very well documented, using experimental methods, in more than 400 cities around the world. The magnitude of the phenomenon may exceed 5 °C and, in some cases, urban heat island intensities exceeding 10 °C have been reported (Santamouris 2016). Urban overheating has a serious impact on energy, health,

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peak electricity demand and the local economy. Higher ambient temperatures increase the cooling demand in buildings and raise considerably the heat-related mortality and morbidity. Recent research investigating the synergies between global and local climate change has concluded that the two phenomena act synergistically and the degree of local UHI intensity seriously increases during extreme climatic events like heat waves (Founda & Santamouris 2017).

To counterbalance the impact of urban overheating, important mitigation technologies have been developed during the last 15 years (Santamouris 2015b). Mitigation technologies are mainly based on the increase of the albedo of cities using white or coloured infrared reflecting materials for roofs and pavements, additional greenery, use of evaporative cooling and ground coupled systems, etcetera (Santamouris 2014a). Existing mitigation technologies are commercially available and are available for implementation in large-scale urban rehabilitation projects (Santamouris et al. 2017). Analysis of the experimental results has shown that correct implementation of existing mitigation technologies can decrease peak ambient temperature up to 2–3 °C, as well as being associated with a significant decrease in the energy spent for cooling, and a very considerable decrease in heat-related mortality and morbidity.

Factors Affecting the Urban Heat Island

The urban heat island phenomenon varies both spatially and temporally as a function of climate, topography, physical layout of the built environment and short-term weather conditions. A comprehensive analysis of the more important climatic and urban parameters influencing the appearance and the magnitude of the urban heat island are summarised by Oke et al. (1991):

- *Canyon radiative geometry* decreases considerably the loss of long wave radiation from urban canyons because of the complex exchange between buildings and the screening of the skyline. The long wave radiation emitted from the various materials and surfaces within the canyons cannot escape to space, as buildings replace a proportion of the cold sky hemisphere with much warmer surfaces which receive a high portion of the infrared radiation emitted from the canyon floor and re-radiate this back to a greater extent.

- *Thermal properties of materials* which when absorbing solar radiation, increase their temperature and subsequently the storage of sensible heat in the fabric of the urban environment during the daytime and release the stored heat into the city through convection processes, mainly after sunset. In parallel, the replacement of vegetation and natural soil by materials of high absorptivity and thermal capacitance, like concrete or asphalt reduces the potential to decrease ambient temperature through evaporation and plant transpiration.
- *Anthropogenic heat* released from cars, air conditioners, industry, combustion of fuels and animal metabolism.
- *Urban greenhouse*, whereby the polluted urban atmosphere increases the incoming long wave radiation. This extra radiative input to the city reduces the net radiative losses and contributes to make more positive the thermal balance of cities.
- *The radiative geometry* of canyons also contributes to lowering the effective albedo of the urban environment, mainly because of the multiple reflection of solar radiation between the canyon surfaces.
- *Reduction of evaporating surfaces* because of fewer water-based urban features and the types of impervious materials used in the urban environment is putting the emphasis more on sensible heat and less on latent heat losses.
- *Reduced turbulent transfer* of heat from within street canyons.

Magnitude of Urban Overheating

As mentioned above, data on the magnitude of the urban heat island is available for more than 400 cities around the world. Important information on the magnitude of the UHI in Asian and Australian cities is given in Santamouris (2015a). According to the study, the UHI intensity in Asia and Australia varies between 0.4 and 11 °C, with an average value close to 4.1 °C, and a standard deviation of 2.3 °C. About 23% of the cities present an UHI intensity lower than 2 °C, while for 58%

of the considered cities the UHI magnitude was found to be lower than 4 °C. Only 27% of the cities were found to present an intensity higher than 5 °C.

In parallel, data on the magnitude of the urban heat island phenomenon in 110 European cities is given in Santamouris (2016). As reported, the average maximum UHI intensity varies between 0.3 and 6.8 °C, with an average close to 2.6 °C. The absolute maximum intensity in the European cities was found to range between 2.8 and 12 °C, with an average around 6.2 °C.

More information of the detailed characteristics of the UHI phenomenon in the selected Asian, Australian and European cities is also given in Santamouris (2018).

Impact of Urban Overheating on Energy and Peak Electricity Demand

As previously mentioned, urban overheating has a serious impact on the cooling energy consumption of buildings, peak electricity demand and heat-related mortality and morbidity. Studies reported in Santamouris et al. (2015) show that there is a quite strong link between ambient temperature and the peak electricity demand. The analysis of data from many countries shows that increase in the peak electrical load per degree of ambient temperature increase, varies between 0.45 and 4.6%. The average rate of increase is 2.65% and the average rise of the electrical load is 226 MW per degree of temperature increase. The average peak electricity penalty per person is 21 (±10.4) W per degree of temperature increase.

In relation to the impact of the urban heat island on cooling energy consumption, data analysed and reported in Santamouris (2014b) shows that urban overheating causes an average energy penalty per unit of city surface of around 2.4 (±1.5) kWh/m^2. In parallel, it causes a global energy penalty per unit of city surface and per degree of urban overheating close to 0.74 (±0.67) kWh/m^2/K. Finally, the research found that the global energy penalty per person is 237 (±130) kWh/p, while the global energy penalty per person and per degree of the UHI intensity is 70 (±45) kWh/p/K.

Mitigation Technologies and Impact

The impact of heat mitigation technologies on the ambient temperature as well as on energy and heat-related mortality has been studied by several authors. Detailed studies undertaken by the CRC for Low Carbon Living for Western Sydney (Santamouris et al. 2018), have shown that existing mitigation technologies can reduce by up to 2.5 °C the peak ambient temperature in the urban built environment.

Figure 18.1 shows the calculated spatial distribution of the cooling degree days in Western Sydney based on the use of several mitigation technologies.

As shown, when reflective materials, water technologies and additional greenery technologies are combined, it is possible to decrease the annual number of cooling degree days by up to 43%.

In parallel, the whole analysis has identified the potential for reduction of the cooling demand in Western Sydney because of the implementation of mitigation technologies. Energy savings in cooling may be as high as 50%.

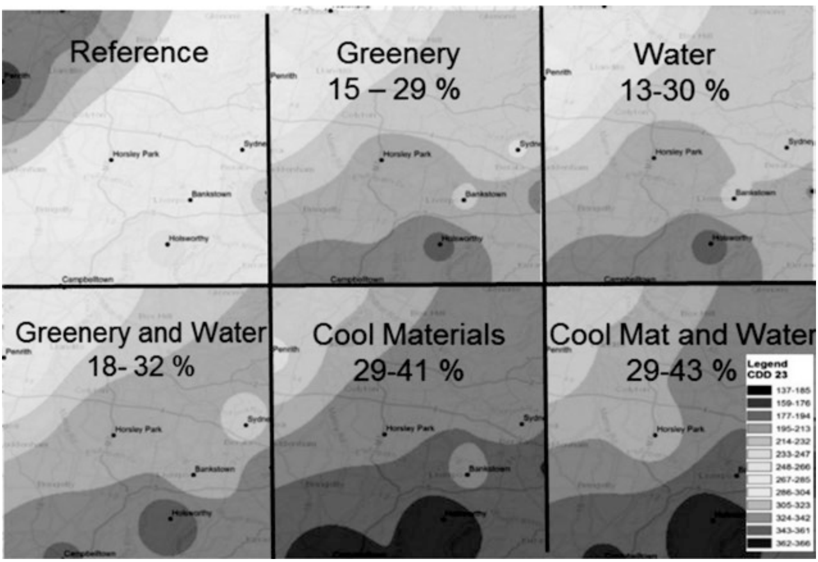

Fig. 18.1 Distribution of the Cooling Degree Hours in Western Sydney when several mitigation technologies are used

Finally, the study has evaluated the potential impact of the considered heat mitigation techniques on heat-related mortality. Considering the summer of 2016/2017 which presented several hot spells, it is calculated that without any local climate mitigation, the cumulative excess deaths per 100,000 people would have exceeded 10 occurrences at 35 km from the coast, reaching peaks of 14 in the areas of Penrith Lakes and Richmond. The combined use of cool materials and water can lower the cumulative heat-related extra deaths even 55 km from the coast to levels which prevail in the unmitigated scenario 15 km from the coast (namely to approximately 7.5 deaths per 100,000 inhabitants). With cool materials and water, the cumulative deaths close to the coast can be lowered to approximately 5 heat-related excess deaths per 100,000 people.

Case Studies

This chapter concludes with three case studies which address the application of urban heat mitigation techniques to three quite different Australian locations. These are tropical Darwin, where a combined strategy is proposed; Western Sydney, where there was a particular focus on water-based cooling technologies, in partnership with Sydney Water; and the challenging high-rise environment of inner Sydney's Green Square, where a new Urban Heat Island Mitigation Decision-Support Tool was used to support modelling of a combination of cooling scenarios.

Case Study 1: Darwin Mitigation Study—Cooling Darwin—Mitigating Urban Heat, Decreasing Energy Consumption and Protecting People

Scope of the Project

Darwin city centre suffers from a significant overheating problem. Temperatures at the city centre are much higher compared to the surrounding suburban and rural areas. The city centre area can be up to

6 °C warmer than the airport, located 13 kilometres further out in the suburbs. Temperatures also vary within different zones of the CBD.

Modern cities replace trees, wetlands, grass and other natural land cover with artificial surfaces like concrete, asphalt and buildings. Dark materials strongly absorb solar radiation and increase the ambient temperature. The lack of urban green spaces and vegetation decreases the cooling effect of shade and evaporation from the ground and trees, while tall buildings and narrow streets trap the heat in the city. Heat generated by anthropogenic activities, like the waste heat from cars, air conditioners, and industrial activities, further increase the ambient temperature in cities.

Overheating of Central Darwin is more intense during the daytime. At night, ambient temperature is usually 1–2 °C higher in the city than at the airport.

Dark coloured materials used in streets and car parks have a maximum surface temperature up to 70 °C. Light coloured materials are about 30 °C cooler, while greenery and water are the coolest surfaces. Use of dark colour materials increases the ambient temperature by at least 2 °C compared to lighter materials.

Wind transfers warm or cool air to the city and controls the ambient temperature conditions. Northerly and Westerly winds transfer warmer air and increase temperatures in the city while Southerly and Easterly winds have a less intense thermal impact.

Impact of Overheating

Urban overheating causes an energy penalty of 2.4 kWh/m^2, an Energy Penalty per unit of city surface and per degree of the UHI intensity of 0.74 $kWh/m^2/K$ and a Global Energy Penalty of 237 kWh/person. When temperature in the Darwin metropolitan area is higher than 32 °C and the humidity more than 80%, an increase in daily maximum temperature by 1 °C raises the number of hospital admissions by 263%. Heat coupled with high humidity steeply increases hospital admissions. Increase in daily maximum temperatures by 1 °C raises the average heat-related mortality by 4.9% across the Metropolitan area.

Mitigation Strategy

Urban mitigation contributes to reduction in the ambient temperature and counterbalances the impact of heat islands. Several efficient mitigation technologies have been developed and implemented:

- The use of diffuse reflective materials in pavements and roofs, to reduce absorption of solar heat in the city.
- Urban greenery and its optimum integration in the city structure.
- Development of advanced water and evaporative systems.
- Systems to dissipate the excess heat to lower temperature sinks.
- Urban shading and solar control systems.

Fourteen mitigation scenarios were designed aiming to decrease the ambient temperature in the central Darwin area. Cool roofs, cool pavements, fountains, pools, ponds, additional greenery, green roofs, shading and various combinations of the technologies were considered. All mitigation scenarios were evaluated in detail using advanced simulation techniques.

Main Results

All studies concluded that the peak temperature in Darwin can be decreased by up to 2.5 °C. Furthermore, the reduction in surface temperatures of paving and buildings will increase thermal comfort and make the city much more walkable. During the warmer periods, water mitigation presents a cooling potential up to 6 °C, but the impact is local and is minimised at a certain distance from the water feature. Cool roofs reduce the ambient temperatures up to 0.5 °C, while the potential of cool pavements is higher and cool the city by up to 2 °C. Green roofs have a very similar potential to cool roofs and contribute to reducing the peak temperature by up to 0.5 °C. Increase of greenery may cool down the city by up to 1.5 °C but the impact depends on the position and the density of the greenery.

It was found that mortality increased by 5% for every 1 °C increase in daily maximum temperature, with the result that the combined scenario can save 9.7 lives per year per 100,000 residents within the Darwin Urban Health District. Also, annually, four deaths of people over 65 in a population of 100,000 could be avoided with the implementation of the combined mitigation scenario.

Mitigation technologies when implemented in the Central Zone of Darwin contribute to a decrease of the peak electricity demand by up to 0.8 MVA. Such an important reduction of the peak electricity demand in the city helps to reduce significantly the carbon emissions from the conventional power plants in the Northern Territory and decrease the carbon footprint of the city.

Considering the whole residential and commercial building stock of the City of Darwin, the total cooling load savings, on an annual basis, resulting from the application of greenery are estimated to be 88.4 GWh from the application of cool roofs and 214 GWh from pavements, and from the application of the combined scenario, savings are of the order of 265.2 GWh. This is a very significant reduction of the energy needs in the city that will lead to an important decrease of the energy cost of households and will improve the quality of life in the city (see Fig. 18.2).

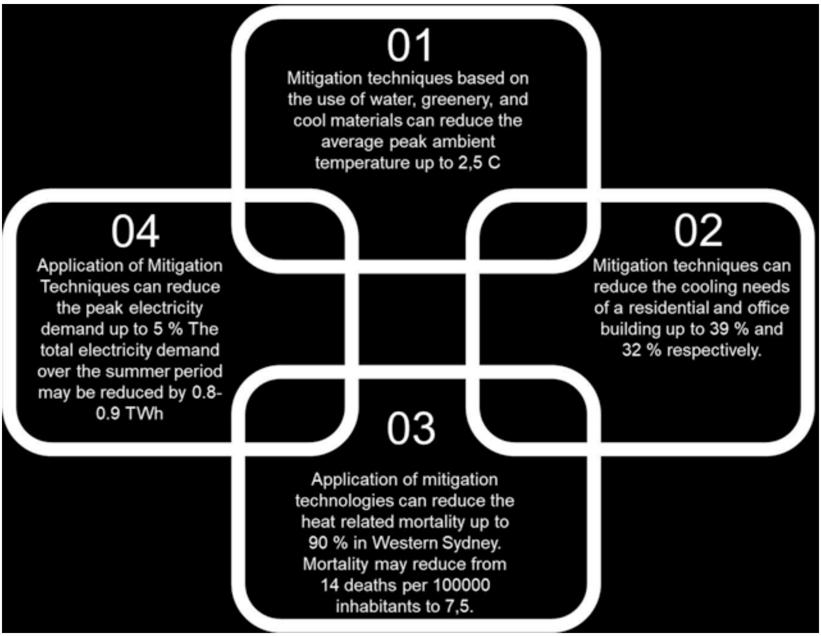

Fig. 18.2 Benefits of urban heat mitigation when applied in Darwin

Case Study 2: Mitigation of the Urban Overheating in Western Sydney

Scope of the Project

Urban overheating is a significant problem for major Australian metropolitan areas. Sydney is characterised by strong UHI intensities with complex patterns influenced by the synoptic weather conditions and the development of the sea breeze and the westerly winds from the arid inland. More specifically, in Western Sydney—a region with a population over 2 million centred 35 kilometres from the Sydney CBD and coast—UHI intensities as high as 7–10 K have been recorded. Moreover, Australia is one of the most vulnerable developed countries in the world to the impacts of climate change with heatwaves becoming longer, hotter and starting earlier in the year. In Sydney, the number of hot days (>35 °C) per year is projected to triple by 2090. It is therefore crucial to adopt appropriate mitigation strategies to counterbalance urban overheating and its impacts. As previously mentioned, advanced mitigation strategies like urban greenery, cool roofs and pavements, and the use of evaporative systems (e.g. water sprinklers, fountains) when properly implemented in urban areas contribute to reduction in ambient temperature and counterbalance the negative impacts of urban overheating. In this context, the CRC for Low Carbon Living in collaboration with Sydney Water and University of New South Wales (UNSW) launched a project called 'Strategic study on the cooling potential and impact of water based and other urban climate mitigation techniques in Western Sydney'.

The following activities have been carried out:

- Collection and validation of weather data from Bureau of Meteorology (BoM) stations.
- Selection of eight urban localities in the region of Western Sydney for which the mitigation strategies were evaluated.
- Development of five UHI mitigation scenarios involving water-based technologies, cool roofs, pavements and greenery.

- Climatic evaluation of the developed mitigation scenarios compared to the existing situation in eight localities in Western Sydney, using advanced climatic simulation techniques (ENVI-met 2018).
- Development of new weather files for each of the selected locations and each of the mitigation scenarios by modifying the weather profiles given by the BoM stations considering the calculated mitigation factors.
- Assessment of the impact of the mitigation strategies on building cooling energy needs using three different approaches: (a) empirical method, (b) a Cooling Degree Days (CDD) based method, and (c) use of dynamic energy modelling.
- Assessment of the impact of the mitigation strategies on total and peak electricity demand using regression analysis.
- Assessment of the impact of the mitigation strategies on heat-related mortality using regression analysis.
- Evaluation of the impact of the mitigation scenarios on human thermal sensation in outdoor spaces by estimating a thermal comfort index (the Universal Thermal Climate Index).

Mitigation Strategies

Five different mitigation scenarios have been developed and their impact has been evaluated for each selected urban locality. The five mitigation scenarios are described in Table 18.1.

Advanced simulation techniques involving 3D microclimate modelling (ENVI-metV4.1.3), have been used in order to quantitatively

Table 18.1 Description of the UHI mitigation scenarios

No	Description of scenarios	
1	Reference Model	Albedo of walls and roofs=0.2, Asphalts Albedo=0.05, Concrete pavements Albedo=0.15, Loamy soil Albedo=0.15, Grass is used as greenery
2	Greenery	Increased urban greenery by planting of 192 mature trees in the area
3	Cool roofs and pavements	Increased global albedo=0.5 by applying cool roofs and pavements in the area
4	Water based technologies	Use of evaporative cooling techniques by the installation of water fountains in 16 locations in the area
5	Combined scenario 1: Greenery and pavements & water based technologies	Increased urban greenery by planting of 192 mature trees and use of evaporative cooling techniques by the installation of water fountains in 16 locations in the area
6	Combined scenario 2: Cool roofs and pavements & water based technologies	Increased global albedo=0.5 by applying cool roofs and pavements and use of evaporative cooling techniques by the installation of water fountains in 16 locations in the area

evaluate the impact of the developed mitigation scenarios in terms of reducing ambient temperatures in comparison with the reference case which represents the current situation. The selected precincts simulated in ENVI-met are located close to each corresponding BoM station. Simulations were performed for peak summer conditions (11 February 2017). The average daytime outdoor temperature for the representative warmest summer day in 2017 was taken as 33.30 °C and the relative humidity was about 53% and wind conditions correspond to north-easterly winds at a speed of 3 m/s. In total 48 simulations were performed. The spatial distribution of the ambient temperature in each selected precinct, as well as the distribution of the surface temperature and of the wind speed were also calculated in detail for each scenario and each selected locality.

Main Results

Western Sydney faces high ambient temperatures and significant overheating problems. The potential of five UHI mitigation strategies to reduce urban overheating in Western Sydney was assessed using advanced simulation techniques. Moreover, the impact of these mitigation strategies on cooling energy needs, peak electricity demand, thermal comfort, and heat-related mortality rate was evaluated. All the mitigation scenarios were found effective in reducing air temperatures in the evaluated areas of Western Sydney and in mitigating the negative impacts of urban overheating on energy, peak electricity demand, heat-related mortality and thermal comfort. Higher reductions were achieved by the scenario of water technologies combined with cool roofs and pavements. More specifically, it was found that increasing the global albedo to 0.5 by the large-scale application of cool roofs and pavements and implementing water-based technologies may result in an average air temperature reduction of 1.5 °C in the area, with local reductions close to the water technologies reaching 10 °C. At the same time, the surface temperature decreases by an average of 10 °C, indicating lower heat release to the surrounding environment through radiation and convection. Regarding the impact on energy, it was found that this mitigation scenario would result in a decrease of cooling degree days—CDD (which indicate the severity of the climate and the cooling energy needs) by 36%.

The global residential cooling load savings for the whole area of Western Sydney resulting from the application of water technologies and cool roofs and pavements combined were estimated to be 852 GWh on an annual basis based on the CDD based method. On average, the application of combined water technologies and cool roofs and pavements would result in a decrease in the annual cooling loads of 39% for the residential and 32% for the office buildings. The global cooling load savings for residential and commercial buildings for the whole area of Western Sydney resulting from the application of water technologies and cool roofs and pavements combined are estimated to 1726 GWh on an annual basis.

Regarding heat-related mortality, the most effective mitigation strategy—the combined use of cool materials and water—can lower the cumulative heat-related extra-deaths by 7.5 fewer deaths per 100,000 inhabitants. The same mitigation scenario was found to improve thermal comfort conditions in the area of Western Sydney in terms of lowering the values of UTCI, a thermal sensation index, by 2 °C during peak summer conditions. In general, the weather stations located further inland (e.g. Penrith and Richmond) are characterised by higher values of the studied parameters, indicating that they are more exposed to higher temperatures, cooling energy needs and peak electricity demand, thermal discomfort and heat-related mortality rates compared to the areas located closer to the coast. This is explained by the local climatic patterns prevailing in Sydney, which are characterised by the influence of hot westerly winds affecting the local climate of areas located inland, combined with the absence of the cooling effects of the sea breeze that cannot penetrate inland and reach these areas. In contrast, areas located closer to the coastline remain cooler as they take advantage of the cooling effects of the ocean and sea breeze. The results of this study indicate that appropriate UHI mitigation strategies can be very effective in lowering ambient temperatures and reducing the negative effects of urban overheating.

Case Study 3: Urban Heat Island Mitigation for Green Square Redevelopment

Main Challenges in Green Square Redevelopment

The Green Square redevelopment is one of the most significant urban transformation programs in Australia, converting Sydney's oldest industrial precinct into a resilient world-class community, including residential and commercial buildings, a library and public plaza, an aquatic centre, parks and playgrounds, etcetera, with a projected working population of 21,000 and 61,000 residents by 2030. Green Square has experienced increased urban temperatures in recent years. For example, the number of days above 38 °C rose to four in 2016 from one in the summer of 2008–2009 (Bodilis, Hawken & Yennet 2017). It is a challenging task to identify and assess Green Square redevelopment alternatives capable of increasing density to match residential and working population growth while minimising the impact of climate extremes, improving outdoor thermal comfort and reducing human health risk.

The impact of urban heat island effects on the existing Green Square redevelopment area was monitored over the summer of 2017–2018. Main challenges identified included a significant lack of urban vegetation and poor outdoor thermal comfort during extreme heat days. Furthermore, a number of potential hot spots were identified from modelling planned buildings, street networks and public spaces (specifically, Library Plaza, the Drying Green and the open area east of the Aquatic Centre) due to a lack of vegetation, external shading structures or tree canopy cover.

Development Alternatives and Mitigation Options

Urban development approaches to urban heat island mitigation need to consider both the public realm and built form elements. Governments are primarily responsible for the development of the public realm including streets, public spaces, parks, etcetera, while developers,

Table 18.2 Examples of development alternatives and mitigation options for Green Square redevelopment

Built Form	Public Realm
• **Building Height** e.g. Existing and proposed building heights. • **Building Lot Ground Cover & Footprint** e.g. Building lot ground cover, setbacks and footprints of future buildings. • **Façade Materials** e.g. Façade materials (high albedo, high emittance and green walls) for proposed buildings. • **Roof Materials** e.g. Roof materials (high albedo, high emittance and green roofs). • **Awnings** e.g. Building awnings	• **Vegetation** e.g. Vegetation, trees, and landscaping design within the proposed public parks, plazas and streets. • **Roads, Footpaths, Public Space (Hard-Scape Surface Materials)** e.g. Cool, permeable, high albedo, vegetated or light coloured pavements. • **Water Evaporative System** e.g. Evaporative water systems (e.g. water misting) within proposed public spaces. • **External Shading Structures** e.g. External shading structures within the proposed public parks and plazas.

builders and designers have control over building design, construction and retrofit. A list of examples of development alternatives and mitigation options in built form and the public realm is presented in Table 18.2.

The City of Sydney Council and developers such as Landcom are committed to creating a vibrant and sustainable Green Square precinct by aiming for the highest Green Star Community Rating (Green Building Council of Australia 2016) with the Green Square redevelopment. To meet the requirements from what is planned, a combination of mitigation scenarios was identified, involving a tree canopy shading plan for the new street networks, increased green and cool roofs for planned buildings, high albedo asphalt for the major roads, etcetera.

Comparative analysis of mitigation performances was suggested by developers and researchers, comparing the historical context (i.e. an industrial precinct) to the present redevelopment (i.e. a mixed-use redevelopment) and its potential by adopting advanced mitigation technologies for the future. Optimal combinations of mitigation technologies proposed include a combination of cool and green roofs, cool surfaces for pavements and roads, water evaporative systems such as water misting systems, etcetera.

An Urban Heat Island Mitigation Decision-Support Tool

An Urban Heat Island Mitigation Decision-Support (UHI-DS) Tool was developed to support decision-making in urban heat island mitigation for the Green Square redevelopment. It provides scenario analysis by showing to what extent the built form elements and the public realm help minimise the impact of increasing temperature extremes and improve outdoor thermal comfort, and potential optimal mitigation options. The UHI-DS Tool framework is presented in Fig. 18.3, including the urban information model storing urban development data for the UHI mitigation scenario analysis. Computational simulation and artificial neural network methods are adopted for prediction of air and surface temperature distributions, wind speed, outdoor thermal comfort and potential reduction of annual cooling loads and peak electricity demand. The UHI-DS Tool provides a web-based interactive 3D visualisation platform, allowing scenario analysis of both existing urban conditions and planned development alternatives across urban and building scales. Scenario analysis outcomes, such as air temperature distributions, can be overlayed onto the Green Square precinct site for 3D visualisation.

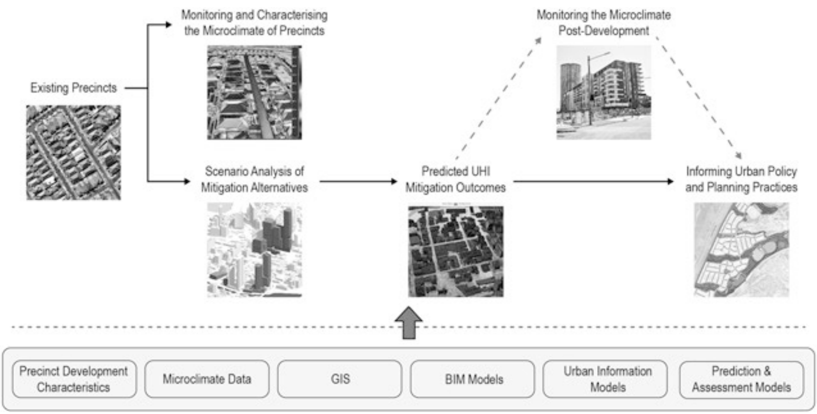

Fig. 18.3 The UHI-DS Tool framework

Main Results

The potential of mitigation options for Green Square redevelopment was assessed using the UHI-DS Tool, which included a tree canopy shading plan, current redevelopment plan for compliance with Green Star Communities Urban Heat Island Credit requirements and a combination of advanced mitigation technologies and options. The potential of average air temperature reduction from the proposed mitigation options was in the range of 0.6–1.3 °C in the Green Square precinct. The potential of maximum localised air temperature reduction for certain identified 'hot spots' in the precinct was in the range of 2.4–6.0 °C. It was found that street tree plantings for proposed street networks and public open spaces could achieve a potential maximum localised air temperature reduction of 2.4 °C, and a combination of mitigation strategies with increased cool pavements, roads and roofs that meets the minimum Green Star Communities Urban Heat Island Credit requirements could achieve a potential maximum localised air temperature reduction of 2.5 °C. Furthermore, a combination of advanced mitigation technologies such as cool roofs on most planned buildings where applicable, cool surfaces for new roads and pavements, and water evaporative systems for public spaces such as the Library Plaza, could achieve a potential maximum localised air temperature reduction of 6 °C. The results indicate the appropriate mitigation strategies are a combination of mitigation options across the public realm and built form elements, and most effective mitigation options for localised air temperature reduction are water evaporative systems such as water misting cooling systems for public spaces.

Conclusion

The interaction between the global phenomenon of climate change and the local phenomenon of the urban heat island, driven by accelerating urban growth (another global phenomenon) is creating an unprecedented challenge to human health, wellbeing and economic development, and ironically, contributing to further overheating via the proliferation of air conditioning. Since most of us live in cities, mitigation of urban overheating is an increasing priority in city planning. Significantly, applied research supported by the CRC for Low Carbon Living has found there is no 'one size fits all'—a variety of mitigation solutions, from interactive water features to urban greening and high-tech materials, singly and in combination—are required to address urban heat across diverse climatic contexts. Furthermore, heat mitigation is necessary across both built forms and public realm elements. There are positive scenarios for urban heat mitigation capable of application now to contemporary urban development and redevelopment.

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19

The Performance of Urban Precincts: Towards Integrated Assessment

Peter Newton

Introduction

Precincts are the acknowledged building blocks of cities—the scale at which our built environments have been historically conceived and constructed (EIT & Climate-KIC 2017; Frater 2013; Infrastructure Australia 2018b; Newton et al. 2013). In advanced economies, they reflect the influence that dominant transport technologies have had in the resultant urban forms and fabrics that have been laid down: the walking city, the transit city and the automobile city (Thomson et al. this volume). Urban precincts have also reflected the spatial imprints of successive global industrial revolutions, from agricultural to industrial, and post-industrial (reflecting the emergence of service, information and creative-based economies: Brotchie et al. 1991; Florida 2009; Jones 1982); and major population, housing market and labour market shifts

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that have radically altered the social and cultural geographies of cities, suburbs and neighbourhoods (Knox & Pinch 2010). Until relatively recently in human history, settlements have also evolved during a long era of relative global climate stability (Steffen et al. 2015a) and freedom from resource constraints (Rees & Roseland 1991).

In the twenty-first century there are several new drivers that require a fundamental change in the way our cities and precincts are planned and designed in order to respond to:

- Climate change (and its associated increasing frequency of extreme rainfall events, heat waves, local flash flooding, megafires in peri-urban areas, sea level rise and storm surges in coastal settings, increased urban heat: Newton et al. 2018) and the need for more *adaptive urban design* that delivers greater urban resilience to vulnerable localities and populations.
- Resource constraints (water and food security; reliable and affordable renewable energy) and resource waste; and the associated challenge of *regenerative urban development* that can radically shrink the ecological and carbon footprints of cities in advanced high-income societies and increase the resource self-sufficiency of neighbourhoods (Newton 2017).
- Mobility challenges for an increasing proportion of residents in big rapidly growing cities where there is increasing geographic separation of home and workplace and a dependence on longer commutes in congested traffic; requiring renewed efforts at integrated land use-transport planning and a focus on *low carbon mobility* requiring extension of public transport as well as designing-in active transport and shared mobility services that deliver the 20-minute neighbourhood and the 30-minute city (Newton et al. 2017b).
- Provision of appropriate and affordable housing supply to accommodate rapidly growing urban populations without traditional reliance on greenfield development; requiring high levels of urban infill development in established greyfield and brownfield suburbs ideally undertaken as *precinct scale medium density redevelopment*—the 'missing middle'—compared to suboptimal small lot subdivision knock down rebuild (Newton 2018; Newton & Glackin 2018).

- Deficiencies in urban governance associated with planning and implementing development in major Australian cities that reflect a planning deficit: lack of horizontal integration across agencies responsible for metropolitan strategic planning as well as lack of vertical integration between the three tiers of government—and local communities; requiring real engagement (Tomlinson & Spiller 2018). *Technological innovation* can provide *advanced digital platforms and instruments* for more effective interaction and participation in decision-making; but they also require new and more effective *process innovations* related to optimising the life cycle performance of urban development projects (Newton & Burry 2018).
- The increased complexity of cities and human settlement systems and the pace at which urban change is occurring requires the development and use of *more advanced digital tools* that can bring evidence from *integrated modelling* of urban development scenarios or urban precinct development designs into decision-making in a more timely manner than is currently the case. Building, Precinct and City Information Modelling (BIM, PIM, CIM) provides an analytical platform where integrated performance assessment can more effectively occur (Newton et al. 2017a).

If cities are to achieve the international performance goals and objectives outlined by the United Nation's Sustainable Development Goals and the New Urban Agenda as well as those identified at a national level *then* it will be necessary for their constituent precincts to demonstrate performance outcomes that align with and add to, rather than subtract from, these objectives.

Urban Development Goals and Precinct Design Context

The global context for urban development is one where the world's current urban population is forecast to double by 2050 (IRP 2018), where global resource use is exceeding the earth's ecological capacity (GFN 2018; WWF 2016) and threatening critical planetary boundaries (Steffen et al. 2015b), most clearly in relation to increased greenhouse gas (GHG) concentrations in the atmosphere. The modelled trajectory of these concentrations is capable of driving global warming 2–4 °C above pre-industrial levels triggering potentially irreversible climate change, unless reductions in GHG emissions of the order of 70–80% are locked in by 2050 (IPCC 2014; Levin & Tomkins 2014; WRI 2018). Contemporary city development patterns along with current modes of industrial production and consumption constitute a driving force for these trends.

A growing body of international studies highlight the unsustainable nature of current development trajectories, unless there is systemic intervention across multiple sectors. To this end, the United Nations has been attempting to redress growing environmental problems on a global basis since the 1970s (UN 1987, 1992, 2000; Ward & Dubos 1972). These efforts have accelerated this century, culminating in the release of the United Nations Development Program's Sustainable Development Goals in 2015 (UN 2018). They outline a collaborative global roadmap with 17 Goals and 169 targets which are meant to be achieved by 2030. The Australian Government is a party to the Agreement and has provided a first Voluntary National Review (Australian Government 2018) and a first assessment of 86 targets and 144 indicators for Australia (DFAT 2018) where there is significant lag in performance against targets, especially in relation to cities and climate action. SDG 11 is directly focused on Sustainable Cities and Communities and SDG 13 on Climate Action, although it is clear that cities and urban development are linked with many of the 17 goals. A further set of 175 objectives are outlined in the UN New Urban Agenda (UN 2017) that are centred on cities and communities.

These global goals are *values-based* and have been designed to raise awareness and create an understanding of the complex challenges facing societies and their development in the twenty-first century. They require a shift from 'siloed thinking' to an *integrated approach* designed to "put to rest the futile debates that pit one dimension of sustainable development against another…. each goal should be analysed and pursued with full regard to the three dimensions of sustainable development - economic, social and environmental" (SDSN 2015, p. 9). The significance of the UNSDGs is this: *if* these values are broadly shared they can provide a basis for all stakeholders pursuing solutions to these challenging goals. There are numerous examples of how these global goals are being used to frame future planning strategies in multiple sectors, especially those related to building and construction (Bioregional 2018) and transport (IST 2018), the two most intensive resource consuming and GHG emitting urban sectors (Newton 2017); where mitigation potential is high but lagging (Climateworks 2018). A major contributor to this is the fact that there is no uniform commitment in Australia across all tiers of government (especially at federal level: Newton et al. 2018) or private sector-built environment organisations (Giesekam, Tingley & Cotton 2018; Newton & Newman 2015) to appropriate renewable energy goals, climate change mitigation strategies, green economy transition policies and sustainable urban development objectives. This hiatus inhibits development and alignment of public and private sector strategies and investment capable of more rapidly and confidently driving the urban, infrastructure and industrial transformations required in the twenty-first century. Moreover, there is no clear and consistent message being communicated to the Australian population capable of building social norms around sustainable behaviours/sustainability. Their surveyed attitudes reflect this (Leviston 2014).

The local context is critical to any national alignment and implementation of broader global goals related to sustainable urban development. Australia's cities have among the highest population growth rates within the OECD and these are projected to continue. The high growth rates have exposed multiple deficiencies in the capacity to plan for urban change at all levels of government (Newton et al. 2017b). The high liveability ratings that Australia's largest capital cities have received for a decade (EIU 2018) have masked the unsustainable dimensions of their metropolitan development (Newton 2012). Their ecological and carbon footprints are among the highest in the world (GFN 2018) as are their urban footprints (Coleman 2017), property prices and household indebtedness are world-leading, and there are increasing levels of spatial disadvantage that are concentrating in the outer suburbs (Randolph & Tice 2015). A major contributing factor has been the failure of metropolitan planning since the 1950s to curb low density sprawl and invest in more integrated land use and (public) transport development that supports more sustainable low carbon living (Newton 1997, 2000); what has been termed a *planning deficit* (Gleeson, Dodson & Spiller 2012). Issues of governance are also at the heart of what has been termed a *democratic deficit* (Williams 2018), referring to the multiple levels of government that are disconnected horizontally (e.g. inter-departmental and cross-agency) as well as vertically (e.g. federal-state-municipal-community) in relation to metropolitan urban planning. Despite clearly articulated performance goals for Australia's cities—competitive, productive, liveable, sustainable, resilient and inclusive (Department of Infrastructure 2011)—there is no metropolitan planning authority accountable for urban development in Australia's four mega-metro regions, much less for precincts which we see as encompassing 'district', 'neighbourhood' and 'street' levels—the building blocks of cities (Newton et al. 2013; Tomlinson & Spiller 2018).

The current problems and challenges facing Australia's cities are a combination of joint failures to undertake and implement integrated land use—transport planning at a metropolitan scale (with particular reference to public transport, services and jobs) and the finer grained urban design of neighbourhoods that are required to accommodate a growing number and diversity of residents. Here it has been argued that the unsustainable nature of today's cities is due in part to poor planning and development assessment at the precinct level (Codoban & Kennedy 2008) as well as lack of horizontally and vertically integrated planning at city scale. The challenge for twenty-first century urban planning and design is to discover effective ways to RE-develop/renew/retrofit/regenerate our cities in a way that redresses deficiencies in past planning and development by pursuing the *objectives* outlined in the following section.

Urban Performance Concepts, Models and Objectives

'Regenerative urbanism' has emerged as a new objective for urban development that presents the opportunity and challenge to go beyond minimal reductions in environmental impact to a new vision of how cities can be designed and operate in an 'eco-positive' manner, while maintaining or enhancing liveability (Birkeland 2008); that is, removing negative environmental impacts from development and providing ecological gain. This requires regenerative development that is based on "*giving back* as well as taking" (Girardet 2015, p. 11) and needs to operate across all urban sectors and all urban scales: building, precinct and city.

Regenerative urbanism is embodied in the technologies, design thinking and new process approaches represented in the Factor 4 and Factor 5 paradigms that outline pathways to achieve reductions in resource and energy use by up to 80% (von Wiezsacker et al. 1997, 2009). Regenerative urbanism also relies heavily on the use of the urban metabolism model framework for representing (and measuring) the flow of resources into and waste outputs from built environments. This model was employed by Newman et al. (1996) and extended by Newton and Bai (2008) for State of Environment Reporting to include the exogenous pressures on human settlement as well as the endogenous urban systems and processes that are required to manage large complex urban systems. It also recognises the two dimensions of urban liveability that are associated with human well-being and urban environmental quality. The latest version of this framework is presented in Fig. 19.1.

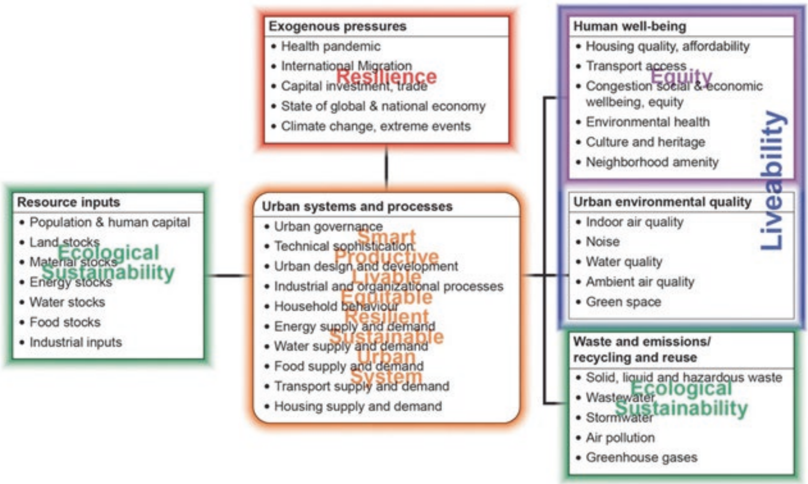

Fig. 19.1 Framework for assessing urban system performance

This framework can be used to highlight the transformational changes that need to occur in our urban systems:

- *reduction* in use of natural resources—dramatically shrinking ecological footprints by dematerialising industrial and construction processes by the adoption of eco-efficient technologies. This involves cities creating more renewable energy than they need—energy *from* the city; and significantly reducing the need to import potable water that has been traditionally diverted from environmental flows in the hinterland of cities
- *reduction* in emissions and waste streams, with particular focus on decarbonisation of energy and deep mitigation of greenhouse gases; capturing and treating stormwater and wastewater for non-potable urban water uses; and creating zero-waste pathways for industrial, construction and domestic waste streams linked to transition to a circular economy based on industrial ecology principles
- *substitution* of *smart* urban systems and processes for those currently in use to achieve more effective and efficient economic, social and environmental planning and management of cities (smart strategies as well as smart technologies)
- *improvement* in urban environmental quality of the public realm (e.g. waterways, green space); as well as responding to the environmental stressors linked to reduced private green space associated with the intensified urban retrofitting and densification of cites; for example, changes in surface permeability and stormwater run-off and increased urban heat; and more effectively integrating concepts of biophilic design and natural urbanism into city planning in the face of global warming
- *improvement* in liveability and well-being across the entire metro region. Long established urban planning concepts such as equity and access are being lost in a neo-liberal era where significant privatisation of urban services has occurred and where housing affordability is a challenge for residents of major cities; liveability outcomes are influenced by where people live and the quality and characteristics of the built environment that surrounds them.

- *increase* in the resilience of cities to the array of exogenous and endogenous pressures now evident. Foremost among these is adaptive capacity to climate change threats of flooding, drought, extreme temperatures, sea level rise, storm surges and mega bushfires.

Smart, sustainable urban development strategies are needed that are capable of delivering transformative change to cities. Newton (2019a) begins to flesh these out in more detail in the context of *performance objectives* capable of guiding design thinking at building, precinct and city levels. It is clear that there are cross domain and cross scale interactions that need to be accommodated in the design process. Regenerative urban development also requires engagement with a new generation of urban infrastructure technologies, more sustainable materials and more innovative design thinking supported by a rapidly evolving digital information platform. It also will require a new generation of built environment assessment tools capable of rapidly and comprehensively assessing the performance of development projects, especially those at a precinct level.

Precinct Design and the Development Assessment Process

The critical relationship between precinct design (and its embedded sets of performance goals, objectives and targets) and precinct design assessment is outlined in Fig. 19.2, providing core elements in the conceptual and methodological frameworks that have shaped specific precinct design assessment tools developed in the CRC for Low Carbon Living.

Ability to positively influence the cost and performance of a built environment project is always highest at the front end, in the concept-design-feasibility stages, a period during which information to aid decision-making in a timely manner has proven more difficult to assemble. The design assessment tools outlined in this chapter, and in much greater detail in the Guide (Newton & Taylor 2019), attempt to redress this information deficit—to lift the information base for

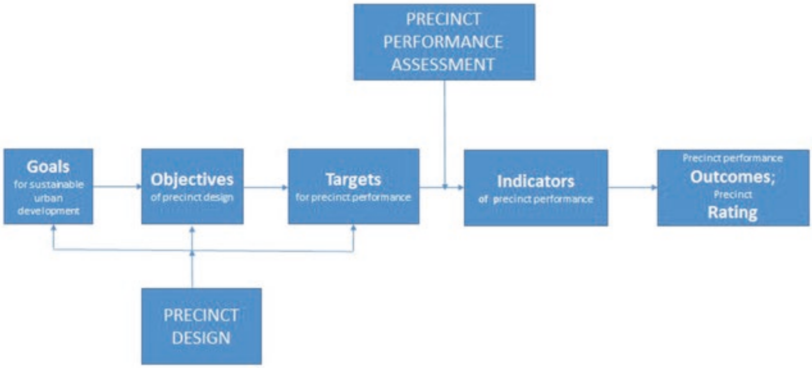

Fig. 19.2 Key design and assessment processes underpinning smart sustainable urban development

decision-making higher during concept/feasibility/design phases. It is for this reason that increasing attention is being paid to new processes, instruments and platforms that can be introduced for smarter precinct planning and design at concept and design phase.

The CRC for Low Carbon Living has developed a framework and tool for the built environment sector to help facilitate strategic conversations within a project team about project impacts (positive and negative), and help conceptualise, prioritise and enhance its capacity to deliver greater value for the environment, society and economy (Haas-Jones & Balatbat 2017). *The Built Environment Impact Guidance Tool* is applied in facilitated sessions with the project team in the process of developing a vision for the precinct development. As part of this process the team will prioritise the thematic areas and issues of significance to its stakeholders and identify the associated tangible goals and indicators for the project (see Fig. 19.3).

Precinct sketch planning and design follows with additional disciplinary skills being assembled for a range of tasks associated with realising specific performance objectives of the development concept.

There is an absence of an appropriate suite of government-endorsed best practice performance standards for precinct scale urban development in Australia. Outside a limited set of prescriptive local government statutory planning regulations and Building Code of

Fig. 19.3 The built environment impact guidance tool framework (*Source* Haas-Jones and Balatbat (2017); CRC for Low Carbon Living, with permission)

Australia specifications there is little stimulus to advance sustainable (regenerative and adaptive) urban development where more extensive performance assessment is required to be built into the development assessment process (see Harrington and Hoy, this volume). This is seen by many in the property development industry as unnecessary 'green tape'. As a result of this government inertia, a number of industry-initiated building and precinct rating and certification systems have emerged in Australia that 'brand' developments according to their preferred criteria and weightings. The motivation is to assist more innovative companies promote the environmental credentials of their project and create market profile and a return on investment premium for the property owners. These rating systems are: Green Building Council of Australia's *Green Star Communities* (https://new.gbca.org.au/green-star/rating-system/communities/), Urban Development Institute of Australia's *EnviroDevelopment* (http://www.envirodevelopment.com.au/), and Bioregional Australia's *One Planet Communities* (https://bioregional.com.au/oneplanetliving/oneplanetcommunities/). Leading international precinct rating tools have emerged from North America (LEED-Neighbourhood Development), Europe (BREEAM) and Japan (CASBEE-Urban Development) and are reviewed in

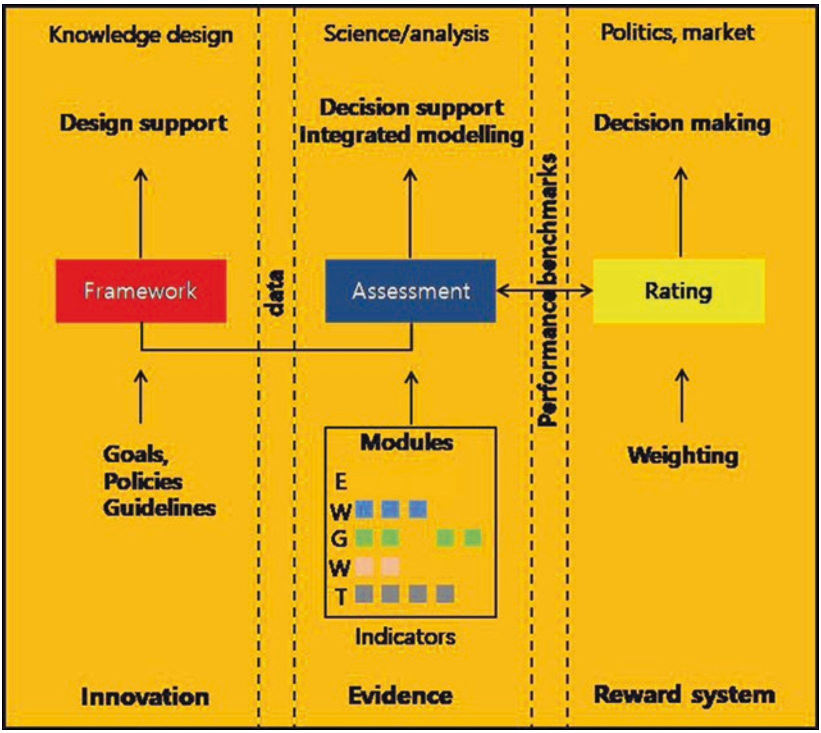

Fig. 19.4 Lenses on precinct assessment and rating (*Source* Newton et al. (2013); CRC for Low Carbon Living, with permission. *Note* Assessment modules address key thematic areas e.g. Energy, Water, Greenspace, Waste, Transport etc.)

Säynäjoki et al. (2012) and Sharifi and Murayama (2015). The consensus from these studies is that a single global tool and associated set of standards is not viable given the specificities of different geographic locations, jurisdictions, sites and stakeholder needs.

There is growing global consensus, however, around themes, issues, goals and indicators linked to sustainable urban development where scientifically validated assessment *is* required. *If* aspirations for city liveability and sustainability are to be realised and global twenty-first century sustainable urban development challenges met, then assessment of the building blocks of the built environment—infrastructures, buildings, precincts—must be advanced beyond current practice. The Precinct Scoping Study (Newton et al. 2013) undertaken at the beginning of the CRC for Low Carbon Living concluded that the quality and veracity of neighbourhood/precinct ratings were only as good as the performance assessments made for each of the built environment issues being rated (see Fig. 19.4). The lack of transparency currently associated with the voluntary project rating systems (e.g. the assessment techniques and processes employed) limits their capacity for the type of *transformational change* required of the built environment.

Precinct Performance Assessment Tools

The research focus for CRC Program 2 (Low Carbon Precincts) was subsequently focused on developing precinct design assessment tools associated with key sustainable urban development goals and objectives that could be directly employed in local government development assessment processes as well as by industry in the design and development assessment and rating of precinct scale projects. Table 19.1 provides a brief snapshot of the assessment capabilities of each tool. A full description of all underpinning analytical methods and data requirements as well as illustrative case study applications of the tools are found in Newton and Taylor (2019).

Table 19.1 CRC Low Carbon Living Precinct Tools—key performance assessment capabilities

Tool	Key performance assessment capability	Key reference
ICM: Integrated Carbon Metrics	A suite of carbon accounting tools that can be applied to the product, building, precinct or city scale to provide a complete picture of the carbon life cycle in the Australian built environment	Wiedmann et al. (2019)
ICM: Embodied CO_2—Products	An eco-efficiency tool that provides an integrated life cycle (carbon) and economic (cost) assessment of building material products	Schmidt and Crawford (2019)
ICM: Embodied Carbon Explorer for Precincts	Quantifies Scope 3 carbon emissions for precincts (i.e. indirect, embodied emissions used in construction and maintenance operations of the built environment provided via materials and services imported into the precinct via supply chains) for use in the Australian government's National Carbon Offset Standard for Precincts, NCOS-P	Wiedmann and Teh (2019)
ICM: Carbon Footprint Analysis of Cities	Quantifies Scope 1, 2 and 3 carbon emissions for cities using multi-regional input-output data that highlights the relative significance of each in a total city carbon map	Wiedmann, Chen and Teh (2019)
PCA: Precinct Carbon Assessment	Tool assesses the whole life cycle of carbon emissions at precinct scale (embodied and operating) via an object-based spatial model that is capable of examining alternative design scenarios (building types and materials; mobility options; alternative energy sources, including renewables; and resident consumption profiles)	Xing, Huang and Pullen (2019)
ESP: Envision Scenario Planner	ESP provides a comparison of alternative greyfield infill precinct sketch designs on the basis of energy and carbon (embodied and operating) and can be linked to a financial feasibility assessment tool to provide an eco-efficiency assessment	Glackin and Newton (2019)

(continued)

Table 19.1 (continued)

Tool	Key performance assessment capability	Key reference
ETWW: Forecasting Demand for Precinct Energy, Transport, Water and Waste (Integrated)	Forecasts demand for electricity, water and transport at a precinct scale linked to utility service provision planning. Provides scenario planning capability for alternative types of precinct development that examines interactions between the different demand domains (e.g. energy-water; energy-transport). Also accommodates impacts of population change and socio-demographic variability of precinct residents. Provides core set of carbon metrics for all scenarios, in addition to other domain-specific indicators	Taylor et al. (2019); Holyoak et al. (2019)
ETWW: Electricity Demand Module	Integrated modelling and optimisation tool for assessing performance of precinct scale micro-grids (in relation to carbon emissions and cost) with distributed generation and storage as core technologies, responding to different electricity demand models of household types, appliance ownership and climate	Percy (2019)
ETWW: Water Demand Module	Provides integrated assessment of water demand and associated energy and greenhouse gas emissions. Accommodates variations in climate (temperature, rainfall), water and electricity supply mix, wastewater treatment, water heating options, rainwater harvesting and household types	Hadjikakou (2019)
Greening Urban Mobility	A suite of three tools for devising alternatives to private car use in suburban settings	Dia et al. (2019)
SNAMUTS: Urban Land Use Transport Model	Tool for exploring changes to public transport services required to shift a significant percentage of trips towards low carbon travel modes for major suburban employment precincts	Perkovic, Stone and Curtis (2019)
AMoD: Autonomous Mobility	Agent-based model for assessing feasibility of Autonomous Mobility-on-Demand (AMoD) services for meeting the first and last kilometre travel requirements associated with origin and destination precincts within cities [20 min neighbourhoods]	Dia and Javanshour (2019)

(continued)

Table 19.1 (continued)

Tool	Key performance assessment capability	Key reference
PSUMC: Precinct Shared Use Mobility Calculator	PSUMC provides municipal decision-makers with assessments of likely impacts of low carbon transport interventions: specifically, the capacity for redistributing private car trips to other modes (e.g. train, tram, bus, walk, cycle, taxi, ride share, car pool)	Moffatt and Dia (2019)
CBC: Co-Benefits Calculator—City Scale	In this mode the CBC calculates and maps distinctive land use typologies that exist across a city and examines the strength of association—'ecological correlations'—with a range of human health and well-being variables (linked to the premise that liveability outcomes are influenced by where people live and the quality and characteristics of the built environment that surrounds them)	Thompson and Stevenson (2019a)
CBC: Co-Benefits Calculator—Precinct Scale	In this context, the CBC is used to identify the relative advantages (as well as challenges to be addressed) associated with specific small scale precincts selected for redevelopment	Thompson and Stevenson (2019b)
Mitigating Urban Heat	A set of tools that provide city wide assessment of suburb level resident vulnerability to episodes of extreme heat; as well urban heat island mitigation options for specific precincts undergoing higher density urban redevelopment	Ding and Craft (2019)
UHVI: Urban Heat Vulnerability Index	UHVI provides a measure of the spatial and temporal patterns of population vulnerability to periods of extreme heat across a metropolitan region, taking into account: the built environment fabric and housing types; the social and demographic characteristics of the resident population; local climate conditions; water bodies; green space etcetera.	Bodilis, Yenneti and Hawken (2019)
UHI-DS: Urban Heat Island Decision Support	UHI-DS is available for use by urban designers and developers to assess precinct redevelopment plans for urban precincts in relation to mitigating increased temperature that is often associated with increased density. It is also a critical tool for use by local governments in their development assessment process	Craft et al. (2019)

Source Extracted from Newton and Taylor (2019); CRC for Low Carbon Living, with permission

Advanced Precinct Assessment: Integrated Precinct Modelling

Given the multiple objectives that are associated with achieving sustainable urban development, how precinct performance is assessed is challenging—even when focus is primarily on environmental performance and economics. We are currently at a similar stage of applied research activity for precincts as we were for buildings at the end of the twentieth century, due to the relative complexity of the topic. Digitalisation proved to be the principal driver of innovation in combined building performance design and assessment, with BIM capability meshing with increased knowledge about the environmental performance of building objects and spaces (Newton, Hampson & Drogemuller 2009).

A similar transition is required for PIM as a new digital platform capable of supporting integrated assessment and integrated modelling at a precinct scale. Figure 19.5 represents this trajectory. At present there is a growing collection of software tools that focus on particular aspects of precinct performance—such as those represented in Table 19.1 and a comprehensive Precinct Design Assessment Guide (Newton & Taylor 2019).

Material presented in this chapter takes us but a small distance up this innovation curve. Most of the material has focused on computer based models targeting some important facets of precinct design performance: energy and water use; mobility; waste generation; influence of dwelling type on resource use and carbon emissions; regenerative impact of distributed technologies such as solar PV and storage and microgrids; integrated

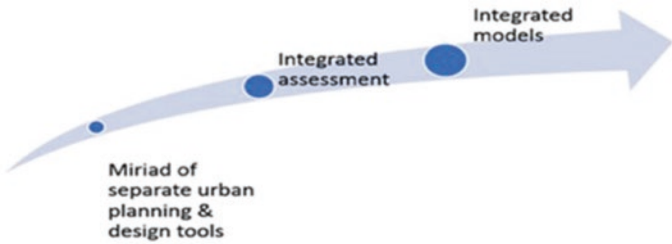

Fig. 19.5 Three horizons of urban analytics

water systems; car and ride sharing; accounting for embodied energy as well as operating energy in relation to the carbon footprints of materials, buildings and cities; assessing the health and wellbeing co-benefits of living in a particular type of neighbourhood; and the capacity of different urban fabrics to adapt to global warming and climate change.

The precinct assessment toolkits to emerge from the CRC for Spatial Information, CRC for Low Carbon Living and CRC for Water Sensitive Cities are considerable in scope. They provide a powerful capability for transitioning to *integrated assessment* of precincts—at any stage of precinct development from 'as conceived/planned' to 'as designed' to 'as built' and 'as operated'. The insights and benefits to be gained from research synthesis workshops employing integrated assessment of a particular precinct are considerable and have been documented for Fishermans Bend, Australia's largest brownfield precinct (Newton 2019b).

Integrated modelling, using PIM as a platform, represents a challenge for the next generation of applied urban research (again see Fig. 19.5, as well as 19.6). Newton et al. (2017a) and Plume, Marchant and

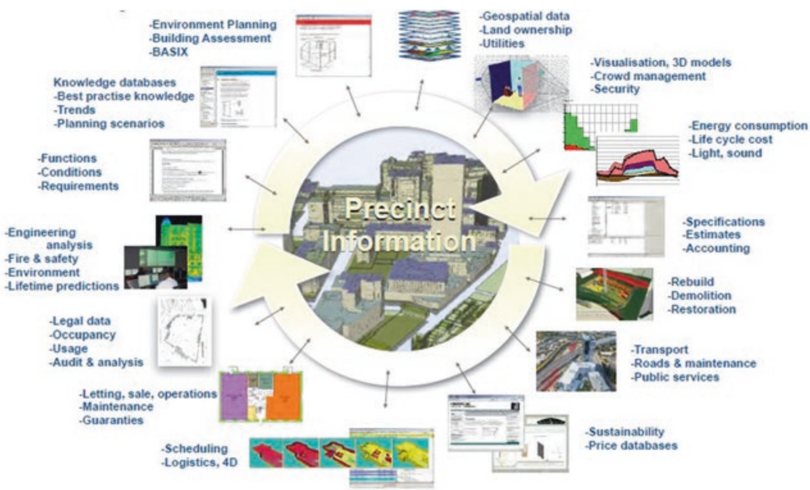

Fig. 19.6 Integrated precinct modelling across the project life cycle (*Source* Plume, Marchant and Mitchell (2019); CRC for Low Carbon Living, with permission)

Mitchell (2019) indicate the benefits to be gained for integrated precinct analytics. Realisation of these efficiency, productivity and performance benefits, however, will require greater engagement from national and international spatial standards bodies as well as major firms involved in BIM, PIM and CIM to establish codes and standards for the interoperability of spatial data and spatial software. The benefits are considerable (BuildingSmart & SIBA 2015; OGC, ISO & IHO 2018).

A New Platform for Transforming Urban Governance and Planning—And Precincts

The mounting calls for better urban governance (Burton 2017; Williams 2018) and better urban planning (ASBEC 2015; Commonwealth of Australia 2018; Infrastructure Australia 2018a; PIA 2018) are connected. A game-changer capable of providing a transition on both fronts has emerged in the form of a twenty-first century smart, networked decision support platform for applied urban research, synthesis and participation. Labelled the *iHUB-Network* (Newton & Burry 2018), it is being developed as a readily scalable state-of-the-art multi-layered facility for applied urban research, synthesis and engagement that enables smart decision support for urban policy-making, plan-making and place-making (Fig. 19.7). Funded by a A$1.8 million Australian Research Council LIEF grant awarded in November 2018 to a consortium of five universities located in Australia's four largest capital cities, this initiative will enable 'city as laboratory' to be realised on a national scale, linking individual university labs as a single collaborative research space (including Swinburne's Smart Cities Research Institute and Centre for Urban Transitions; University of NSW's City Analytics Lab and Urban Pinboard; Monash University's Urban Lab; Curtin's Circular Economy Living Lab; and University of Queensland's individual research centres in the Faculty of Engineering, Architecture and IT)—in combination with governments at all three levels, the built environment industry—and communities. Utilising a common infrastructure and leading software such as outlined in this chapter, the *iHUB*-network is designed to deliver superior computational, visualisation and broadband

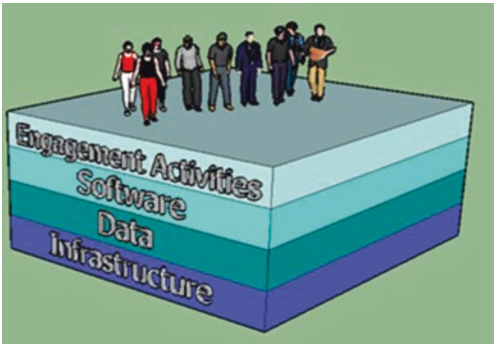

Fig. 19.7 *iHUB* facility layers

communications infrastructure capable of supporting a broad spectrum of applied and strategic urban research and engagement objectives with digital pin-ups, high speed computing and broadband, enabling real time distributed synchronous computing and communication nationally and internationally 24/7. The objective: creating and implementing sustainable solutions to the nation's growing list of urban development challenges.

Conclusion

Clearly, precinct design assessment tools of the type featured in this chapter are a necessary but not sufficient trigger for transformational change in built environment outcomes that seek to deliver on global, national, metropolitan and local sustainable urban development goals and objectives. But they provide a critical step in that direction. However, they also need to be embedded in new urban governance frameworks and processes supported by new digital platforms capable of effectively locking in *built environment assessment*—as designed, as built and as operated—as a routine feature of city management and reporting. That would provide a basis for achieving sustainable urban development in twenty-first century cities.

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Part IV

Human Factors in Low Carbon Living

20

Consumer Responses to Rating Tools and Residential Energy Efficiency Disclosure

John Gardner, Stephen White, Zoe Leviston, Murni Greenhill, Henry Adams and Lygia Romanach

Introduction

A thermally efficient home maintains comfortable living conditions inside the home with minimal need for mechanical heating and cooling and its associated energy consumption. Through good design and appropriate selection of materials (including insulation, thermal mass and ventilation) a thermally efficient home stays warmer in winter and cooler in summer. This leads to lower energy bills, improved comfort

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and a reduction in the likelihood of various serious health conditions. These benefits are very good for home occupants.

In order to ensure acceptable quality housing, most jurisdictions have minimum construction standards for the thermal design of homes. However, noting the positive attributes of thermally efficient housing, one could imagine astute home buyers demanding higher performance than just the minimum construction code requirements.

Unfortunately, thermal efficiency is not obvious from casual inspection of a home or home design. As a result there is significant information deficit, amongst the public, in how to identify and value thermal efficiency as a desirable criterion when purchasing a house.

In order to overcome this information deficit, a number of rating tools have been devised to simplify the comparison of homes, on the basis of thermal efficiency. These rating tools provide consumers with a "language" for communicating with industry professionals (e.g. architects, builders, real estate agents, and valuers) and, in some cases, a basis for ascribing eligibility for government incentives. Ratings tools have been devised for application in various stages of the property life cycle, including construction, resale and renovation.

This chapter aims to better understand how consumers respond to such rating tools and systems, and how effective they are at creating market demand for high performance houses, by examining the results of surveys of consumers and industry stakeholders in Australia.

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Appetite for Energy Efficiency Information

A recent survey of 866 Australians (Romanach, Jeanneret & Hall 2015a) found that a large majority (89%) of respondents would find a home more attractive if they were told a home is "energy efficient", and more than half of the survey respondents indicated that the energy efficient home would be "a lot more attractive to them". Most respondents (57%) indicated that they would be willing to pay for energy efficiency information with 45% of respondents willing to pay up to $250, and a further 33% willing to pay up to $100. Similarly, a 2011 Auspoll survey of Australian consumers (cited in AEMC 2012) found "89 per cent said they were willing to take action to use less energy, half knew little or nothing about the key aspects of their energy use".

A survey conducted for Sustainability Victoria (Couper & Ferguson 2013) found that "sustainability" (81%) and "energy efficiency" (89%) were considered important in the planning stages of a renovation. However, the report found that, in the subsequent renovation journey, consideration of energy efficiency measures were often crowded out by other elements of the build. Competing considerations included perceived cost barriers and cost trade-offs, retaining original or period features, compromising of lifestyle, renovation fatigue/decision making fatigue, and adhering to timelines.

In contrast to these findings, Laine (2011) found that homebuyers were most concerned about location, cost and size of homes, with only 14% of buyers considering energy efficiency as important. Similarly, Instinct and Reason (2014) found that only 8% indicated that "environmental factors" were important in going ahead with [renovation] work.

This view is supported by a survey of Australian real estate agents (Romanach, Jeanneret & Hall 2015b), who indicated that potential buyers and tenants either sometimes or rarely enquire about the energy efficient features of a property. More than half of the surveyed agents claimed to never have clients that enquire about a home's energy costs at the point of sale or lease.

A survey of 3000 European households (IDEAL-EPBD 2011, p. 44) concluded that households tend to include energy efficiency as part of a broader home renovation, and that "many people do not make a strict distinction between energy efficiency and other renovations, and view all renovations as investments in making their home their own, more comfortable and more valuable".

It appears that buyers are broadly supportive of both environmental and energy efficiency goals, but these factors are second order criteria when purchasing or renovating a home.

In order to increase market demand for quality housing, and unlock the concomitant health and affordability benefits, the task is to improve public awareness and understanding of available rating systems. This requires that information be targeted toward more front-of-mind motivations.

Comfort Motivations

A survey of 954 home buyers across New South Wales, Australia (Instinct & Reason 2014) provided a list of attributes of a house (only some of which related to environmental considerations), and asked which of these attributes would be taken into account and which one would be the most important, when purchasing a home to live in.

Survey results illustrated in Fig. 20.1 show that "A comfortable home to live in" is the most frequently cited factor that is taken into account in the purchase decision, and it is the second most frequent response when respondents are asked to select their most important factor.

Additional focus group research (Hall, Jeanneret & Romanach 2014), found that the characteristics of a comfortable home to live in are well aligned with the benefits offered by a thermally efficient home. Common words used to describe a comfortable home are illustrated, in word cloud form, in Fig. 20.2.

This research highlights the potential for using concepts of a "comfortable lifestyle" as a way of raising the importance, awareness and understanding of thermally efficient housing amongst home buyers, and

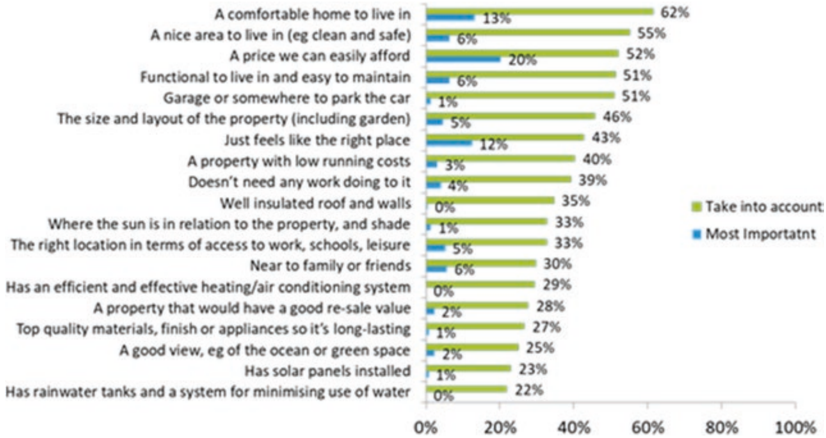

Fig. 20.1 Factors taken into account when considering potential properties to buy to live in

for framing the utilisation/role of ratings in house buying and renovating practices.

To this end, Hall, Jeanneret and Romanach (2014) suggested message frames for motivating home buyers and renovators such as "naturally cool in summer and warm in winter", "natural light" and "good airflow/ventilation".

Financial Motivations

Another important motivation for home buyers that ratings and property media should convey is financial. While there has been significant effort to identify cost-effective energy efficiency measures, and the phrase "low running costs" scores well in surveys of purchasing considerations (Amecke 2011; Instinct & Reason 2014; Laine 2011), the ubiquitous failure of home owners to implement rapid payback energy measures suggests that bill savings is an important but not primary motivator for most people.

Both Instinct and Reason (2014) and Hall, Jeanneret and Romanach (2014) found that tangible-observable energy saving features of house,

Fig. 20.2 Word cloud representation of the most frequently used words to describe a comfortable home to live in

such as solar PV and particularly insulation resonated more strongly, as desirable in a house, than the more abstract concept of "reduced running costs".

A further important, but relatively untapped, financial consideration is the uplift in property value associated with thermally efficient housing. In jurisdictions where a consistent rating approach for point of sale labelling and minimum standards is available, it is possible to correlate sales data with energy rating while controlling for other variables. A meta-review by the International Partnership for Energy Efficiency Cooperation (2014) found that virtually all such studies indicate a positive relationship between better energy performance and increased property value. In many jurisdictions, an indicative 2% uplift in the value of a property (on the low end of typical findings) would offset the cost of upgrades to the property owner. This is a significant finding, as "split incentives" is a commonly cited barrier to the adoption of energy efficiency upgrades in rental properties; landlords can't directly capture the benefits of tenants' energy bill savings that result from energy upgrades (Beillan et al. 2011; Gillingham, Harding & Rapson 2012; Hernández & Bird 2010; Pelenur & Cruickshank 2012).

An online survey (Greenhill et al. 2017) of 1532 home buyers was used to further explore Willingness To Pay (WTP) for a higher star rating, and the meanings behind declared preferences. To ensure homogeneity of variances, the WTP amount for each participant was normalised as a proportion of their maximum budget (i.e. WTP Proportion = 0 to 100% of budget). The results of this study are illustrated in Fig. 20.3.

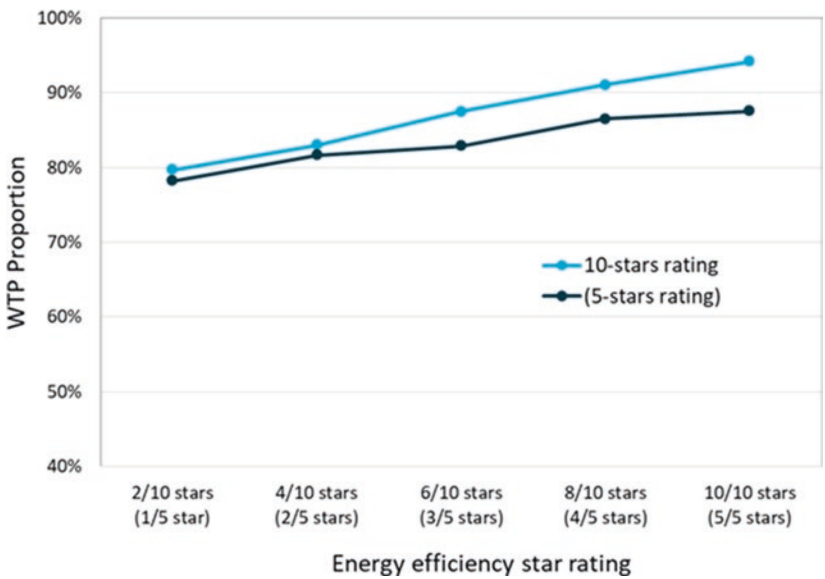

Fig. 20.3 Influence of star rating on the willingness to pay proportion

WTP proportion increased by around 1.8% per star for those respondents exposed to the more granular 10 point rating scale. The influence of star rating was slightly lower when ratings were shown on a 5 point rating scale, with some sign of a plateauing of impact at higher star rating levels. It appears that people respond more strongly to higher ratings on a rating scale with more points on it; although a 4/5 and an 8/10 score are mathematically equivalent, the latter appears to convey more perceived value to consumers.

Older respondents, and those with a higher budget, were found to be more willing to pay for energy efficient homes. Social norm was also found to be an important psychological variable for predicting WTP proportion. If people believed others were willing to pay more for energy efficient homes, then they would increase their WTP proportion for a higher star rated home. This is consistent with studies such as Shewmake and Viscusi (2014), who note that value uplift is not uniform, and that value premiums are more prevalent at the upper end of the market.

Communicating Rating Information to Buyers in the Real Estate Moment

Real estate agents are well placed to utilise these motivations and information, in property negotiations. A survey of real estate agents and solicitors in France (European Commission DG Energy 2013) found that 66% of agents and 84% of solicitors would "often" or "always" include a good Energy Performance Certificate when selling a property.

Leviston et al. (2015) explored the role of ratings and associated message frames in informing and influencing home buyers, with particular focus on WTP and related real estate performance indicators. This was achieved through an online survey, administered to 2008 representative home buyers across Australia. Respondents were randomly assigned to one of nine "EnergyFit" message frames with and without rating icons. The message frames were taken from the Liveability Real Estate Marketing Framework. Respondents were asked to evaluate these EnergyFit home messages against both (i) a "Control" home message (an analogous home containing no energy information) and (ii) a "Features" home message (an analogous home containing no energy information but containing non-energy related features that had previously been ascertained as desirable to the respondent) (Fig. 20.4).

The study found that:

- People found EnergyFit homes more preferable than a Control home on a range of financial and non-financial criteria.
- The asking price of both the EnergyFit home and the Features home were perceived to be significantly greater than that of the Control home, and people were quite willing to pay their estimated additional asking price for an EnergyFit home.
- People estimated that the Features home (with several additional non-energy related features) would be about the same price as the EnergyFit home (with no additional features).
- When comparing a Features home with an EnergyFit home, message frames become an important determinant of a range of perceived benefits. Adding non-energy related features to an EnergyFit message frame condition did not make an appreciable difference in the perceived value of the home.

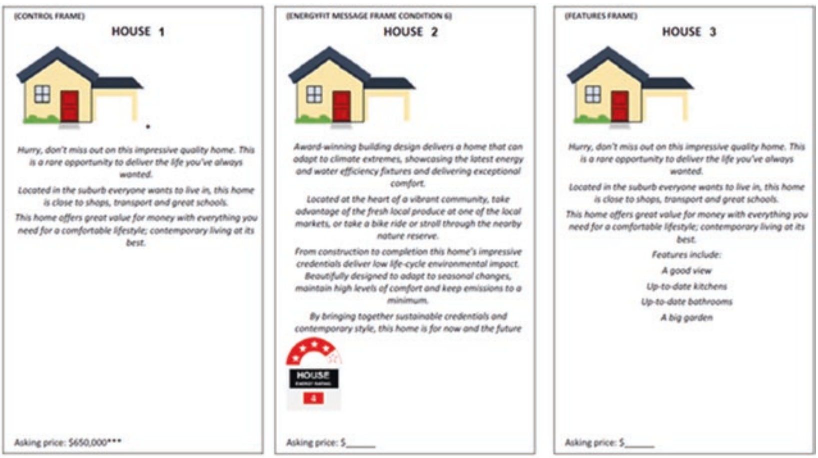

Fig. 20.4 Examples of alternative real estate message presentations to survey respondents

Overall, the combination of both the Liveability Real Estate Marketing Framework messages and a star rating icon (visual endorsement) gave the most favourable response from consumers, with associated WTP. It appears that both message framing and star rating information can influence consumer's perceptions of house values. Similar to the finding that buyers resonate more favourably with "insulation" over "low running cost", it appears that a simple claim or stamp needs some further level of justification of how the additional benefit is achieved, in order to deliver maximum impact.

This research highlights the latent potential of *a well-designed rating scheme, with consumer-facing messaging*, to drive a voluntary market for thermally efficient homes.

While this latent potential may exist, an online survey (Romanach, Jeanneret & Hall 2015b) of 140 Australian real estate agents and property managers highlighted the ongoing need for significant transformation in the real estate industry. Typical barriers, expressed by real estate agents, toward communicating energy efficiency information are illustrated in Fig. 20.5.

Comparison of trained "Liveability Real Estate' agents with untrained agents found that training significantly improved the confidence of real estate agents to discuss energy efficiency at the point of sale and lease.

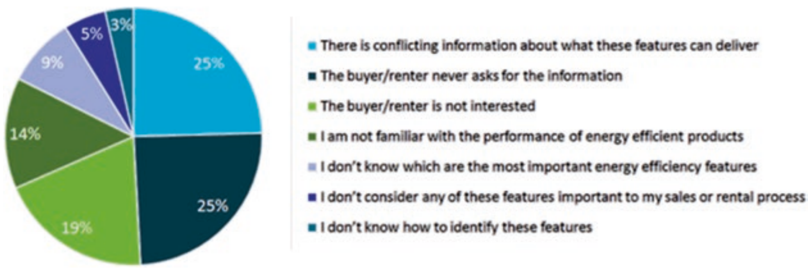

Fig. 20.5 Concerns expressed by real estate professionals toward discussing energy efficiency

Delivering a Rating Scheme to Home Buyers

Adams, Clark and Potts (2016) reviewed various national and international rating schemes and conducted a consultation process with key Australian industry stakeholders to better understand how best to implement a consumer-facing rating scheme for existing homes.

This review distinguished between ratings, rating tools and rating systems. A rating is method to measure, benchmark and communicate information (in this case on the energy efficiency performance of existing homes). A rating tool is a web, paper or device-based application for performing these three functions. Most importantly, a system is the organising framework of rules, processes, resources, and relationships required to consistently manage the governance, administration and delivery of ratings.

A key finding of the Adams et al. review was that for a rating to become recognised as a national standard it requires awareness and adoption amongst a critical mass of consumers and building trades people and professionals. They identified and benchmarked 22 existing Australian ratings tools, none of which they considered held a critical mass of understanding and use. In order achieve such a critical mass of adoption, they concluded that a rating needs to be supported by an overarching governance system to ensure the relevance, accessibility, integrity and reproducibility of the information generated by ratings tools.

The review also provided detailed findings on different design considerations of a system and the attributes of the ratings a system would deliver. Some of these key attributes for a rating are shown in Fig. 20.6.

Two of the key trade-off dilemmas faced in devising an effective consumer-facing rating scheme are described in more detail below.

Simplicity Versus Rigour in the Assessment Approach

As described above, while broadly supportive, consumer interest in stand-alone energy efficiency measures is relatively low. Consequently, Crawley et al. (2010, p. 5) promote an energy efficiency engagement

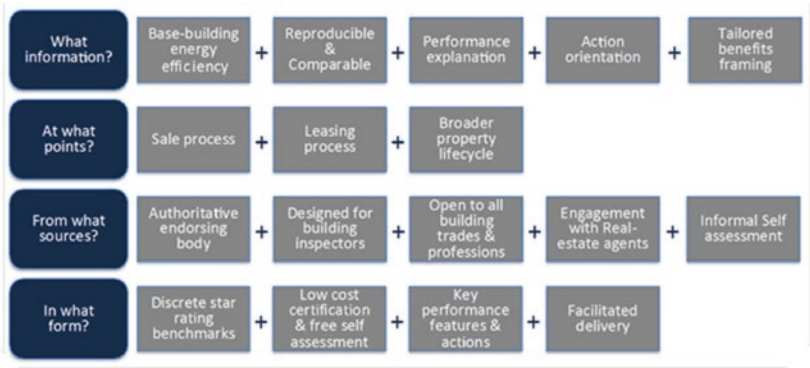

Fig. 20.6 Key considerations for an effective rating scheme

strategy that aims (amongst other things) to "make it easy via demonstration, and chunking the desired behaviours down". This aims to avoid cognitive overload and to simplify by making desired actions easier, quicker and more convenient, minimising the physical and psychological demands needed to perform the action and reducing perceived uncertainty. Hulse et al. (2015) found that visual media is vital, with renovators wanting to see design layouts, features, appliances, colours etcetera, rather than read text. They also found that online platforms and apps for sharing visual content are increasingly important in the early stages of design. Similarly, the IDEAL-EPBD (2011) study suggests that energy efficiency information could be made more relevant and easy to action by linking ratings (as a one-stop-shop) with relevant decision-influencing factors, such as the condition of the dwelling, the cost of renovations to improve efficiency, and where to find expert advice.

More qualitative easy to use tools exist, many of which can be operated by the home owner at no cost. Anecdotal experience suggests that, in a voluntary market setting, low (or no) cost assessment is vital for uptake.

However, these simplified assessment tools typically have only a limited number of generic options available for achieving improved thermal efficiency, with a focus on energy savings rather than broader amenity and design suitability. And where a rating is intended for use in policy settings (e.g. to satisfy regulation, or to attract incentives) the selected tool must be robust against the potential for gaming by assessors.

In order to manage the conflicting constraints of consumer psychology and rating usefulness, it may be necessary to have a two-tiered approach with rule of thumb qualitative entry points, leading to more rigorous assessment for formal rating recognition.

Authoritative Versus Influential Endorsement

Many studies suggest that trust in the rating/certificate is important for scheme effectiveness (European Commission DG Energy 2013). As a result, most energy efficiency rating systems are established by government and delivered by certified assessors. This approach is considered particularly important where the information may have direct financial value. Consumer surveys, in a number of jurisdictions, also confirm the value of an on-site energy efficiency expert in influencing household decisions (Amecke 2011; Wilson, Crane & Chryssochoidis 2014).

However, the value of a thermal efficiency assessment, and/or on-site expert advice comes at a cost. A Parliamentary Committee investigating the early implementation of the Green Deal scheme blamed the high cost of the assessment on low take-up for the scheme (House of Commons 2014).

Trust is not restricted to experts and government authorities. Romanach, Jeanneret and Hall (2015a) reported that the survey respondents' preferred channels of information were via friends and family, product brochures, and browsing at hardware stores.

When survey respondents were asked "who would you go to for information or advice when considering potential properties to view?" Instinct and Reason (2014) found that real estate agents were the most frequently cited source, even if their advice was not relied upon (Fig. 20.7).

Judging from these results, real estate agents may be the most effective channel for communicating energy rating information in the short-duration, high-pressure real estate moment even if their information is not fully trusted.

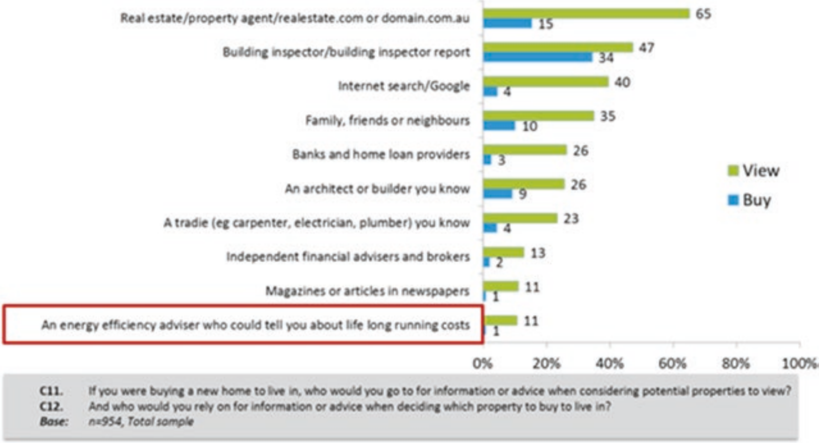

Fig. 20.7 Key sources of information for home buyers

Whether it's family and friends, or real estate agents, it is quite possible that these influential actors may be more important in the decision making process than other more authoritative (and presumably more trustworthy) expert actors such as government and accredited assessors.

Complementary Policy

Some successful voluntary rating schemes include (i) the Minergie label, which was used to rate 15% of new homes constructed in Switzerland in 2008, and (ii) the KfW-Effizienzhaus system which was used to rate more than 1 million German houses between 2006 and 2009. Utilisation of the Energy Star Homes certification has also been successful in various States in the USA. In 2013, more than 20% of buildings were certified as Energy Star Homes in five southwestern and north-eastern states, and more than 60% of new buildings were certified in Arizona.

A key ingredient of their success is the established links to government policy. This is particularly evident by looking at the positive correlation between the US States that exhibit high adoption of voluntary ratings, with the American Council for an Energy Efficient Economy's (ACEEE) State by State ranking of energy efficiency policy and programmes. The States with the best policy environment are typically the ones with the highest adoption rate.

An example of high uptake is the KfW-Effizienzhaus system, which offers loans to certified homes at very competitive rates using government funds to support private investment in energy efficiency measures. Between 2006 and 2009, the German government contributed 2 billion Euro in subsidies that generated a total of 17 billion Euro in private investment.

While this is a very positive outcome, such examples of a simple "financial subsidies" successes suggests that (in the absence of consumer understanding, through compelling new information) consumers are generally resorting to cognitive short cuts. As a result, they are responding to a typical first cost approach, with a tendency to heavily discount future savings, and to not account for other benefits (e.g. health, comfort).

Conclusion

Rating systems have the potential to uncover and highlight the ability of high performance homes to satisfy the comfort and financial motivations of home buyers and renovators. However, the complexity of thermal efficiency is such that ratings are only one component of a successful scheme. As described above, one of the possible additional components is to use ratings as an eligibility bar for attracting subsidies. Alternatively (or in combination), our research suggests that a truly transformational rating scheme should be accompanied by consumer marketing to the buyers of broader psychological benefits (beyond running costs) and aligned with more informed industry intermediaries, who mediate the real estate buying moment.

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The Low Carbon Readiness Index

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Introduction

An effective response to climate change requires private citizens to adopt a range of low carbon practices in their home and personal travel (DEFRA 2008; Gardner & Stern 2008; Pears 2011). The required changes amount to a cultural transformation whereby low carbon living becomes the norm. However, simple belief in human-caused climate change is not sufficient to create a shift to low carbon living

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(Hall, Lewis & Ellsworth 2018). As Blake (1999) identified, several factors will create a gap between an environmental concern like belief in climate change and corresponding action to address this concern. These include factors that affect (a) motivation (e.g. placing a low personal priority on environmental matters, feeling like the responsibility for change lies with institutions) and (b) capability (e.g. not having money for infrastructure changes, not having time for lifestyle changes). We designed the Low Carbon Readiness Index (LCRI) to identify the level of personal motivation to reduce household emissions (O'Brien et al. 2018). As we describe below, the LCRI consistently predicts people's general level of engagement in low carbon behaviours and it can be used in several different ways by both practitioners and policymakers.

While it is not the only tool of its kind, the LCRI is distinguished by its sharp focus on household greenhouse gas emissions reduction, its validation across a wide range of low carbon behaviours and its extreme brevity (Hall, Lewis & Ellsworth 2018; Hawcroft & Milfont 2010). This chapter provides an overview of results from: (i) three cross-sectional waves of a nationally representative population survey conducted in Australia, (ii) a longitudinal subsample of this study and (iii) two waves of a longitudinal survey of participants in Australian homes where energy consumption is tracked.

Design and Rationale

The motivation to live a low carbon lifestyle can be understood as a personal goal or 'personal striving' to conduct oneself in a certain manner (Emmons 1986). Kashima, Paladino and Margetts (2014) showed that strivings to improve the natural environment predicted pro-environmental behaviour. Building on this work, the LCRI was conceived and measured as a personal striving to reduce carbon emissions (see O'Brien et al. 2018). Scored on a 5-point scale (Strongly disagree; Disagree; Neutral; Agree; Strongly agree), the LCRI measure is the average of three items:

- I work hard to reduce my greenhouse gas emissions whenever possible
- I feel very good when I am successful in reducing my greenhouse gas emissions
- I would feel very bad if I failed to reduce my greenhouse gas emissions.

Note that the items are phrased in terms of 'greenhouse gases' to cover all types of GHGs (e.g. methane), making the LCRI relevant for a wider set of behaviours (e.g. waste reduction).

Low carbon household behaviours are diverse and manifold, including but not limited to reducing consumption of energy (e.g. using alternative heating and cooling methods and investing in energy saving household infrastructure and appliances), using sustainably sourced electricity, and reducing transport related emissions (e.g. carbon offsetting flights, using public transport, or driving a green car). For a range of reasons—including geographical, relational, lifestyle and economic—different people find it easier to adopt different low carbon behaviours, and consequently a general measure like the LCRI will not be very good at predicting the performance of a specific behaviour (Ajzen & Fishbein 1977). However, it can predict overall level of low carbon behaviours across multiple different behavioural options. As described here, we have so far validated the LCRI as a predictor of low carbon behaviours in terms of (i) summary measures of self-reported low carbon behaviours and (ii) actual household level of energy consumption.

To create measures of self-reported low carbon behaviours that could be used to validate a general measure like the LCRI, we referred to past research showing that multiple behaviours tend to group or 'cluster' together. Gilg, Barr and Ford (2005) found that, in the UK, pro-environmental behaviours grouped into three clusters: shopping, composting, and reuse; domestic water and energy conservation; and recycling. Once a person has performed one behaviour within a certain type or 'cluster', they are more likely to perform another behaviour within that cluster. For example, people who have an efficient fridge are more likely to acquire efficient washing machines compared to those who do not (Mills & Schleich 2010). We therefore concluded that summary measures of how much activity people have within behavioural clusters will provide measures of low carbon behaviour that reflect actual levels of behaviour without being specific about the nature of the behaviour. Consequently, activity within behavioural clusters is an ideal way to validate the low carbon strivings captured by the LCRI. Similarly, actual energy consumption can be seen as an aggregate of carbon-consuming behaviours and it can thereby act as a general measure of behaviour that should be negatively correlated with the LCRI.

Descriptive Statistics and Covariates

Before we discuss validation of the LCRI, this section sets out the level of low carbon striving in the Australian population and its association with several relevant covariates. Across three cross-sectional waves of a nationally representative population survey ($n_{2015} = 716$; $n_{2016} = 1006$; $n_{2017} = 1355$) the LCRI items had good reliability as a scale (Cronbach's α range: .83–.87) and a stable mean between 3.7 and 3.8 within the possible range of 1–5, which placed low carbon readiness significantly above the midpoint (=3; $p < .001$).

Participants in the national survey reported several demographic characteristics. Correlations and regression tests showed that a higher LCRI was consistently associated with being older, female and multilingual, and with having a gross annual household income of less than $130,000 (median Australian income is $84,032: ABS 2017). In contrast, household size, being born in Australia, residing in a house and owning one's own home were not consistently associated with the LCRI. We also measured an alternative quality of life goal: "living in a comfortable and attractive home". Across the three cross-sectional samples it was not significantly correlated with the LCRI, but had a stable mean significantly above the midpoint ($M = 3.9 - 4.1$; $p < .001$).

Across each wave of the national survey, around 70% of people surveyed agreed or strongly agreed with the LCRI items and the same percentage of people believed in human-caused climate change (measured as per Leviston, Greenhill & Walker 2015). These measures were significantly correlated. However, in each of the three survey waves, nearly

20% of people who believed in human-caused climate change were neutral or below the LCRI midpoint, suggesting that not everyone who believes in human-caused climate change takes the goal of carbon emissions reduction upon themselves as a personal striving.

Validation

Reported Low Carbon Behaviour

To examine how the LCRI predicts low carbon behaviours, participants in the national survey were asked to report their possession of low carbon infrastructure and performance of low carbon routines (for more detail see O'Brien et al. 2018; O'Brien, McNeill & Kashima 2018). A data analytic technique (hierarchical clustering using Ward's method and Squared Euclidian Distances) was applied first on infrastructure and then on routines. Based on these analyses, six different types of low carbon behavioural clusters were identified: solar (e.g. panels), efficient appliances (e.g. washing machine with 5–6 star energy rating), efficient temperature system (e.g. reverse-cycle heater/cooler), efficient car (e.g. small and fuel efficient), temperature curtailment (e.g. control home temperature with curtains) and green travel and payments (e.g. avoid driving).

We then examined whether the LCRI could predict people's activity within the low carbon clusters while statistically adjusting for the variables discussed in section 'Design and Rationale' (see summary in Table 21.1, and O'Brien, McNeill and Kashima (2018) for more detail). Across each wave of the survey, the LCRI significantly predicted all but one of the low carbon behavioural clusters measured. That is, people who were higher in LCRI were more likely to have greater activity in each of the low carbon behaviours. The exception was efficient temperature system, which was not predicted by the LCRI, but was associated with wanting to live in a comfortable and attractive home. Demographic characteristics rarely had a consistent influence on activity in the low carbon clusters, however, owning a house consistently

Table 21.1 LCRI prediction of routine low carbon behavioural clusters

Low carbon behavioural cluster		Survey wave	Regression co-efficient	Analysis method
Infrastructure	Solar	2015	0.21*	Ordinal regression
		2016	0.31*	
		2017	0.21**	
	Appliances	2015	0.34***	
		2016	0.29**	
		2017	0.41***	
	Temperature system	2015	−0.20	Binomial regression
		2016	−0.21	
		2017	−0.08	
	Car	2015	0.35***	
		2016	0.29***	
		2017	0.31***	
Routine	Green travel and payments	2015	0.33**	Linear regression
		2016	0.21***	
		2017	0.29***	
	Temperature curtailment	2015	0.34***	
		2016	0.22***	
		2017	0.30***	

*$p<.05$, **$p<.01$, ***$p<.001$
Note This table summarises results presented in Tables 8 & 9 in O'Brien, McNeill and Kashima (2018), with permission from the Low Carbon Living CRC

predicted investment in solar technology, while older age predicted owning an efficient car and efficient appliances. Finally, while the 2015 data did indicate that people who believed in human-caused climate change were more likely to invest in a piece of solar infrastructure (rather than having none; see O'Brien et al. 2018), this finding was not replicated in later waves of data. Belief in human-caused climate change did not predict any other measure of low carbon behaviour (O'Brien, McNeill & Kashima 2018).

Actual Energy Consumption

To examine the LCRI's capacity to predict actual energy consumption we surveyed 96 adults already participating in a study called the 'Residential Buildings Study' conducted by the Commonwealth Scientific and Industrial Research Organisation (CSIRO: Ambrose et al. 2013).

Participants in this study had tracking devices installed in their homes to record actual energy consumption. Newton and Meyer (2012) showed that contextual and structural factors (e.g. income, number of residents, type of housing) have a large effect on the total amount of consumption, but that individual factors can still make a small difference. Therefore, when using the LCRI to predict average weekly power consumption, we also adjusted for number of residents, size of occupied floor space, income, gender and the previous year's average weekly power consumption. Consistent with Newton and Meyer (2012), our regression analysis showed a small but significant effect: those higher in LCRI tended to have lower average weekly power consumption. The time points we examined were only one year apart so, given that changes to low carbon infrastructure tend to happen episodically over long time periods, it is likely that the identified influence of LCRI on energy consumption was due to routine behaviour. However, our other research suggests that the LCRI will show a greater influence on energy consumption when considered over longer time spans, as the self-reported data show it motivates both low carbon routines and low carbon infrastructure acquisition.

The Low Carbon Goal, Household Regulation and Social Norms

The successful execution of a goal is greatly influenced by the social environment in which the behaviour must be performed. To examine some key aspects of this dynamic, our national survey included three measures of low carbon social support: (i) a *low carbon descriptive norm* measuring perceptions of whether people in general think and act in terms of a low carbon goal; (ii) *community informational support* for low carbon behaviour in the form of advice and support from friends and family; and (iii) *household regulatory support*, which concerns household members' active regulation of each other's low carbon behaviour via keeping track of what is happening and reminding each other to behave in a low carbon manner (see O'Brien et al. 2018).

When examining the national survey, statistical analyses with each of the cross-sectional samples found that people who scored higher on the LCRI also consistently scored higher on the low carbon descriptive norm, community informational support, and household regulatory support. These effects remained significant even when adjusting for all covariates used in the national sample. The only other variable that predicted the LCRI so consistently was belief in human-caused climate change. In addition, a small group of participants in the national surveys completed all three of the surveys conducted ($n = 206$). The mean level of LCRI did not change in this longitudinal subpopulation, but some people showed an increase or decrease over time. A further analysis showed that this increase or decrease in low carbon readiness was associated with a parallel change in level of household regulatory support and community informational support.

Using the national survey cross-sectional samples, we also found interactions between LCRI and two of the social factors (household regulatory support and low carbon descriptive norm) when they were used to predict a higher-order summary measure of all routine measures averaged together (significant in 2017, trending in the same direction in 2016). Underscoring the importance of household regulatory support, this factor was positively related to the engagement in low carbon routines, and this relationship was particularly strong for those who scored higher on the LCRI. In contrast, when people had higher LCRI then (i) a higher perceived norm for low carbon living was associated with less participation in low carbon routines and (ii) a lower perceived norm was associated with greater participation in low carbon routines. The perceived norm interaction with the LCRI suggests that seeing low carbon behaviour as rare and novel (i.e. not normative) can sometimes amplify low carbon strivings, perhaps by highlighting the need for cultural change. Further analyses indicated that this sort of thinking tends to be associated with people who engage in low carbon routines and have begun to invest in low carbon infrastructure despite not necessarily having demographic drivers of investment, such as being older and owning one's home (effects significant in both 2016 and 2017).

The Utility of the LCRI

The LCRI is a very short tool and can be used as a low-cost way of gauging public engagement in low carbon behaviour and planning next steps in all phases of the policy cycle. First, it can be used to identify whether a target population is motivated to transform to low carbon living. Where LCRI is high, indicating that motivation is present, policy and interventions can be directly targeted at (i) informing the public about specific behaviours that can reduce carbon emissions in their household and (ii) removing barriers to their ability to perform them. In contrast, when a population scores low on the LCRI, motivation-based interventions are better framed in other ways, such as energy saving initiatives, and then longer-term policy and projects will need to focus on fostering low carbon strivings as a desirable and rewarding personal goal. Second, the LCRI can be used across time to monitor, evaluate and adjust the impact that policies and interventions are having on people's motivation to engage in low carbon behaviours. Thus, the LCRI can be used both to measure a population's willingness to transition to low carbon living and to gauge the impact of policies and programmes designed to promote that transition.

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A Social Psychological Guide for Transformation into Low Carbon Living

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Introduction

To promote transformation to low carbon living we need to start with an appreciation of the complexity of human behaviour. Our daily lives are filled with a plethora of different actions, each of which are intertwined with many others. The complexity of this web of actions quickly becomes apparent once we start thinking about a common activity,

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such as getting ready for work. What seems to be a simple action is, in fact, a web of many intertwined actions. For example, getting ready may entail a combination of exercising, having breakfast, showering, getting dressed, packing lunch, and grabbing one's car keys or public transport card. All these actions will compete for the limited amount of time available between waking up and starting one's journey to the workplace. Further, many of these actions will depend on other actions. For example, the successful completion of 'preparing and eating breakfast' will depend on whether the necessary ingredients made it onto the shopping list the day before, and the completion of 'getting dressed' will be influenced by staying on top of laundry and ironing. The complexity increases even further when we consider that our actions do not occur in a social vacuum, but instead, form a part of a large web that includes the actions of others as well. For example, the timing of showering will not only be tied to whether your hair needs washing, but also to showering by other household members.

Taken together, it quickly becomes clear that it would be impossible to start every day by sitting down with other household members to figure out a way to reach an equilibrium between all of these 'getting

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ready' actions. This is why the successful execution of our daily actions largely relies on our use of behavioural habits and routines. Behavioural habits and routines tend to form over time based on functioning equilibria of actions and, once established, entail the repetition of these actions without much conscious deliberation about how each action fits into the surrounding web of actions. The fact that we strongly rely on habits and routines is also why behaviour change is so difficult: asking someone to change a behaviour in their morning routine, whether this is shortening their showering time, or taking public transport instead of a car, means asking them to upset their state of equilibrium and to stop relying on the habits and routines that maintain this equilibrium. They then need to think about how the changed behaviour fits into their existing web of actions until they've been able to integrate the changed behaviour into a new equilibrium, which can then form the basis for new habits and routines over time. So, given this complexity, how can we help people transform into low carbon living?

In this chapter, we guide the reader through a series of theoretical ideas stemming from Behavioural Practices Theory (BPT; see also O'Brien, McNeill & Kashima 2018), with the purpose of helping the reader make sense of the complexity of human behaviour and the difficulties involved in changing it. BPT integrates elements from the Theory of Planned Behaviour (Ajzen 1991), Action Identification Theory (Vallacher & Wegner 2012), and Social Practice Theory (Shove, Pantzar & Watson 2012). At the core of BPT lies the idea that in order to effectively change behaviour, the behaviour needs to be analysed in terms of two key dimensions. First, the 'Why–How' dimension spans thinking from 'why do I do it?' to 'how do I do it?'. Second, the 'Intrapersonal–Interpersonal' dimension spans thinking in purely individual terms of Whys and Hows to behaviours that are shaped by different kinds of social interaction with others (i.e. *who* is involved).

Throughout the chapter, we provide notes to practitioners about how to use these dimensions when designing and deploying policies and interventions to promote low carbon living. We also provide snapshots of results from survey research conducted with representative samples of Australians between 2015–2017 and snapshots of illustrative quotes taken from interviews conducted with a sample of Australians in 2017 (this research is described in detail in O'Brien, McNeill & Kashima 2018).

⇒ *Practitioner's note 1*

Our recommendation to practitioners is that they use this chapter's notes to conduct a BPT-based assessment of where the desired behaviour sits in people's web of actions before and during any attempt to change existing behaviour. However, before doing so, a first question that needs be answered is 'Who are you targeting?' Do they all have similar webs of action or do you have several different target groups? If the answer is the latter, you will need to consider this chapter's notes separately for each group.

The Why–How Dimension

For every behaviour that exists, it is possible to ask *Why* a person is motivated to perform the behaviour and *How* the behaviour is performed, and the answer to each of these questions can often be stated in terms of another behaviour, with its own set of Why and Hows attached to it. In fact, if behaviour 1 (e.g. reduce climate change) is a Why for behaviour 2 (e.g. reduce carbon footprint), then behaviour 2 automatically becomes a How for achieving behaviour 1. These Why–How connections between behaviours form an important binding mechanism in people's web of actions (see Fig. 22.1 for an example snapshot of Why–How connections). As can be seen in Fig. 22.1, many behaviours take the role of being a Why to one behaviour, whilst being a How to another. For example, people may want to reduce their carbon emissions to reduce climate change (Why), and they may do so by cycling instead of driving (How 1), and by using solar panels (How 2). In addition, they may cycle not only to reduce their carbon emissions (Why 1), but also to maintain their good health (Why 2). As we scan upwards in the figure, the behaviours become more abstract and are more closely linked to people's values, identities and aspirations. Scanning downwards, on the other hand, the behaviours become increasingly concrete, and more closely linked to people's skills, practical knowledge and resources.

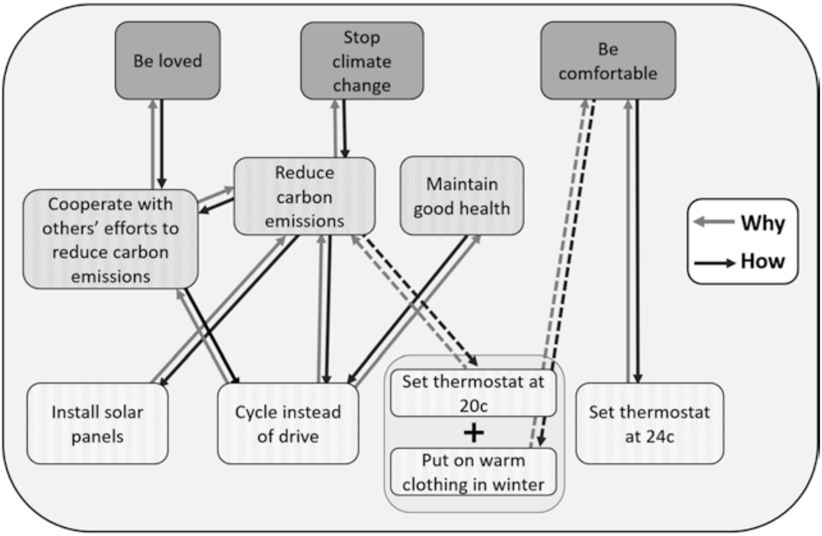

Fig. 22.1 A simplified example of behaviours connected along the Why–How dimension

People interested in behaviour change should keep in mind that the Why and How connections in a person's pre-existing web of actions will influence the likelihood of successful behaviour change. This has several implications for behaviour change strategies. Firstly, the new behaviour needs to be linked to existing Whys that are strong enough to motivate its performance, and to Hows that contain the knowledge, skills, and resources that people need to carry out the new behaviour.

⇒ *Practitioner's note 2*

Consider the Whys and Hows people already possess, and how these may be linked to the behaviour you are trying to change. Are the Whys strong enough to motivate the desired behaviour? And do the Hows cover all that is needed to perform the behaviour? If not, additional work is needed to develop a sufficient Why–How base for action.

⇒ *Research snapshot*

The Low Carbon Readiness Index (LCRI) is a validated measure of a Why that is attached to a wide range of low carbon behaviours. It contains 3 items, rated on a 5-point scale (1 = strongly disagree, 5 = strongly agree): *I work hard to reduce my greenhouse gas emissions whenever possible; I feel very good when I am successful in reducing my greenhouse gas emissions; I would feel very bad if I failed to reduce my greenhouse gas emissions*. In our survey research we captured both the LCRI and a comfort goal (*Living in a comfortable and attractive home is an important goal for me*). Whereas the LCRI was found to be a positive Why connected to a wide range of low carbon behaviours, the comfort goal was found to be a positive predictor for purchasing energy efficient temperature systems, but it also predicted *lower* engagement in temperature curtailment in two out of three waves of data collection (negative predictor; O'Brien, McNeill & Kashima 2018). Thus, the comfort goal appeared to form a Why for purchasing efficient temperature systems, but also for generous habitual use for those systems, rather than temperature curtailment behaviour.

Secondly, any existing behaviour will likely serve multiple Whys, and do so in a way that is satisfying for the actor. Introducing change in a way that reduces satisfaction of a Why by removing a connected How behaviour will likely reduce willingness to follow through with the changed behaviour. For example, convincing someone to turn their thermostat to a lower setting in winter (i.e. replacing their old How-action of setting their thermostat to 24 °C by a new action of setting it to 20 °C) will likely not be effective if the connected Why of creating a comfortable home is left unsatisfied. One solution is to sustain satisfaction by connecting another How to the pre-existing Why; in the thermostat example, people could be encouraged to preserve their comfort (old Why) by wearing warmer clothing during colder months (new How; see broken lines in Fig. 22.1). Offering new connections will be particularly effective if it helps people discover that new Hows might in fact serve their Whys better than the old How did. For example, once people start putting on more season-appropriate clothing they may be delighted by the added ease created by no longer having to layer up as much when leaving the house. Still, in determining which Whys might be left unsatisfied by a change in behaviour, it is important to consider the presence of less obvious Whys that need to be dealt with to achieve lasting behaviour change. For example, when you ask people to change their thermostat setting, offering an alternative solution to remain comfortable may not be enough. The old thermostat setting may also serve less obvious Whys such as having a hospitable home or avoiding conflict with other household members.

> ⇒ *Practitioner's note 3*
>
> Consider how any desired change in behaviour might:
> (i) reduce satisfaction of an existing Why, or
> (ii) improve satisfaction for an existing Why.

The analysis above will set the basis for mapping out which Why–How connections need to be removed (e.g. 'use heater' connecting to 'be warm') and which connections need to be built (e.g. linking 'put on a sweater' with 'be warm' but also 'feel more freedom as you can now leave the house without having to put extra clothes on') to achieve successful behaviour change.

Third, even with everyone putting in their best effort, mapping all the existing Why–How relationships for every person targeted by a behaviour intervention is often impossible for two key reasons. First, people will not necessarily have conscious insight into all the Why–How connections that underpin their behavioural choices (Nisbett & Wilson 1977). Secondly, the Whys attached to certain behaviours will often vary across different people, and not all interventions will be designed in a way that allow them to be tailored to each individual's map of Why–How connections.

> ⇒ *Practitioner's note 4*
>
> Be ready for people to do things that are not necessarily in line with their overtly stated priorities. In addition, accept that Why–How-based interventions will only be effective for a certain proportion of people.

Even where people's Why–How connections are truly transparent, it is worth emphasising that substituting existing patterns with a more desirable alternative is difficult and time-consuming. A person's existing Why–How connections are not just adaptive, they are strongly habituated, and they automatically prompt the undesired behaviours in response to situational cues. In addition, because daily life also involves careful sequencing of seemingly unrelated behaviours (e.g. going to work and doing the shopping) this means that changes to apparently discrete behaviours can have unanticipated flow on effects (e.g. cycling to work may stop you from doing the grocery shopping on the way home). Hence, our fourth point; effective change is often iterative. Establishing a new behaviour is difficult and not sustainable unless the necessary planning and work is done to establish new routines.

⇒ *Practitioner's note 5*

Don't expect initial ways of accommodating a new behaviour to last. To truly incorporate a new way of thinking and acting, a person will often have to adjust many aspects of their life and worldview.

The Intrapersonal–Interpersonal or 'Who' Dimension

People do not enact their behaviours in an individualistic, autonomously empowered vacuum. Instead, interpersonal factors pervasively shape people's thoughts, feelings and behaviours through social influence (Forgas & Williams 2001) and changing old behaviours, or simply introducing new ones, will often disrupt established habits of interaction with others. So, in designing an intervention, technology or policy, it is important to consider the social environment of the target audience. Below we discuss several key social influence mechanisms.

⇒ *Practitioner's note 6*

Consider the sorts of people with whom your target audience associates. Would these other people help or hinder the uptake and maintenance of the new behaviour?

Firstly, a **descriptive social norm** entails our perception of whether a behaviour is commonly enacted by others or not (Cialdini, Reno & Kallgren 1990). Descriptive norms predominantly provide us with information on *how* people behave in certain situations, and not so much on *why* they do so. Often, we do not have a strong sense of where a norm has originated from; we are simply aware that it exists. However, even though descriptive norms do not include information on why *others* perform a behaviour, they do influence behaviour by creating a Why for the perceivers of the norm. More specifically, people have a strong inclination to take their cues about how to behave from others, especially people with whom they feel connected (e.g. Masson & Fritsche 2014). So, seeing other people behave in a particular way can create a Why of 'fitting in with other people by doing what they are doing'. This Why is most likely to occur in ambiguous situations where more straightforward Why's are lacking (Kim, Kim & Niederdeppe 2015). However, sometimes people respond to descriptive norms by forming an alternative, counter-normative Why, namely 'doing something because others are failing to do it'. This has been referred to as reluctant altruism (Ferguson et al. 2012). Research has shown that this counter-normative Why tends to play a role in motivating behaviour when a person cares about a goal that can only be achieved through the actions of multiple people (i.e. a collective goal) *and* this person has the impression that others are not contributing enough to achieve the goal (e.g. Koo & Fishbach 2008; Mutz 1995).

⇒ *Practitioner's note 7*

Ascertain what people think the existing descriptive norms are, and whether they are motivated to act in line with these norms or to act in opposition to them.

⇒ *Research snapshot*

Our 2017 survey of the Australian population found that if people had higher LCRI (i.e. a stronger low carbon Why) *and* a perceived lower descriptive norm for low carbon living then they tended to have greater participation in low carbon routines (e.g. temperature conservation, avoiding car use). This suggests that, for some, the motivation to act on a low carbon goal comes from the belief that other people are not doing enough.

People are not only influenced by what others do. They are also influenced by the approval and disapproval others have of different behaviours. This type of social norm is called the **injunctive social norm** (Cialdini, Reno & Kallgren 1990). For example, Cialdini (2003) found that the extent to which ads conveyed an approval of recycling was positively related to the persuasive capacity of the ad, which in turn was related to a greater intention to recycle. Like a descriptive norm, an injunctive norm influences behaviour by creating a Why attached to the behaviour, in this case taking the form of 'doing something because other people approve of me/do not disapprove of me doing so'. Research has shown that injunctive norms may be particularly helpful in cases where the descriptive norm is setting a bad example (i.e. many people performing an undesired behaviour or very few people performing a desired behaviour; Cialdini et al. 2006). However, they have also been shown to strengthen the effect of a positive descriptive norm on behaviour when the two types of norms align (e.g. the behaviour is both performed *and* approved by others; Göckeritz et al. 2010).

⇒ *Practitioner's note 8*

Ascertain what people think the existing injunctive norms are amongst others that are most likely to influence them.

Interpersonal **negotiation** occurs when behaviour in one person's web of actions is misaligned with behaviour in another person's web of actions. For example, when a person decides to change the thermostat setting, they are changing a behaviour that is closely linked to the actions of other members of the household. To avoid a situation in which different members endlessly adjust the thermostat back and forth to maintain their own equilibria, a negotiation needs to take place with the aim of finding a shared equilibrium around the thermostat setting. Negotiation often takes the form of each person attempting to change actions within the other's web of action to produce a more favourable equilibrium for themselves. However, in doing so people often forget to consider the pre-existing Whys and Hows of the other party. Although the outcome will partially depend on the strength and form of the Whys and Hows of each party, the quality of the negotiation (and chances of reaching the desired outcome) can be improved by determining these Whys and Hows and connecting the desired change to them, rather than forcing one's own Whys and Hows on the other person. For example, when it comes to temperature curtailment in the home, whilst one person may be primarily motivated by a low carbon goal, this person may have to consider and develop other Why-based arguments, like saving money, if they wish other householders to behave in the same way.

⇒ Practitioner's note 9

Consider the negotiations that may occur amongst people before the new behaviour can be implemented. The existing Why–Hows of all people involved will impact on how well any one person can adopt the new behaviour. Plan to directly or indirectly support any negotiations in favour of the desired change.

Illustrative quote from interviews

"My brother and I tried to minimise the usage of electric heating and cooling. Everyone agreed to use less artificial heating and cooling in the home. Sometimes my mum would tell us to use more because it is cold or hot and we would convince her to use less not about the environment but monetary value."

Once the behaviour in one person's web of actions is aligned with behaviour in another person's web of actions, this sets the stage for interpersonal **facilitation**. This occurs whenever one person does something that helps another person carry out a behaviour. One person's *facilitating* action and another person's *facilitated* action can both form a part of an established collective routine, such as a person taking their wake-up cue from another person knocking on their door to say it is their turn to shower. However, facilitation can also play an important role in the early stages of a new equilibrium that has not yet reached routine status. An example of this would be household members reminding each other of ways to reach their shared goal of reducing their carbon footprint.

⇒ *Practitioner's note 10*

Identify opportunities for interpersonal facilitation where other people can provide cues for engagement in the desired behaviour or goal.

⇒ *Research snapshot*

Our survey research consistently found that people with a strong low carbon Why (i.e. high LCRI) also tended to be in households where members remind each other to engage in low carbon behaviours (i.e. household regulation). Our 2017 survey also found that if people had higher household regulation they tended to have greater participation in low carbon routines. This effect shows how collective pursuit of low carbon living can amplify the tendency for low carbon behaviour.

⇒ *Illustrative quote from interviews*

"My partner sometimes doesn't want to wash out glass jars, so instead of recycling them, they will put them in the rubbish, not the recycling bin, so I gently ask if that is the right thing to do."

Finally, behaviour can also be shaped by interpersonal **information sharing**. This occurs when a person provides another person with information or practical aid to help them learn about either the Hows that are needed to achieve desired Whys, or the Whys that can motivate different Hows. This might take the form of a friend explaining how to arrange the installation of solar panels, or a family member explaining why it is important to recycle. It can also take the form of modelling or social learning (Abrahamse & Steg 2013), in which case a person learns how to do something by seeing someone else do it.

⇒ *Practitioner's note 11*

Consider who is available to give concentrated or incidental aid to help the people you are targeting, in terms of the Hows and Whys attached to the desired behaviour.

⇒ *Research snapshot*

From our surveys in 2016 and 2017 we found that people who had both (i) many pieces of low carbon infrastructure and (ii) well established habits of performing low carbon routines also tended to have greater access to knowledge and support around low carbon living from relatives and friends compared to those with few items of low carbon infrastructure and poor low carbon routines.

Putting the 'Why–How' and 'Who' Dimensions into Practice

This chapter outlined the role of the two key dimensions of BPT (O'Brien, McNeill & Kashima 2018) in behaviour change: Why–How and Intrapersonal–Interpersonal (i.e. Who). The material discussed in this chapter is relevant for anyone considering the design, implementation or evaluation of a policy, technology or intervention that is designed to promote low carbon behaviour. Figure 22.2 summarises our practitioner's notes and shows how they relate to each other.

Importantly, any practical application of our BPT-based analysis must be done with the awareness that behaviour change is an iterative process, in which the structures of the Why–How and Who dimensions change over time, and practical problems can only be identified and solved through trial and error and with sufficient resources. Further, when it comes to behaviour change there is no one-approach-works-for-all solution, and some people will reject even the most carefully designed attempt to change their behaviour. Hence, we recommend using this chapter as a framework to guide an iterative process of policy and intervention development, including design, evaluation, adjustment and review. By applying our BPT-based analysis practitioners will be able to identify and manage key social psychological factors that drive behaviour, which will greatly support, if not guarantee, better outcomes for their policies and interventions.

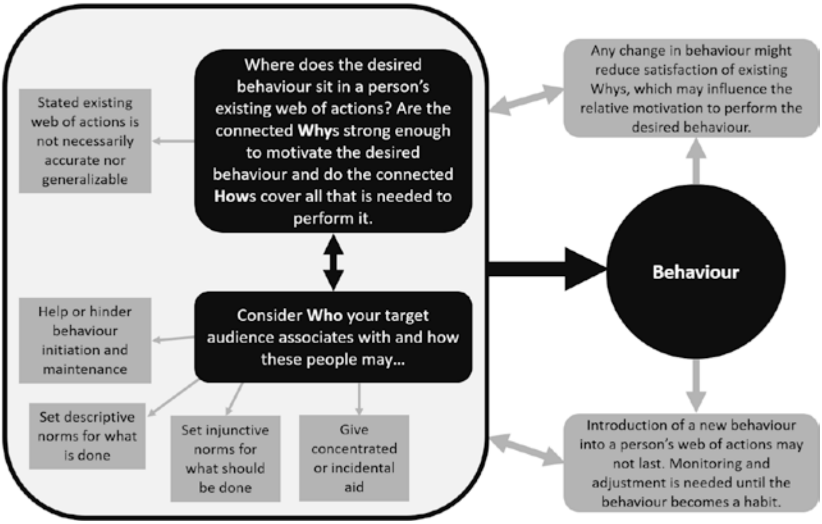

Fig. 22.2 A BPT-based analysis of the Why–How and Who dimensions

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23

Shifting Home Energy Consumption Through a Holistic Understanding of the Home System of Practice

Christine Eon, Jessica Breadsell, Gregory Morrison and Joshua Byrne

Introduction

Energy reduction in residential buildings is considered to be one of the most straight forward ways of reducing carbon emissions. Many OECD countries and jurisdictions currently have energy efficiency policies in place, usually targeting the improvement of building shells for higher thermal efficiency, the installation of energy efficient appliances and the

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adoption of renewable energy. While valuable, these measures do not provide a holistic approach to the energy reduction challenge.

Previous research has shown that highly energy efficient or net zero energy buildings (i.e. buildings that produce as much energy through onsite renewable energy generation as they consume) do not achieve their full potential despite performing better than conventional buildings (Watson 2015). There are a number of reasons for this underperformance, including poor construction practices; nevertheless, the unpredictability of occupancy constitutes an important factor. Previous research has shown that identical buildings can consume very different levels of resources mostly due to their occupants, which may not only own different appliances, but are also likely to follow different routines and have distinct behaviour patterns (Hansen 2016; Strengers & Nicholls 2017). Household and occupants' level of skills and understanding of specific technologies also impact the dwelling's metabolic system—that is, its resource flows (Pettersen et al. 2017).

A popular approach to decreasing the negative impacts of occupancy on residential energy use has been through the implementation of methods grounded in social psychology. These methods attempt to persuade change without consideration of the full picture; that is, people's environments, lifestyles, needs and everyday practices. An alternative and more contemporary approach to influencing residents is based on social practice theory (Røpke 2009; Schatzki 2002; Shove et al. 2007; Warde 2005). Rather than targeting the individual in isolation, practice theory emphasises people's daily activity patterns and interactions with their technology, dwelling and urban infrastructure contexts. Practice theory also considers skills and abilities and intrinsic motivations for undertaking certain practices (Eon et al. 2018a). As an integral part of the home, occupants need to be considered when innovative buildings and associated technologies are planned for, designed and constructed. Energy reductions are more successful when enabled through the integration of good design into the home system (Smale, van Vliet & Spaargaren 2017).

This chapter introduces the concept of home system of practice (HSOP) and discusses how this notion can be useful in shifting energy consumption in residential buildings in both the long and the short term. Firstly, the layers that form the home system are briefly described, then the more customary theories for changing consumer behaviour are reviewed and finally we advance how effective comprehension of the HSOP can act as an enabler for achieving more sustainable built environments—as designed as well as operated.

The Home System

The home is a complex environment which can be conceived as a combination of three systems: the physical, the metabolic and the social systems (Fig. 23.1). The physical system is an ensemble of objects,

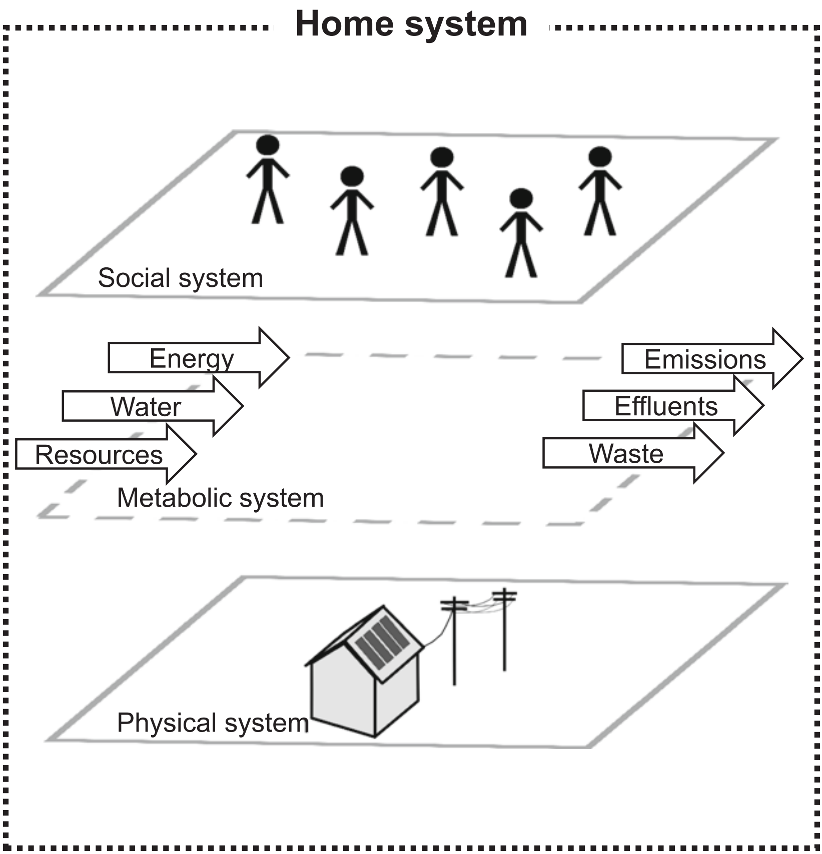

Fig. 23.1 The home system complex: social, metabolic, and physical systems (*Source* Adapted from Eon et al. 2018a)

technologies and infrastructure that make up the building. The social system consists of the building occupants, who are affected by their cultural beliefs, values, knowledge, skills, their personal networks and wider society. The metabolic system involves the movements of materials, water and energy, which flow through pipes and cables and are internally processed through the daily operation of appliances and fittings. The metabolic system is affected by its interactions with the physical and the social systems (Eon et al. 2018a). To effectively reduce energy use in the home, it is necessary to influence both the physical and the social systems.

Effective technologies for reducing energy consumption and carbon emissions in the residential sector are all well-studied and increasingly affordable. These include energy efficient building envelope design and low carbon materials, energy efficient appliances and renewable energy systems. The social system, on the other hand, is not so well understood and is often ignored. It is typically not until after new building technologies have been implemented and failed in their objectives to reduce energy consumption that the occupants come into focus and an attempt is made towards shifting their customary behaviours (Gram-Hanssen et al. 2017).

Traditional Methods for Shifting Behaviour

Conventional methods for shifting occupant behaviour are grounded in four major psycho-social theories: cognitive dissonance, planned behaviour, normative conduct and habitual behaviour. The theory of cognitive dissonance posits that individuals are conflicted when they recognise that their values and their actions are inconsistent and work to realign them, resulting in either a change in behaviour or a change in attitude (Festinger 1957). The theory of planned behaviour proposes that behaviours are a product of attitudes, social norms and the perceived control individuals have over the outcomes of their own actions (Ajzen 1991). A change in behaviour would therefore require an alteration of these three factors. The theory of normative conduct suggests that individuals are influenced by wider societal norms and unspoken judgements (Cialdini, Kallgren & Reno 1991; Schultz et al. 2007). Information about customary community behaviours and expectations is believed to shift individual behaviours. Finally, the theory of habitual behaviour considers that behaviours become automatic and unconscious when repeated regularly (Aarts, Verplanken & Van Knippenberg 1998). Hence, breaking established habits would require either a drastic change in context or frequent prompts (Steg & Vlek 2009).

Common interventions are based on the above theories and include: the provision of information and feedback to increase awareness; the delivery of social norms to make accepted and unaccepted behaviours explicit; the request for a clear commitment or highlighting of hidden personal values to promote cognitive dissonance; and the delivery of prompts to break established undesirable habits (Abrahamse et al. 2005; McKenzie-Mohr 2011).

These interventions have been deployed in research and practice through a range of approaches that generally fall into three categories classified here as social, technological and knowledge-based interventions (Table 23.1). The most successful interventions often integrate social, technical and knowledge-based methods together, such as through real-time feedback, coaching and information campaigns; however, there are few long-term studies of the kind.

The use of in-home displays or dashboards, have become increasingly popular for conveying information and prompts and seeking some response from the users. A driver here is that house metering technology has become more accessible and enables real-time feedback that is often not possible through more conventional methods such as coaching or personalised letters. Nonetheless, opinion about the effectiveness of feedback displays is divided; some researchers claim that they are effective in the reduction of resource use and identification of faulty equipment (Berry et al. 2017; Stromback et al. 2011), while others have found that they are not effective in the long term as they do not become embedded into users' routines and their use is discontinued after the novelty wears off (Brynjarsdottir et al. 2012; Hargreaves, Nye & Burgess 2013). It is also argued that feedback systems are developed by technologists and do not necessarily meet user requirements.

Table 23.1 Conventional methods for shifting behaviour

Insights and interventions	Social interventions	Technological interventions	Knowledge-based interventions
Information provision	Audit, coaching	Website	Mass campaign, letters, emails, factsheets
Feedback	–	Website, SMS, in-home display	Bills, letters, emails, direct metre readings
Social norms	Social interaction	In-home displays, website	Letters, marketing campaign
Commitment	Verbal or written	Website, in-home display	–
Value activation	Coaching, audit, peer interaction	–	Survey
Prompts	–	SMS, email, in-home display, website, alarms	Stickers, written reminders

Information campaigns through media advertisements are popular among governing bodies and utilities (e.g. water and electricity providers), who see this as a means for attempting to rapidly 'broadcast' awareness through society.

Social psycho-social theories address resource use from a top-down perspective, persuading home occupants to change individual attitudes, perceptions and behaviours based on information being provided through the methods on Table 23.1. Nevertheless, behaviours are influenced by the wider society and culture (Shove, Watson & Spurling 2015; Stephenson et al. 2010) and changing them entails a societal transition, being based on a more systemic approach.

The Home System of Practice

The concept of HSOP (Eon et al. 2018a) emerged from practice theory, which offers an alternative to understanding and shifting actions by focusing on everyday practices as opposed to resident behaviour, knowledge and attitudes (Schatzki 1996; Shove et al. 2007). Practice theory suggests that individuals do not use energy resources directly, but rather as instruments to achieve specific outcomes (Hargreaves 2011). For instance, energy is used in the practice of cooking with the objective of preparing food for consumption; water is used in the practice of personal hygiene through a shower; and driving a car is used in multiple practices such as shopping, getting to work and dropping children at school.

Practices conducted by users are affected by three elements: meaning, skill and technology (Gram-Hanssen 2014; Schatzki 1996). Meaning is the reason behind the execution of a practice; skill is the understanding of how to execute the practice; and technology encompasses the objects and infrastructure necessary to undertake the practice. It follows that affecting one or more of these elements should result in a modification of the practice and subsequently the resource use, enabling (as opposed to persuading) occupants to save energy while continuing to meet their needs (Brynjarsdottir et al. 2012).

As technologies and infrastructures evolve and are adopted, existing social practices become obsolete and are replaced by new ones (Shove, Watson & Spurling 2015). Practices are also place and time dependent, being adapted to the configuration of different settings and circumstances.

The repetition of practices in a habitual routine become interdependent and interlocked (i.e. interconnected) in a system of practice (SOP) (Watson 2012). For instance, the practice of composting is interlocked with the practice of food preparation; in other words, composting cannot exist unless food waste is generated. Likewise, practices are often reproduced in a sequential manner, interlocking with preceding and subsequent practices (Eon et al. 2018a). For instance, the practices of showering, eating breakfast and driving to work are all constrained by the practice of working and its schedules (Southerton 2013; Torriti 2017).

In a home occupied by multiple individuals, each individual possesses a unique SOP. These SOPs interlock with each other as some practices are shared between individuals (e.g. eating a meal), occur sequentially (e.g. showering) or take place as a consequence of another set of household activities (e.g. cleaning up after children). This network of SOPs in the home forms a HSOP (Fig. 23.2), which is part of the social

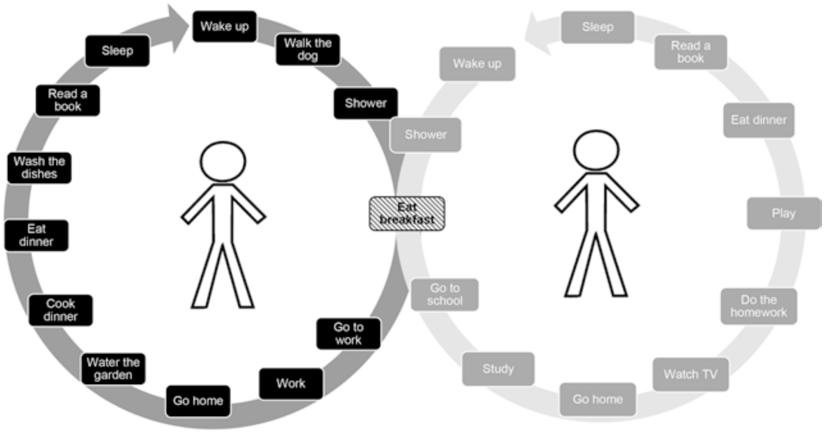

Fig. 23.2 Interlocked practices and routines in the HSOP (*Source* Adapted from Eon 2017)

system of the home. The HSOP can be regarded as a form of home equilibrium, and while complex, works in harmony to achieve desired outcomes for household members (Eon 2017).

Shifting Energy Consumption Within the HSOP

Shifting domestic energy consumption requires a deep understanding of the HSOP; that is, the interconnections that exist between an individuals' own practices as well as within the HSOP as a whole and incorporating the meanings, skills and technologies-in-use behind those practices that use energy. These are explored in the following section.

Implications of the Interlocking of Practices

Practices can have different degrees of interlocking; being highly or lightly interlocked in the HSOP. Research has shown that practices occurring during workdays usually happen within tight timeframes as they are limited by predetermined activities, such as work or school and their timetables (Eon et al. 2018a; Torriti 2017). In such cases, practices have a high degree of interlocking and are more strongly bound in the home equilibrium. This means that altering these practices, their times, duration or order, can prove hard as not only the practices themselves need to be affected, but all other interlocked practices in the HSOP. Conversely, practices that occur during non-working days or that are not bound to recurring scheduled activities, are deemed to be lightly interlocked. These are usually more flexible, have varying timetables and durations and are less dependent on the household routine, being therefore potentially easier to modify.

Whenever a new practice is introduced in the home, interlocked practices need to be re-aligned so that the new practice becomes incorporated in the HSOP (Fig. 23.3). Unless a new home equilibrium is reached and the new practice becomes embedded in the HSOP, it is not adopted by the home occupant. This tends to be the case with persuasive approaches, such as the use of feedback systems. While occupants usually value information about their energy use, the practice of accessing the feedback system platform fails to become integrated in the HSOP and does not have significant lasting effects. Reasons can vary from lack of time and being busy, to forgetting about it (Eon et al. 2018b).

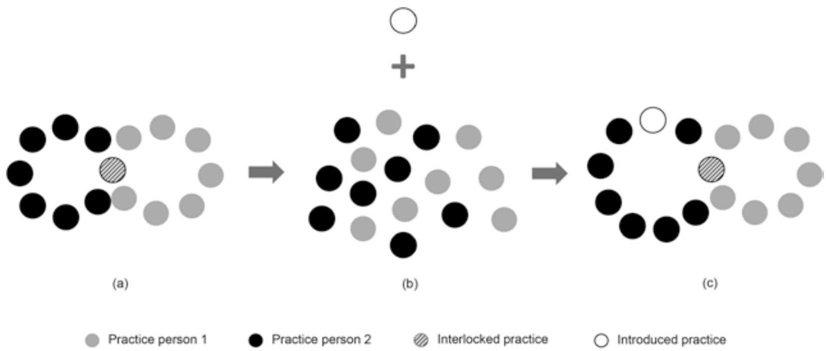

Fig. 23.3 Conceptual diagram of the equilibrium of practices in the home (*Source* Adapted from Eon 2017. *Notes* **a** Original home equilibrium. **b** Destabilisation of the home equilibrium through the introduction of a new practice. **c** Realignment of practices and establishment of a new home equilibrium)

A HSOP realignment does not necessarily mean that practices themselves are affected. While the timing of practices may realign and reach a new equilibrium, the meanings, skills and technologies of the practices may remain the same; that is, the manner in which occupants perform specific practices to achieve a particular meaning may not be affected. As resources are consumed indirectly through the performance of practices, the realignment of the elements may result in the same level of resources being consumed during the practice (Eon et al. 2018a).

The Implication of the Meaning of Practices

The technology and related skills required for carrying out a certain practice are relatively constant over time in a specific context. In contrast, more than one meaning can be attributed to the same practice (Shove 2003). For example, research has shown that the practice of using a heater can be associated with multiple meanings or associations; for example, warmth, comfort, health and habit (Eon, Morrison & Byrne 2018). Different meanings impact differently on the resources required for the execution of a particular practice. For showering, it has been shown that meanings such as cleanliness or refreshment are associated with shorter showers and thus less energy and water consumption. Meanings such as warmth and relaxation, on the other hand, are associated with longer showers and therefore higher resource use (Breadsell et al. 2019).

Individuals who assign multiple meanings to the same practice and thus use varying amounts of resources at each instance may be able to make a conscious decision to only adopt one of its more resource-efficient meanings and associated consumption patterns. Conversely, individuals who have one sole meaning for a practice may not be willing or may not have the skills to reduce the associated resource use.

Requesting that occupants change the meanings of their practices without providing a suitable alternative to meet the same need is challenging. If the heater is turned on with the purpose of comfort, it may be hard for its use to be reduced without negatively impacting the user's lifestyle. Information campaigns that have urged consumers to reduce their shower lengths, for example, have failed as they have not properly addressed the meaning behind the practice. In this case, the adoption of an alternative technology, such as a more efficient shower head or water heating appliance, may be a more suitable solution for the purpose of reducing energy consumption in the home.

Enabling Change in the HSOP

To enable change to consumption patterns in the home, one of three scenarios needs to take place:

- a new practice needs to be incorporated in the HSOP leading to a new home equilibrium;
- one of the elements of the targeted practice needs to be modified; or
- a practice needs to be dis-interlocked or disconnected from the HSOP in order to act independently of the other occupants.

Individuals that perform habitual and highly interlocked practices are unlikely to change them unless there is a major modification in context (e.g. a change in lifestyle, family structure or to the technology element of the practice) causing practices to realign. Practice theorists posit that rather than persuading individuals to change behaviour and realign existing routines, the elements of practice should be targeted (Eon et al. 2018a; Spurling et al. 2013).

A change in meaning can be challenging as it is the reason behind the execution of a practice (Shove, Pantzar & Watson 2012); that is, meaning relates to a need that an individual wants to fulfil and that directly impacts on the perceptions of lifestyle, comfort and wellbeing. The skill associated with a practice is learned through the observation of other practitioners over the years, being family, society and culture dependent (Gram-Hanssen 2010; Scott, Bakker & Quist 2012). Affecting skills might therefore entail a shift in an individual's perception; which is also problematic to achieve in the short term. In contrast, the technology element of the practice can be more easily adjusted as it usually consists of a one-off change that does not affect the HSOP nor has a major impact on established habits and comfort (Eon et al. 2018b). This is supported by research that suggests that consumers are favourable to more efficient technologies but perceive convenience, practicality and cost as factors in take-up (Dolnicar & Hurlimann 2010). Technology changes can often be made when an individual is moving to a new house or purchasing new appliances.

Innovative technologies must be designed to meet occupant needs and be properly understood to avoid the risk of generating undesired rebound effects (Wolff et al. 2017). Scott, Bakker and Quist (2012) propose that enabling change in practice should be conducted through practice-oriented design, comprising the following steps: understanding the baseline practices; challenging the status quo by identifying alternative solutions; and co-creating solutions with the users. This process encourages the development of innovative technologies capable of meeting users' needs including more efficient use of resources. An example of this is the redesigning of bathing practices by Kuijer and De Jong (2009).

Another solution to enable energy reduction in the home is through unlocking practices from the HSOP; that is, making them independent of other occupants or other systems of (low carbon) energy supply. This can be achieved through the use of automation that can be built into the physical systems of the home. For instance, the practices of dishwashing, clothes washing and pool cleaning can be automated to occur at times when renewable energy is being generated but when occupants are not necessarily present to carry out the task themselves. Battery storage will expand the opportunity here. Similarly, appliances on standby can be programmed to be switched off when not in use and air conditioners can be controlled to function optimally in line with external factors such as temperature. While the aforementioned practices can be executed manually, they are considered a hassle by occupants and seldom integrated into established routines (Hobman, Stenner & Frederiks 2017).

Manual practices are bound in space and time in a tightly interlocked routine and can be changed through a change in the elements. Automated practices, in contrast, are bound only in space as they can function at flexible times and operate in conformity with the physical home system and independently from the HSOP. For instance, a timer could be installed to the reticulation system so it is independent of the rest of the HSOP. Careful consideration needs to be given when designing and deploying automated technologies as they are required to meet occupant needs and skills to work effectively and produce the desired outcomes for the household—and society more broadly.

Conclusion

This chapter outlined the theoretical concept of the HSOP, which can be used to provide a deeper understanding of the social system associated with the home and inform solutions for enabling energy reduction at a household level. More traditional methods have attempted to persuade occupants to change through the use of information campaigns and feedback technology. However, their effects are usually short-lived. Interventions aimed at affecting specific practices may ignore the underlying reasons for these practices and their interconnectedness within the home system. The effective modification of occupant behaviours and everyday practices requires a holistic understanding of the HSOP, which includes occupant practices, routines, and their interconnections.

While HSOPs can be realigned, they constitute a challenging task without a more fundamental change in context. Affecting the technology elements of practices on the other hand may be more readily accepted as they do not impact occupant meaning, comfort and lifestyle. This extends to the use of automated technology that can be operated independently of users. Even though the idea of utilising automation for improved house performance is not new, aligning it with the concept of HSOP can assist with improved design, deployment and adoption of technologies that enable low carbon practices.

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24

Engaging Home Renovators: Opportunities and Challenges for Low Carbon Living

Kath Hulse and Esther Milne

Introduction

Australian households contribute an estimated 12% of the nation's annual greenhouse gas emissions (DEE 2017), not including indirect energy embodied in building materials, fixtures, fittings and appliances nor the energy used by household members in transport to and from the home (Monahan & Powell 2011). Household emissions comprise predominantly carbon dioxide emissions associated with energy consumption, namely electricity, natural gas and other fuels, exacerbated by the use of hydrofluorocarbons in refrigerators and air conditioners. The major contributors to energy consumption in the home are space

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heating/cooling (40%); use of appliances and equipment including refrigeration and cooking (33%); water heating (21%) and lighting (6%) (DEWHA 2008). Reducing household energy consumption is important in tackling the nation's greenhouse gas emissions along with measures directed at other sectors.

Attempts to reduce energy consumption in the home have focused largely on improving the design, layout and construction of Australia's housing, particularly new housing. Improvements include housing layout, construction of the roof, walls, windows and floors, the orientation of windows and shading for sunlight and cross ventilation and suitability for local climates. In Australia, these factors underpin a system of 'star rating' which has been incorporated into the National Construction Code and also been applied in various state and territory building regulations (NatHERS 2018). The 'star rating' system applies to new building and major renovations but does not apply to renovations for which a building permit is not required. There are also some state-based schemes including the New South Wales Government's Building Sustainability Index (BASIX) and the Victorian Government's Residential Efficiency Scorecard. These rating systems refer to design and construction; they do not take into account household use of appliances in the home, such as air-conditioning units and hot water services, which are major sources of energy consumption based on daily practices within the home such as heating/cooling, personal hygiene and washing and cooking.

Improving the energy efficiency of new housing is important but it would take a long time to reduce carbon dioxide emissions in this way. Newly constructed stock typically adds less than two per cent to housing stock each year (NHSC 2013), notwithstanding increase in new construction 2013–2018 (HIA 2018). The challenge in lowering carbon dioxide emissions in the home is to focus on established homes and to take advantage of the opportunity presented when owners renovate. This is the time when decisions are made and funds committed to improving layout/design and fixtures/fittings which could reduce energy consumption and improve thermal comfort. Importantly, renovation is a time when households consider their current and proposed day-to-day household practices which affect energy consumption in the home (Judson & Maller 2014).

The Home Renovation Sector in Australia

It is hard to get a complete picture of home renovation in Australia since it includes different combinations of property maintenance, minor renovation, major alterations and newly constructed additions which are counted in different ways. What we can glean from a variety of traditional and commercial sources, however, is that renovation is typically carried out by homeowners living in detached or semi-detached houses rather than renters or apartment dwellers (Roy Morgan Research 2017). The most common work involves repairs/maintenance and improving bathrooms and kitchens (Maller & Horne 2011, p. 67), living/family rooms, guest and master bedrooms and laundry rooms (Houzz 2018). Just over half are small renovation jobs of $70,000 or less and more than a third of renovators also engage in new building work (HIA 2015). Many Australian renovators also make upgrades to outdoor spaces and structures (Houzz 2018).

Renovation is big business with an estimated $33.2 billion, spent in this sector in 2017, roughly a third of the total value of all residential construction in that year (HIA 2018). Commercial estimates of the percentage of homeowners renovating each year (taking the broad definition used in this chapter) range between 50 and 62% (Houzz 2018; Roy Morgan Research 2017). While the renovation sector is very large, renovation activity is the result of the planning, decisions and actions of many small players. They are a very mixed group ranging from those who do a great deal of work themselves (Do-It-Yourself, known colloquially as DIY) to those who make extensive use of building professionals (Maller & Horne 2011, p. 61). The renovation industry comprises a large number of small businesses: 80% of firms employ five people or less and a quarter of the market comprise lone traders. The trades most commonly used in renovations are electricians and plumbers followed by plasterers, painters and carpenters (HIA 2015). In addition, there is a whole raft of intermediaries between renovators and building practitioners including designers, product manufacturers, installers, local councils, building suppliers and retailers, (Karvonen 2013), many although not all of which are small businesses.

A large renovation sector with many small players poses challenges in changing renovation practices to achieve a reduction in energy use. Governments in Australia's federal system have tried a number of approaches to persuade households to change their renovation practices (Burke & Ralston 2015). A first approach is to educate home renovators about means of improving energy efficiency in the home, typically involving technical and financial information such as online tools which calculate dollar savings from improved energy efficiency. A second approach is via financial incentives to households to install energy-efficient appliances, typically via state government programmes such as the Victorian Government's Solar Homes Package (Sustainability Victoria 2018) and the NSW Government's Energy Saving Scheme (OEH 2018). These schemes are based primarily on the assumption that renovators want to reduce their ongoing energy costs. As Wilson, Crane and Chryssochoidis (2015, p. 12) assert, they are based on an assumption that households would undertake energy-efficient renovations but are 'prevented from doing so by capital constraints and uncertainties about energy savings, financial returns, and contractors' quality and reliability'. Such a premise underlies applied behavioural research searching for better ways to achieve behavioural change. A third approach is to regulate for greater energy efficiency in renovated homes, but governments are reluctant to introduce regulation on building-related energy efficiency standards, except in the Australian Capital Territory (ACT) where there is mandatory disclosure of energy rating for all homes for sale and when offering a property for rental (Sale of Residential Property Act 2003). In lieu of this a fourth approach is to encourage households to consider energy efficiency when buying, selling, renting or renovating properties through a property marketing framework. The key contemporary example of this approach is The 17 Things™, originating in the real estate sector and developed for the Centre for Liveability Real Estate, which is now owned and supported by the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The Centre offers renovators practical information about these 17 features (climate zone, living locally, orientation, cross ventilation, zoning, insulation, density of building materials, windows, shading or sun control, efficient heating and cooling devices, energy-efficient lighting, efficient hot water system, solar photovoltaic system, low water garden, water efficiency devices, rainwater tanks and home energy rating). It also provides a benchmarking system approved by CSIRO with six of these features required to get the Liveability Features Icon attached to property details at the point of sale/rental (Centre for Liveability Real Estate 2018).

In this chapter we draw on a body of research which investigated means of engaging with households about home renovation in the context of their everyday, routine practices, rather than changing rational decision-making behaviour through education and financial incentives and exhortations to undertake 'green' renovations which have been relatively ineffective. This builds on prior work which takes this approach, including a special issue of the journal *Building Research and Information* (ICRIBC 2014), and Maller, Horne and Dalton (2012) and Wilson, Crane and Chryssochoidis (2015). These home practices take place in an environment in which renovators are exposed, and contribute to, changing cultural and commercial contexts in which the media play a key role.

(Re)Shaping the Cultural and Commercial Context for Australia's Renovators: The Role of Media

Australian households in aggregate spend a lot of their own money in improving their homes but also invest heavily in time and emotional engagement. While the policy focus has been on persuading renovators to include energy-efficient features in their renovation plans through education which stresses the ongoing financial benefits of such measures, our research suggests that a variety of factors are important to households in planning a renovation including liveability/comfort, appearance/aesthetics, budget and increasing the value of the property—*before* issues such as energy and water efficiency are considered (Hulse et al. 2015, p. 15). This tension between an emphasis on appearance and aspirational lifestyle on the one hand and increasing financial value on the other provides a complex context for renovation (Mackay & Perkins 2016). This is unlike the commercial sector where both building owners and lease-holders are aware of building performance and negotiate on any improvements, detailing the flow of financial benefits.

'Australia's obsession with renovations' (Allon 2008) takes place in a distinct cultural context which emphasises factors such as aesthetics and appearance, aspirations and social signalling. Media play an important role in shaping and reshaping this cultural context. Traditional media (broadcast and print) are important in creation and transmission of cultural values which pair homemaking and home improvement particularly through entertainment broadcasting, with popular TV shows such as Australia's *The Block* (Channel 9) and *House Rules* (Channel 7) and *Grand Designs* (Channel 4 UK and shown in Australia on ABC1 and the Lifestyle Channel on Foxtel). Such programmes provide stories and images about products and renovation methods not only through programme transmission (e.g. high level of awareness of latest features such as double showers and butlers' pantries) but also through an interconnected online and social media presence (Podkalicka et al. 2016). For example, *The Block* has an active social media presence including Facebook, Twitter, Instagram and Pinterest and an Internet presence that includes an online shop which sells featured products, indicating a complex intertwining of cultural context and commercial interests. *The Block* has, however, only highlighted energy efficiency during one of its seasons, Sky High season seven, in which the sponsor was Energy Australia (Podkalicka et al. 2016, pp. 19–20). This series indicated tension between a stylish renovation and creating value; sustainable renovation was portrayed as desirable but detracting from investment to add value (Aggeli & Melles 2015).

A further part of the cultural context involves changing attitudes towards housing which is now often seen as a financial asset as well as a place to live. Housing is increasingly 'financialised', that is seen is seen as a fund which can be drawn upon, borrowed against and traded as an asset (Aalbers 2016). In this context, the financial touchpoint in renovation is as much about 'adding value' in a dollar sense as in lowering ongoing energy costs, the latter being prominent in top-down educative messages about using home renovations to reduce carbon dioxide emissions. Media plays a role in shaping and reshaping cultural values about 'creating value' as much as 'creating home'. TV shows such as *The Block* (Channel 9), *Selling Homes Australia* (The Lifestyle Channel, Foxtel) and *Love It or List It Australia* (The Lifestyle Channel, Foxtel) are geared to renovating homes to sell for a profit. There are also embedded and layered digital media associated with these shows. *Selling Homes Australia*, for example, communicates via Facebook and Twitter under the names of well-known programme presenters. The show's website has links to shopping for products and finding recommended suppliers, again indicating the important role of traditional and digital media in connecting cultural values and commercial interests.

Home renovation shows are embedded into global and Australian property advertising and real estate businesses. Two of the most popular TV shows, and their related online and social media presence, are now connected to the two biggest online portals for property and real estate businesses operating in Australia. Domain.com.au is now branded as the 'official property app' of *The Block*; after the 2018 merger between Channel 9 and Fairfax, the latter being majority owners of Domain.com.au. The TV show *Selling Houses Australia* is linked to Domain's main competitor—realestate.com.au which is part of the REA Group, with majority ownership by News Corp Australia, itself a subsidiary of News Corp (International). The business models of these media/property companies are primarily concerned with buying and selling properties and improvements that increase capital value rather than improvements which enable improved energy efficiency, unless such improvements are reflected in price and saleability.

In brief, engaging with home renovators with the aim of changing home renovation practices has to be cognisant of the ways in which media influence cultural values about renovating for living—and renovating to sell (at some stage)—noting that these influences may be indirect or direct and short or medium/longer term. For example, while there is a high level of public awareness of the renovation/property/lifestyle shows as evident in audience viewing figures (Milne & Podkalicka 2019), their role in popular culture is enhanced by the multiplicity of media types—and interconnected media—that are used to share information and ideas. Media are an important contributor to the cultural landscape in which people imagine, design and make practical decisions about renovating their homes. Next, we consider how media on home renovation provide important learnings on how best to engage with home renovators.

Learning from Media: Narrative and Visualisation in Mainstreaming Energy-Efficient Renovations

Media studies has long recognised the cultural significance of reality and lifestyle TV with a rich body of research investigating its impact through a range of critical perspectives including discourse analysis, audience engagement and political economy (for a comprehensive literature review of the field see Podkalicka, Milne and Kennedy 2018). However, there is limited research focusing specifically on media consumption and home renovation. Notable exceptions include Allon (2008, 2011), Lewis (2008) and Rosenberg (2011). What remains to study in depth is how home renovators use media both materially and symbolically during their renovations. In this section, we draw on research conducted for the Cooperative Research Centre (CRC) in Low Carbon Living in Victoria (Australia) to fill this gap. As this was exploratory research, it used a number of research methods including an online survey of home renovators, focus groups with renovators and building practitioners, interviews with key experts, the use of data analytics through the social media tool known as TrISMA (Tracking Infrastructure for Social Media Analysis) to map public engagement with sustainability issues on Twitter and analysis of data supplied by Sustainability Victoria from a survey and focus group sessions with home renovators and some ethnographic research into 'speed dating' sessions between renovators and designers/builders organised by the not-for-profit organisation Alternative Technology Association (ATA) (now known as Renew) (see Hulse et al. 2015; Podkalicka et al. 2016).

Conventional attempts to convince renovators to change their renovation practices to include more efficient designs, features and products emphasise buildings, financial information and data. Our research into home renovation practices and media indicates that a different approach is required that emphasises people rather than buildings, story-telling rather than financial/technical information and what has been referred to as 'narratives rather than data' (Gardner 2008, cited in ARUP and Naked Communications 2010, p. 5). This type of approach accords with some of the more general literature on media as a means of engaging and communicating with people (e.g. Hartley 2012). Our research indicates that planning a renovation is about dreams and desires, and imagining new ways of living and new daily practices, although budget is always important (Hulse et al. 2015, p. 16). In this context, renovators respond to human stories which can be aspirational and/or about a 'renovating journey' in which there are obstacles along the way to be overcome, both of which are synonymous with the leading building and renovation TV shows.

The *Grand Designs Live* trade show speaks to the successful mainstreaming of 'green' messages. This event is a *Grand Designs* spinoff featuring host Kevin McCloud, which has been touring London, Birmingham, Sydney and Melbourne for over 10 years. It presents opportunities for the building and sustainability sectors to communicate with consumers about both small scale and ambitious renovation projects. In terms of the impact of reality TV on public engagement a similar event is *The Block's* 'Open for Inspections'. These occasions are held on site at the conclusion of each season just prior to the renovated properties being auctioned. In 2018 thousands of people attended in Melbourne to see the refurbishments of the historic Gatwick Hotel. Both these events demonstrate the significant potential offered by these mainstream renovation programmes to move their audiences, quite literally from the living room to public spaces.

Current attempts to induce renovators to implement more energy-efficient renovations often focus on decision-making about which products, materials and appliances to use. This may be too late to change renovation practices. At the early stages of a renovation, visual media are very important in enabling renovators to get inspiration and ideas as well as learning from other renovators. Renovators want to *see* designs, layouts, features, appliances and colours rather than reading text (Hulse et al. 2015, p. 7). Pictures are very important to this early stage of a renovation with renovators using image-heavy social media (e.g. Pinterest and Instagram) as well as online platforms such as the renovation website *Houzz*. Sharing of pictures is very important at this stage. While visualisation is relatively easy for some products and appliances (e.g. heating systems and air-conditioning units), it is more of a challenge for unseen products (e.g. underfloor insulation or double glazing) which improve thermal comfort and lower noise levels. While some renovators use laptop computers to gather ideas, mobile devices (smartphones and tablets) are increasingly important at the ideas and inspiration stage. The research indicated that some 'low tech' strategies can also be useful here, such as ATA's Sustainable House Day initiative in which people can visit renovated houses and see what improvements look like in situ, as well as asking questions of owners (Hulse et al. 2015; Podkalicka et al. 2016). Renovators also use magazines (hard copy and increasingly online) and brochures such as the Ikea catalogue, which is free and widely distributed, to get ideas about renovating.

It is important to note that once renovation is underway, renovators often keep pictorial records of their renovation 'journey' which is often shared on social media. Building practitioners also keep records of a renovation including 'before' and 'after' pictures which they share on their websites or on Facebook to highlight the transformation they have achieved. However, all parties to a renovation are reluctant to share financial information with renovators reporting that it was hard to know how much ideas about renovation would cost and building practitioners wanting to know how what the budget of renovators was before discussion ideas about renovation (Hulse et al. 2015, p. 24).

Learning from Media: Influencers and Intermediaries

Home renovators are a mixed group ranging from the DIY renovators who renovate in stages, sometimes over an extended period, to households who used professionals and practitioners throughout the process of design and construction. Whatever the process, research indicated that renovators want to be in charge of the renovation: it is 'their renovation; their ideas, and their money' (Hulse et al. 2015, p. 6). We have described renovation as a practice but most renovators have either never renovated before or have only done so occasionally. In this context, influencers and intermediaries assist them to turn their aspirations, dreams and financial goals into reality in an environment where they may feel unsure about how to proceed. Within media and social sciences research, the terms 'influencer' and 'intermediary' have quite specific critical trajectories. The literature on digital influencers, sometimes referred to as 'microcelebrity' or 'instafame', encompasses new forms of celebrity advocacy, personal branding and the increasing monetisation of social media. A useful definition is provided by Alice Marwick and danah boyd (2011, p. 141) who argue that influencer culture involves the practice of 'viewing friends or followers as a fan base; acknowledging popularity as a goal; managing the fan base using a variety of affiliative techniques; and constructing an image of self that can be easily consumed by others' (see also Abidin 2016; Mavroudis & Milne 2016; Raun 2018). While influencers are usually understood as particularly visible or famous figures, the term 'intermediary' is used to describe a diverse range of people and organisations between a household planning a renovation and building practitioners or trades who undertake the renovation works (or part thereof). In this section, we look at the messages about renovation which are conveyed and taken up from a variety of influencers and intermediaries, with a particular emphasis on media.

Sometimes influencers may emerge from the renovator's personal networks. Renovators talk to people that they already know and trust: family and friends and other people within their personal network such as work colleagues or neighbours or people recommended by them. Influencers can also be indirect and general as in the case of renovators using traditional and digital media to gather ideas about their renovation. Media of various types can also influence renovators' friends, family and others in their personal network who act as intermediaries.

The research indicated that in the early stages of imagining and researching about renovation, many initially search the Internet for ideas and inspiration. Using a search engine such as Google for 'home renovation ideas Australia' brings up sites which provide lifestyle and decorating sites often attached to magazines (e.g. *Home Beautiful*) or TV shows (e.g. *Selling Houses Australia*) as well as 'renovation tips' and guides from the two big online property portals (domain.com.au and realestate.com.au). The Internet site most frequently mentioned by renovators in the research was *Houzz*, a US-based company which has an Australian operation. *Houzz* is an online platform with related social media apps which can be used on mobile devices (Facebook, Instagram and Twitter), providing photos and stories about home renovation. Its model is to operate as an online community in which information can be shared.

Most of the popular Internet sites have associated social media (Facebook, Pinterest, Instagram and Twitter) which can be used on mobile devices. They provide pictures and tell stories as discussed earlier. Importantly, these sites and related apps feature presenters of broadcast media that households may already be familiar with such as Cherie Barber on the *Home Beautiful* website, known to TV viewers through her work on *The Living Room* (Channel 10) who founded and owns a company called Renovating for Profit. Another example of this type of influencer is Shaynna Blaze who co-hosts *Selling Houses Australia* and is a judge on *The Block* who is active on Facebook and Twitter. It is important to note that this type of engagement is not a one way process and certain organisations and people generate many replies to the Tweets they send out, with the most notable example being *The Block* and TV celebrities Shaynna Blaze (*The Block*) and Johanna Griggs (*Better Homes and Gardens* and *House Rules* (Channel 7) (Podkalicka et al. 2016, p. 37).

A wide range of intermediaries are involved in the home renovation space. These range from personal networks to small and large companies and sometimes governments. Our study found as ideas are turned into more specific plans, households who only renovate occasionally turn first to their own personal network of family and friends to get information about key trades, such as electrical and plumbing, and recommended building practitioners. If a design professional is required, the same process applies. These networks are based on mutual trust between network members. Those who do not have networks which can elicit trusted people or firms, search the Internet using a general search term or go straight to sites which provide lists of practitioners, such as lists of registered builders. A general search on the Internet can often be confusing but does help renovators to learn some of the language of renovation and to have an idea of what sort of questions to ask. If renovators are specifically interested in improving energy efficiency in their renovation they can search specific sites on the Internet. Renovators find it hard to know how trustworthy the information they find is and to compare products. Building professionals and practitioners, on the other hand, rely on their associations and suppliers' representatives for trusted information on new and sustainable products, supplemented by Internet searchers (Hulse et al. 2015, p. 27).

Media can be seen as an intermediary as well as an influencer; they not only influence renovators to imagine and develop ideas (as discussed above) but also connect renovators with building professionals and practitioners, products and suppliers in a curated way. Sites such as *Houzz* contain links to practitioners and products. Similarly, websites from popular TV programmes such as *The Block* and *Selling Houses Australia* also have such links to The Block Shop (https://www.theblockshop.com.au) and *Selling Houses Australia* Shop (https://www.lifestyle.com.au/tv/selling-houses-australia/shop). After initial browsing, sites such as *Houzz* require registration via Facebook or Google to enabling tracking of data about enquiries and potentially targeted advertising of products or professionals/practitioners.

Renovators are, however, not only consumers via media but also share their aspirations and ideas on a peer to peer basis through social media with family and friends (e.g. Facebook, Pinterest and Instagram) but also sometimes more generally. This occurs through online blogs such as Reno Addict and House Nerd as well as blogs on sites such as *Houzz*. Renovators also exchange ideas and information via moderated peer-to-peer forums such as Whirlpool (Whirlpool.net.au; includes many conversations that are about renovation and technology; Podkalicka et al. 2016, p. 14) in which renovators can provide details of their experiences as well as asking others for the answers to questions that they may have and which is considered in detail in the chapter by Podkalicka et al. in this volume. In addition, this type of communication occurs through Facebook and Twitter as well as the more visual media of Instagram and Pinterest.

Conclusion: How Could More Effective Engagement with Households Lead to More Energy-Efficient Renovations?

Effective engagement with households about improving the energy efficiency of their homes when they renovate requires language that is about people and that talks to their dreams and ideas about ways of improving their everyday living, rather than the language of improving building performance (retrofit). A good example of this is The Centre for Liveability Real Estate, discussed earlier, which promotes incorporating 'The 17 Things' when renovating to achieve housing that is 'healthy, efficient, comfortable and connected to your local community' (Centre for Liveability Real Estate 2018). Our research indicated that changing renovation practices must speak to the ways in which households want to meet their aspirations through improving their homes: for improved comfort, to modernise, achieve light open-plan living within their available budget and which will also add value to their home if they on-sell it (Hulse et al. 2015, p. 14).

While engagement with ideas about 'home' is important to gain traction, our research indicates that households appear increasingly aware of the financial value added to their homes when renovating, as housing is increasingly seen as an investment as well as somewhere to live. Encouraging households to improve energy efficiency when renovating must talk to both emotional and financial aspects although the households may favour one over the other (e.g. the 'forever home' versus the 'property flipper'), although many households have elements of both within different time frames.

There is much to be learnt from analysis of media in the renovation space. It is important that new approaches to engage with home renovators about ideas for more energy-efficient homes focus on narratives as well as technical information; stories about people's aspirations and more down to earth journey to a 'successful' renovation through the various obstacles that present themselves. These stories mean that people can engage at an emotional as well as a practical level, indicated by our research which found some tension between the emotional aspects of renovation and the financial ones (Hulse et al. 2015).

It is important to engage renovators as early as possible while they are considering how they want to change their daily practices (e.g. joining in family life from the kitchen, having light filled living spaces, being able to move easily between the inside of a house and an outside entertainment area, having separate bedrooms for the children). At this stage, visualisation is all important; renovators want to visualise how their home could look if they make changes to meet their objectives. Visual social media such as Pinterest and Instagram are used heavily, particularly by women, at this stage.

Traditional media, particularly reality and lifestyle TV formats are widely viewed for their entertainment value and renovators' personal journeys. As mentioned, one of the lessons from *Grand Designs* is its capacity to make 'green' messages mainstream. People are fascinated by its stories because the sustainability theme is consumed as part of a grander narrative of homemaking.

Lifestyle and property programmes also have a strong digital presence which links to social media and major online property portals, which offer curated access to products used on the TV shows and recommended professionals and practitioners. Since they already engage renovators, the options appear to be either inserting energy-efficient ideas, products and suppliers/installers in these layered media or attempting to develop new ones which take as granted mainstream renovations which reduce carbon emissions rather than framing this as a 'green' or 'sustainable' niche in the broader renovation market.

Our research found that renovators increasingly use their mobile devices (tablets and smartphones) as the primary tool for e-communication, which indicates that mainstreaming lower carbon renovations will require apps. that are useful and easy to use.

There are also some bottom-up approaches available. These include developing communities of practice using digital and social media in which like-minded people can share their renovation journeys, perhaps using blogs, online forums and other social media. Another approach is to involve key influencers in providing advice and information and answering questions on energy-efficient renovations, such as celebrities from traditional media. Some of the potential influencers are personal ones; informed building practitioners—and intermediaries such as designers, building suppliers and retailers—which are geared to providing practical solutions within a householders' budget. The major point is that influencers and intermediaries are not aiming to change values nor to instruct but to encourage and inform renovators on how to achieve more liveable homes which will have the effect of reducing carbon dioxide emissions. In other words, these figures have the potential to speak directly to renovators in conversational style rather than in the didactic terms of official channels.

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Sharing Advice Online to Foster Sustainable Homes

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Introduction

There has been a significant amount of interest by various formal and informal actors to enrol the internet and social media in the

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communication about and promotion of pro-environmental ideals and action because of digital media technologies' capacity to provide open, large-scale access to information, participation and social networking. Early attempts to improve the public dialogue about sustainability were made, for instance, by non-governmental organisations such as World Wide Fund for Nature (WWF) involving moderated online discussion forums about local sustainable development (Dyer 2002). Local governments have used websites and social media to disseminate information about sustainability policies and programmes to stimulate engagement and participation—although questions remain regarding the extent to which real public participation and conversation occur in these instances (Tirado-Valencia et al. 2014, based on the European experience).

Scholarly work has also captured communication practices by people who share personal views, opinions and advice on environmental sustainability as part of everyday life. One such study, conducted in Sweden, examined the sharing of individual experiences on blogs and social network sites such as Facebook, Twitter, YouTube and Instagram, drawing attention to how online forms of posting about sustainability are governed by the social and networked processes of 'visibility or publicness' inherent in the social media systems (Haider 2016, p. 483). As Jutta Haider argues:

> although the underlying rationale of most of the set tasks and miniprojects [e.g. recycling, buying less, etc.] people write about and reflect on is individualistic, we also see that it happens in networks of shared interest and of publicness—which can be seen as a form of online civic engagement. (Haider 2016, p. 486)

Interdisciplinary research considers the internet and social media as important sites for popular communication and discourse on sustainability—and therefore significant for how understanding and values of sustainability are negotiated, mediated and integrated into everyday contexts (Haider 2016; Joosse & Brydges 2018; Merrick 2012; see also Podkalicka & Rennie 2018, Chapter 2). Importantly, communicating about environmental sustainability online is discussed not as freewheeling and unregulated but rather as a set of communicative practices bound up by the material structures of technologies they utilise (thus making certain types of engagement possible), social norms they follow and broader political frameworks such as neoliberalism that encapsulate them (Haider 2016).

Relevant too is the critique of the algorithmic construction of information determining what content is visible online, and information overabundance resulting in what has been termed 'infoglut' (Andrejevic 2013). The problem consumers confront in making informed choices is information fragmentation and its endless proliferation (Webster 2014), which shapes specific lived experiences of sustainability. It is in this complex context of online and social media communication that the issue of trust has been raised as a key requirement for information quality control and network building. As Sonja Grabner-Kräuter and Sofie Bitter observe, popular online social networks (OSNs)

> allow for connecting with known friends, Web 2.0 environments and OSNs also provide for anonymity, facilitating the provision of false or misleading information and lacking or impeding verification mechanisms. (2015, p. 50)

The establishment and consequences of trust in online contexts are critical for cultural and business research (Wu, Chen & Chung 2010)—and a focal point of our discussion in this chapter that centres on the role of the internet and digital media in fostering public interest in and activities aimed at creating sustainable homes. Broadly understood, sustainable homes are those with a holistic approach to design, construction, use and demolition, focusing on minimising the impact of resource use associated mainly with energy, water and waste and contributing to restoring the natural environment. The objective is to minimise the resources a home requires to be built, renovated and used through resource efficiency and recovery. It's necessary to note that 'efficiency' (i.e. the reduced quantity of energy for powering the home) is only one dimension of a sustainable home; sustainability is a more encompassing category, going beyond technical high performance and low carbon materials and features. Sustainable homes aim to minimise the resource requirements of the home through solar orientation, shading, insulation, energy and water efficient appliances, landscaping and transport based on the location of the home and then supplement the home with energy and water needs through renewables like solar energy, rainwater harvesting and greywater reuse systems. Many of these measures can also contribute to improving the quality of the indoor environment (including sufficient daylight, thermal comfort, indoor air quality) which contribute to the occupants' health.

This chapter examines the role of open moderated discussion forums and online platforms in assisting people, in *practical* ways, to make informed purchasing decisions to transform contemporary homes into sustainable homes using two Australian examples. One is the independent, well-established community online discussion forum *Whirlpool* that explores a range of user-generated topics related to home sustainability. The other is a newly launched interactive website *Build4Life* that aims to promote sustainability through establishing online communities of local renovators that offer tailored professional advice. While *Build4Life* is about peer-to-peer engagement and facilitated interactions between designers, builders, tradespeople and renovators, it is, unlike *Whirlpool*, a commercial venture. Contrasting these two examples, we discuss the processes of exchange and trust in online communities formed with the purpose of providing quality consumer advice. We ask what lessons can be learned from them for environmental communication programmes, especially in relation to sustainable housing and home renovation.

Background and Methods

We draw on two separate Cooperative Research Centre for Low Carbon Living (CRC LCL) projects that engaged with the topic of digital media and sustainability in the context of home renovations as key to supporting the transition to low carbon living. The residential sector in Australia is responsible for 11.7% of all greenhouse gas emissions, and ~25% of electricity-related emissions (Commonwealth of Australia 2017). Focus here is the ongoing operating energy used to run the home rather than the energy embodied in construction materials. Commonwealth and State Governments in Australia have supported a variety of approaches to encourage the public to improve housing sustainability and energy efficiency. These measures include basic information provision through marketing and information campaigns or reference material (e.g. YourHome Technical Manual); energy audits and assessments (e.g. Nationwide House Energy Rating Scheme ratings); voluntary energy efficiency disclosure assessments (e.g. Victorian Residential Energy Scorecard); financial incentive or support (i.e. grants, rebates, low interest loans); certification and training of contractors; and support for vulnerable or low income households (e.g. Low Income Energy Efficiency Program). On the whole, these measures have met with variable success; for example regulatory standards have shown some efficacy while voluntary, behavioural programmes have been harder to justify (Ambrose et al. 2013). Wilson, Crane and Chryssochoidis (2015, p. 12) in the UK point out that

> Sociological research on domestic life points to limitations in [the behavioural research] understanding of renovation decision making that emphasises houses but not homes, energy efficiency but not home improvements, the one-off but not the everyday, and renovations but not renovating.

Instead, effective, residential energy efficiency programmes need to operate in an extended, emotive, dynamic, competitive and social decision-making environment (Karvonen 2013). A significant gap in the research on renovations and sustainable homes has been the scant attention paid to the 'everyday mediatisation' (Hepp & Krotz 2014, p. 1); that is, material and discursive impacts on the renovation practice brought about by the ubiquitous media. The CRC project has addressed this by providing a systematic, empirically grounded overview of home renovations as shaped by a range of intersecting traditional, digital and social media, drawing attention to the importance of informal, trusted networks for information and advice, especially family and friends (Hulse et al. 2015; Podkalicka et al. 2016). This research confirmed the role of trust as a key feature of engagement between renovators and building practitioners in informing purchasing decisions.

One of the ways in which renovators navigate what they described as a space with ‘abundant but fragmented information’ is through the use of online forums, with *Whirlpool Forum* identified as a trusted platform for informal information and advice sharing among home renovators in Australia. The national home renovation and media use survey ($n = 156$) conducted by the CRC researchers in 2015 found that the second most used media type when planning a renovation is online discussion forums like *Whirlpool*, after retailer websites being the most used (Hulse et al. 2015). Another survey ($n = 504$) conducted with individuals visiting the public Sustainable House Day event in 2015, developed in collaboration between the CRC researchers and Alternative Technology Association (ATA—now Renew), revealed that online discussion forums and reviews are the third most frequently used by renovators media type, after the ATA *ReNew* magazine and website, and regulatory media and websites. This chapter also includes the research material from the thematic analysis of *Whirlpool* forums (covering the period 2014–2016) using combinations of key terms associated with renovations, sustainable renovations, green renovations and low carbon renovations (see below).

The other CRC project we include here has drawn on the media research to develop a new social media platform to promote the widespread uptake of sustainable houses. The chapter uses the observations from the lean start-up methodology and Business Model Canvas (BMC) approaches deployed to design the platform. Business Model Canvas was used to break a business idea into nine components that could be tested with prospective customers, suppliers and partners to validate the overall business proposition: partners, activities, resources, value proposition, customer relationships, channels, customer segments and costs and revenue (for more information see Osterwalder 2004; https://strategyzer.com/canvas). This approach is different from the typical project development lifecycle within Government that employs a waterfall methodology to project development usually involving some variation on the following sequence: Discover—assess the business/policy context, establish a mission and vision; Define—define the benefits/need and establish your objectives; Plan—create your operating plan, financial plan and establish KPI’s; and Execute—put the plan into action.

The dilemma for the design of sustainability strategies is that this waterfall methodology assumes the project manager knows exactly what solution needs to be implemented. However, in tackling intractable challenges such as those related to sustainability, what's required is the creation of new scalable products or services that are often innovative or disruptive in an environment of extreme uncertainty—and therefore have more in common with start-ups than established organisations.

Whirlpool

Whirlpool is an independent, uncensored, moderated online discussion forum established by Simon Wright as a private company in 1998 (Whirlpool 2018a). Although it emerged as a place for discussions about the internet in Australia, *Whirlpool* continued to grow to include a broad range of discussion topics such as home, green tech, finance and gadgets, as well as forums on renovations (e.g. Life and Lounges; Whirlpool 2018b). As of October 2018, the *Whirlpool* had a total of 819,610 registered members and counting (Whirlpool 2018c): between April 2016 and September 2018, the Forum increased the number of registered members (↑11%), and posts (↑13%) (Whirlpool 2018c). As an independent *community* forum, all the topics are created and managed by users, representatives and moderators in an effort to provide a basis for discussion, answering questions and sharing experiences. The community of users, representatives and moderators voluntarily engage in the open forum around a topic or 'thread' with the premise that the discussion is beneficial to the wider audience and not solely the individual looking to find an answer or discuss a topic of personal interest (Whirlpool 2018d).

A snapshot of public discussion and interaction on *Whirlpool* was captured in our 2016 research focused on topics related to renovation. The case study identified the top twenty renovation discussion subjects as related mostly to bathrooms, kitchens and renovation for profit (Podkalicka et al. 2016). *Whirlpool* users look to gain insight and share information about home renovations and associated technology within the *Whirlpool* community by learning from others about expectations, the required expertise; project management; sourcing and using services, products, technology; and the knowledge and skills required to complete a renovation or home energy solution project. The topics typically focused on sharing knowledge and experiences related to the renovation process: from inspiration, planning, finance and sourcing products and services to managing and conducting a renovation as part of a family home or for investment and profit-making. These discussions included a broad range of topics such as the type of trades required; comparison of methods; hiring a project manager; demolition; choosing, sourcing and quality issues related to materials, products and technology; how to save money; designing, planning, costing and sourcing materials and trades; expectations (e.g. timeframes, referrals, comparing real renovation to renovation shows on television); using online tools; scepticism about using the internet to source trades when many trusted word of mouth; and lastly warnings like '*you get what you pay for*' (Podkalicka et al. 2016, pp. 24–25).

The issue of trust when seeking advice was also evident in our focus group discussions. One of the renovators explaining:

> on the trust side of things is if I've found a product that I want some information on, I look at Whirlpool forums, and I check that out because I found that they're very good because you get a mix of users. The consumer in that, and also often the installer, they can give you some really good background information, and most of the time it's well thought out. So, that's one of the first things that I do in terms of looking for a review, is go to *Whirlpool*.

Another participant-renovator observed that they use '*Whirlpool* forums [for] checking reputation for professionals and products'. The main finding indicated that because it is a user-generated discussion forum,

> the language and topics used in the forum are not agreed upon and can vary widely based on the user(s) and the discussion topic(s), indicating that there is a low level of understanding of the terminology and little to no consensus or culture of sustainability, green or low-carbon in the general public when discussing home renovations or associated topics. (Podkalicka et al. 2016, p. 25)

Whirlpool is organised on a 'trust network' with users seeking or giving unbiased advice based on their knowledge and experiences relating to a topic. Users are encouraged to avoid duplication of topics and abide by a set of Community Rules enforced by 'user moderators' (Whirlpool 2018e) that include etiquette on the internet with outlining detailed expectations and consequences relating to serious offences like personal attacks, defamation, intolerance and vilification, foul language, trolling, inappropriate content, illegal content and activities. They refer also to activities inhibiting the forum's operations such as advertising, research, marketing, cross-posting, duplicate posting, pointless posts, etcetera. Breaches to the Community Rules can result in a warning, a post or thread deletion or penalties such as restricted use or being banned from the forum for a period of time on a temporary or even permanent basis (Whirlpool 2018e). There is a 'zero tolerance' (ZT) policy, and when applied, it comes with an immediate ZT response phrased as '*Breaching this rule will attract a Zero Tolerance response from the WP Moderators*' (Whirlpool 2018e). This may also be posted at the top of a thread or posted as an indication that the ZT is in effect for some or all rule breaches and as a warning to others who would like to continue the discussion in an appropriate manner. Representatives from a commercial enterprise (e.g. hardware vendors, software manufacturers, service providers, product salespeople) or government organisations can be members of the forum as long as they abide by the Community Rules and advertising guidelines (Whirlpool 2018f). They are required to be tagged as such with their company name for transparency when interacting with the other community members and pay a fee to participate in the Whirlpool Forum in this manner (Whirlpool 2018f).

The forums are moderated by a 60 member-based volunteer group who respond to questions from the public and moderate the forum activity based on a set of community Rules (Whirlpool 2018d). The voluntary moderators are responsible for supporting the wikis, that is, pieces of server software users can engage with in a simple text format to enable the development and engagement the Whirlpool internet-based discussion forums. Moderators are either self-nominated or nominated by another member and selected by the existing moderator team after verification that their online behaviour aligns with expected behaviours. Moderators can hide and restore posts; move, rename, close threads; delete and restore threads; put users in the penalty box; institute forum-specific bans; clear inappropriate user details; and perform moderation of the Knowledge Base/Wiki (Whirlpool 2018d; Podkalicka et al. 2016).

Build4Life

Build4Life began in 2016 as a practical response to the recognition that despite existing informal networks of trust used by renovators to guide their decisions via friends or family, the mainstreaming of sustainable housing is far from realised. A group of 60 key stakeholders in Australia proposed that a dedicated online platform could expand those trusted networks while aggregating renovators in such a way that made the delivery of good advice for sustainable homes more effective. This group comprised representatives of State and Local Governments, large and small construction companies, land developers, architects and designers, peak bodies, product suppliers and manufacturers and niche sustainability product retailers. The proposed website was conceived as integrating TripAdvisor's review features and Facebook's social connectedness—and situated within a broader competitive ecology of online home renovation services available to the renovator in Australia at the time when *Build4Life* was being first developed (see Fig. 25.1). This 'map' captures selected key organisations and services available in the renovation space in 2016/2017, collocating their respective primary value proposition on the horizontal axis and their revenue model on the vertical one. The size of the bubble demonstrates the approximated size of the market they serve. The map is intended to aid conceptual understanding of the competitive environment into which a new business can offer its services.

To date, the platform has been built and refined through a number of iterative research and practical steps. Initially, a survey of renovators was commissioned to test key elements of a prototype website including brand name, website functions and to determine the most likely user groups ($n=518$). Results indicated strong support for trustworthy information, reviews and social networking with other renovators

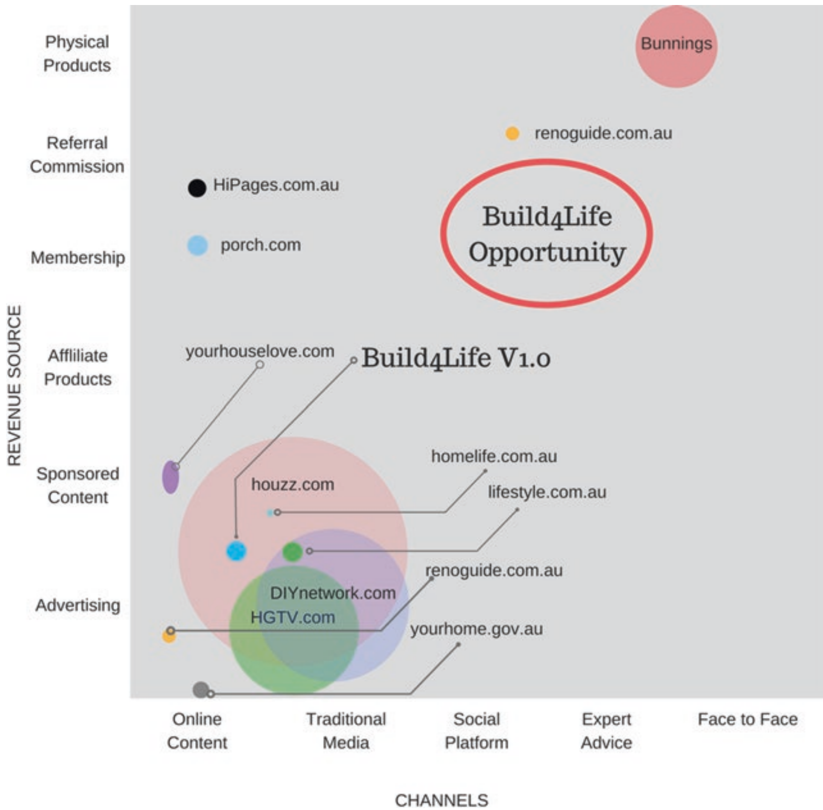

Fig. 25.1 Strategic Group Map in the renovation space reflecting the 2016 ecology

(see Table 25.1). A follow-up survey testing the 'brand narrative' for the website ($n = 1009$) revealed that the majority of respondents found the brand narrative appealing.

Subsequently, industry consultation (3 workshops with approximately 60 attendees at each) were conducted, further consolidating the platform's emphasis on quality sustainability information offered to renovators at exactly the time when they were making critical decisions. Building on the previous research about the value of close networks of trusted friends as influential in guiding renovations decisions, including the CRC LCL empirical research (Hulse et al. 2015; Podkalicka et al.

Table 25.1 Responses to the Build4Life 'brand narrative'

First Impressions	Prototype website survey (%)	Brand narrative survey (%)
Extremely appealing	18.5	16.2
Very appealing	32.0	32.5
Somewhat appealing	33.4	33.7
Neither appealing nor unappealing	14.1	14.1
Somewhat unappealing	0.8	2.3
Extremely unappealing	1.2	1.3
Total	100.0	100.0

2016), the *Build4Life* business model was adapted to focus on a face-to-face 'facilitator' to act like a party planner—like a Tupperware party. The facilitator was conceived as a social networker in their community, a trusted guide to renovating and a moderator on the *Build4Life* website. The first facilitator was found through a recruitment process. However, it was anticipated that future facilitators would be sourced primarily from within the website community. The facilitator was provided specially tailored training based on CSIRO's Livability training, reimagined for *Build4Life* facilitators.

The facilitator would perform functions such as arranging and leading face-to-face renovator 'coffee clubs' (that is, places for informal/mediated interaction between fellow renovators) where geographically proximal renovators could share stories, tips and contacts, recruiting renovators to the website and guiding their online interactions and providing renovation advice. Ultimately, the facilitator was to ensure that poor advice was not transmitted through their network and that good advice was provided at important points in the renovation process.

With the development of the facilitated 'coffee clubs', the business model for *Build4Life* moved away from an online, advertising-funded business model (at first assumed to be the most viable means of generating online income, but eventually abandoned as conflicted, highly competitive and unlikely to generate sufficient income without global scale) to a commission/membership-driven model with a greater emphasis on local, face-to-face interaction. A Facebook group of local renovators was also established to provide feedback and for the project team to observe.

The renovator ($n = 12$) and trades ($n = 7$) interviews and feedback from Facebook confirmed that the subscription model, whereby renovators paid (either as a percentage of work undertaken using the website, or as a subscriptions fee) resonated with the research participants. Trades are used to discounting and a percentage of payment approach did not deter them. Renovators were not averse to paying for services through the platform and were prepared to pay additional fees if necessary to access premium services such as one to one facilitator time. These interviews also led to a new conclusion—while a general population of renovators had responded positively to earlier surveys asking if they would value an online or in-person social space to discuss their renovation, women with children (the target demographic) responded negatively to the concept. Most responded that they did not have time to attend or participate in such activities, although they did consider Facebook groups to be a viable platform for such communications and already used that service. The *Build4Life* concept was redeveloped again to de-emphasise social networking and increase the emphasis on simplifying complex decisions, facilitating relationships between renovators and trades and co-ordinating paperwork.

The interviewees included recent renovators (renovated in the last 3 years $n = 12$) who were asked about the difficulties they had faced while renovating. Key issues were shown to be: managing trades on site as trades frequently did not attend the property to quote despite having arranged to do so, or trades not providing quotes even after attending a meeting with the renovator; managing the communication and approval of variations and keeping track of budgets. Trades including builders, plumbers, electricians and carpenters ($n = 7$) were also interviewed. Main concerns of trades were ensuring a good client fit (i.e. making sure that the client and job were suited to the work that tradesperson sought), document management, managing variations and maintaining their own online presence (websites, social media etc.).

Building on this research the *Build4Life* model was further refined to collect paperwork all in one place, to provide a record of budget decisions and project management advice. Renovators would be attracted to the site via free services to plan renovations including simple tools such as a specification planner, floor plan drawing tool, budget management tools, trade reviews and linked Facebook groups. To engage tradespeople the platform would offer the ability to quote on well-developed project briefs, a variation, payment and approval tracking service to minimise disagreements over variations to their contracts by recording when decisions are made, documentation management (i.e. certificates, approvals, warranties etc.) and the options to display their work using a simple website template. The business model operates almost like a contract manager or project manager, co-ordinating trades, managing contract variations and providing advice to renovators while also adding value through reviews, interaction with local Facebook groups and website services for trades.

These ideas were put up for a review in another round of qualitative interviews where they received much greater support than earlier models. Renovators were particularly supportive of budget and specification tools, while tradespeople valued variation management (the ability to track and variations to the original contract) and website provision. The *Build4Life* team began work on a minimum viable product (MVP) online platform. During this process, mock-ups of various functions (i.e. budgeting, variation management, product specification) were workshopped and then tested with prospective users. As part of the lean start-up approach, any function that received universal support from a small group of testers ($n = 5–10$) was retained and any function that was not liked or received qualified support was redesigned until consensus support was achieved.

When the MVP was universally supported in wireframe the final code was developed. At the time of writing the *Build4Life* platform is being tested prior to its first commercial deployment scheduled for early 2019. It comprises a specification planner, budget tool, floorplan tool, payment and escrow services, automated sustainability 'nudges' and access to a facilitator and will shortly add scrapbook functions to display finishes renovations, document management services, website templates for trades and review.

Conclusions

One of the main challenges for the promotion of sustainable homes in relation to media and communications is cutting through the abundant but fragmented information available online to identify quality information and advice that is *relevant* and *practical* to specific local circumstances. The establishment and maintenance of trust among online communities, as the vast literature suggests, is necessary for both social and commercial exchanges (Wu, Chen & Chung 2010). As our two case studies have demonstrated, trust comes in different guises and can be made meaningful and actively fostered through different organisational structures and means.

Whirlpool is a well-established online forum created and managed by members of the community under well-defined user rules and without a pre-conceived or pro-environmental agenda—although the forum has been found popular for sharing accurate advice on many aspects related to sustainable home renovations and energy-efficient products and methods more broadly. It is built around collective knowledge sharing, the system of moderation and transparency mechanisms. Its popularity derives from and is sustained by the value and protection of the independence of opinion and recommendation—hence the explicit rules about company representatives participating in the forums.

Whirlpool founder, Simon Wright, described some key messages he has learnt about managing an online forum. These lessons include: (1) develop the network with clear rules to promote and encourage transparency, (2) create a sense of community, (3) don't answer all the questions posted and (4) don't censor valid opinions about a business's product (Gone 2009). The community forum is created by establishing and communicating the expectations and moderating the discussions based on a system where the users determine the members who are helpful and rate them and their responses accordingly. This networked system of 'accreditation' (or credibility) serves as a visible proxy for trust-building for informal collective expertise at the heart of *Whirlpool*. In order to create a sense of community, the forum organisers consolidate similar topics into common threads to avoid isolating discussions and allowing the forum to feel empty (Gone 2009). The representatives and moderators are community members tasked with running the forum transparently with the aim of avoiding answering every question and instead seek to create the space for the other community members to respond to questions posted (Gone 2009; Podkalicka et al. 2016). Although the community moderators manage the forum, they do not censor the discussions and opinions even negative comments or experiences about a product or technology unless they are considered abusive or personal (Gone 2009). In an online environment, these mechanisms of moderation and safeguarding are paramount for establishing trust in the sense of security for users to participate and share information in an online forum. A safe place of exchange is particularly critical in the context of home renovations given the personal (and emotional) nature of homemaking, and because home renovators can be unwilling to share some renovation details (e.g. financial) even with their friends and family (Hulse et al. 2015; Podkalicka 2018).

The Build4Life platform is in the early stages of development and, unlike *Whirlpool*, is a commercial venture. While *Whirlpool* enables discussions on many different topics for a broad audience with some forums devoted to various aspects of renovation and energy efficiency, *Build4Life* has been developed with the explicit purpose of offering quality advice for home renovators and facilitating trades-renovators relations effectively and is targeted specifically to—in its final iteration—couples and particularly female renovators in their 30s–40s with children. Its use of the trusted facilitator to manage community interactions and a proposed team moderating behind the scenes while the model is in start-up mode bears resemblance to *Whirlpool*'s (and similar moderated online forums) social networking functions.

There are lessons to be learned from the academic research on online engagement in the arena of everyday consumption and environmental sustainability and *Whirlpool* regarding the quality of information and transparency, especially in relation to commercial interests by participating users. For example, a study of an online forum about ethical shopping published on the UK version of *The Guardian* online identified a breadth of discursive strategies and arguments posted on the forum—and importantly revealed 'the tendency of Web 2.0 toward self-moderation and self-regulation', despite the online discussion being initiated by the newspaper (Cooper et al. 2012, p. 116). An Australian study of online forums promoting sustainable living emphasised the genuine communication and community building as 'core to the sites' functioning' (Merrick 2012, p. 2).

A key value in using internet sites and moderated open discussion forums to communicate about sustainability in homes is the ability to share scientific evidence, public knowledge and individual experiences through social networks. While the *Build4Life*'s subscription model, grounded in iterative user feedback, is designed to provide incentives for participation, filling a recognised gap in the market, the questions of moderation and platform regulation loom large and remain to be tested in relation to the enabled interactions between facilitators, community, professionals and trades engaged. Going forward, important too is the attention to platform specificity, which means that different forms of digital and social media offer different forms of online participation (see also Joosse and Brydges 2018). The previous research has found renovators are time-poor (Hulse et al. 2015), and with the plurality of media available, the *Build4Life* operation needs to keep its target demographics' specific needs and (shifting) media practices continually in focus. Finally, academic work has emphasised the challenge and necessity of translation, in the sense of helping home renovators make online information relevant and suitable for their specific local needs and circumstances (Podkalicka & Anderson 2019; Podkalicka & Milne 2017). This finding is reflected in the studies of pro-environmental blogs. For example, Joosse & Brydges argue that

> Rather than merely mediating scientific knowledge and disseminating information, personal green blogs act as key intermediaries by brokering green norms, tastes, and identities, *translating* the complex concept of sustainability at the "*street level*" into ideas and hands-on advice on desirable sustainability practices. (2018, p. 697—emphasis added)

The *Build4Life* project represents an innovative approach to government policy that has involved applying the insights from social sciences, media studies and the application of a lean start-up methodology to create a viable self-sufficient business entity aimed at guiding people to consider sustainable housing options. Ultimately however, it will take time to determine the effectiveness of the *Build4Life* platform in the complex multi-actor space of home renovation—and undoubtedly there will be more lessons learnt along the way.

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26

Engaging Local Communities

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Introduction

While it is imperative to move to a zero carbon Australia as quickly as possible, and it is becoming more technologically and economically feasible to do so, this transition is happening much too slowly and sporadically across businesses, institutions, and the general community.

There are many possible reasons for this. Change can run up against established ways of thinking and acting. Despite general community concern about climate change, the need to reduce carbon competes

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for attention with many other demands in life that may seem more urgent, serious or obvious. Change may be difficult to implement, in terms of marshalling the right information, finance, people, products, and approvals, and meeting the needs and preferences of all involved. Those involved may be unaware of the full range of carbon reduction 'co-benefits' such as lower costs, better health and comfort, and social engagement. As well, change may mean doing things differently to our peers, which may make us uncomfortable. Change may run up against particular interests and worldviews, and the change process may require ongoing encouragement and support over the time it takes to get results.

Nevertheless, these challenges can be addressed through behavioural change interventions, carefully designed for particular settings, that provide a structure for change, relevant information, professional and peer support, and incentives that reward change (such interventions to address these issues are the subject of a large body of literature; see, for example, Arup & Naked Communications 2010; Manning 2009). This chapter describes three projects that have done just this and, as a result, have delivered significant changes in their particular settings. These three projects focused on reducing carbon emissions in, respectively, regional tourist businesses, schools, and inner urban neighbourhoods, though the first two have now broadened beyond their original focus. The projects have operated quite differently because their settings have been different, and this has been a key to their success.

Decarbonising Tourism and Local Communities

Low Carbon Living Blue Mountains was developed in 2013 by Blue Mountains World Heritage Institute (BMWHI) and supported by the Cooperative Research Centre (CRC) for Low Carbon Living (LCL).

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It began as a 'living laboratory' to test a double incentive strategy for reducing carbon in the tourism sector and local community in the Blue Mountains of New South Wales (NSW).

The original partners included NSW National Parks & Wildlife Service (NPWS), Blue Mountains City Council (BMCC), and the Universities of NSW, Melbourne and Curtin.

The program's research team comprised Assoc Prof John Merson (BMWHI/UNSW), Dr. Alex Baumber (UNSW), Annabel Murray (BMWHI) and auditors Nick Moodie (BMCC), Cameron Little, Sonya Sinclair, and later Chris Lochart-Smith. The Blue Mountains Council Business Waste Reduction team helped with auditing by sharing skills and resources.

By late 2014, twenty-eight tourism businesses had been recruited for a pilot program. They were provided with a free carbon audit, based on their energy, waste and water use, plus a report on how to increase efficiency in these areas to reduce carbon and save money.

The first year's audit data in June 2015 revealed an average carbon reduction of 14% for that year. While these savings were from a limited set of pilot firms and focusing only on 'low hanging fruit', it certainly showed the potential for cost-effective carbon action.

By 2016 a program website was in place, featuring bronze, silver and gold ratings for participating firms based on the first year's carbon reduction, so that visitors and residents could use this rating to choose low carbon businesses and services (see Fig. 26.1). Consumers of services were encouraged to recognise that they could reduce their own carbon by purchasing services from businesses attempting to reduce theirs, and the promotion of low carbon tourism gave businesses added incentive to continue reducing carbon, achieve higher ratings and attract more customers.

A monthly newsletter for program members and the wider community was commenced, with information on carbon reduction in participating businesses and how it was achieved (also available in blog form at https://lowcarbonliving-bluemountains.com.au).

In April 2016, 500 Blue Mountains visitors and residents where surveyed on their attitudes to lower carbon tourism, and both groups' responses were surprisingly positive (Fig. 26.2).

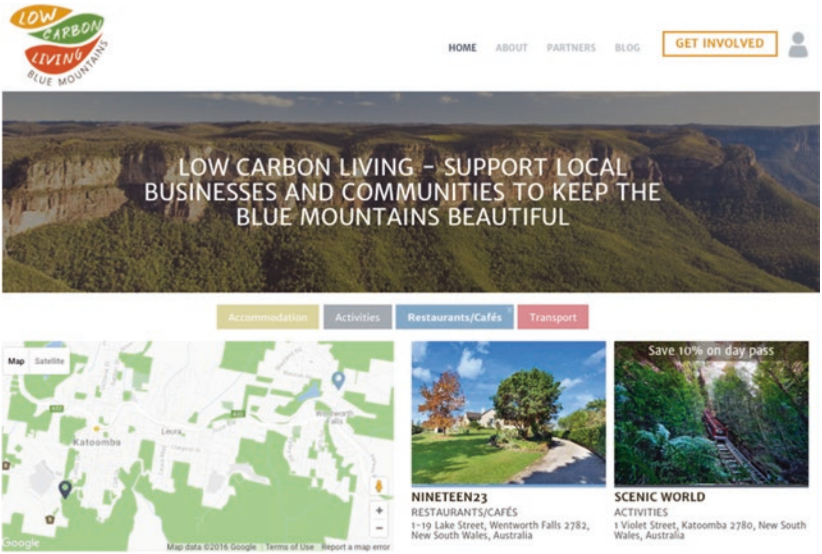

Fig. 26.1 Program website 2017

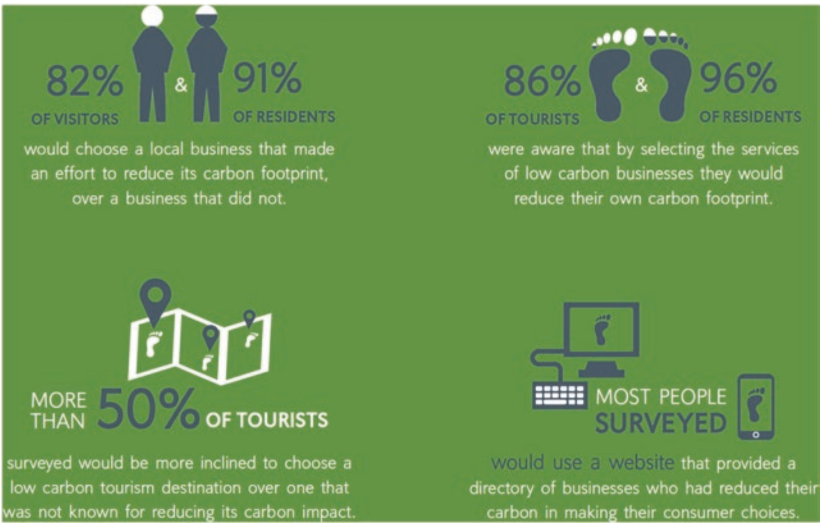

Fig. 26.2 Responses from Blue Mountains residents and visitors to LCL 2016 survey

The double incentive—reduced costs for businesses and low carbon options for consumers—seemed to be working. But before moving from a 'living lab' to a self-funded social enterprise, a second survey was needed. Pilot businesses were asked if they were prepared to pay an annual membership fee (based on business size) to be part of an ongoing program, and to further reduce their carbon, and 95% said they were. Thus, the Low Carbon Living-Blue Mountains program was launched in May 2016.

New businesses were recruited, and by May 2017 the number had doubled to over 60, with membership fees able to fully support the project's ongoing growth and operation. Late 2017 saw over 80 members, and a membership shift beyond tourism to schools, tertiary education, retailers, and community organisations. One gold-rated Blue Mountains accommodation provider reported that 34% of guests had come via the website.

A longer term objective of this program was its take-up in other regions, and ultimately the establishment of a national network. By 2017 interest had spread to other regions with strong tourism sectors, beginning with the NSW Southern Highlands. However, CRC funding had given the Blue Mountains pilot two years to build membership numbers to a financially and operationally feasible size, and so other programs would most likely also need such initial funding.

Fortunately, the CRC and Wingecarribee Shire Council provided equal funding to start the Southern Highlands program, and a franchise model was developed to protect program integrity and IP, and to identify program elements best managed by the BMWHI and those best managed locally.

Organisations supporting the Southern Highlands program included Wingecarribee Shire Council, the regional tourism association, the Chamber of Commerce, and most importantly a local NGO, 'Climate Action Now, Wingecarribee' (CAN Win), with additional financial support from the local BDCU Bank. These organisations worked with the Blue Mountains team to establish Low Carbon Living—Southern Highlands, launched in August 2018.

In March 2018, a mini Low Carbon expo saw the announcement of a planned national LCL program, with representatives from the Blue Mountains and Southern Highlands, the CRC-LCL and Ecotourism Australia.

Ecotourism Australia was seeking to develop an Ecotourism certification program for regional tourism destinations, with a carbon reduction component, and over twenty regions were interested. The BMWHI's LCL program offered a way to achieve this, and so the two organisations signed an MOU, and two new destinations were identified for trials—Port Douglas in Queensland and the Byron/Tweed region in NSW.

The CRC provided extra finance for this next stage, which included developing a national organisational structure with a new website 'Low Carbon Living – Australia' (www.lclaustralia.org). New and more efficient tools were also needed. In both the Blue Mountains and Southern Highlands well-trained carbon auditors were available to collect data relatively quickly, but in more remote regions this was not the case.

So an online audit system was sought. Ecologic, a start-up emerging out of University of Technology Sydney's Energy Research Lab, had developed an excellent system for household energy, measuring usage and advising how to reduce it.

BMWHI contracted Ecologic to develop a similar self-assessment tool for carbon reduction based on the LCL programs, with auditing protocols for energy, waste, and water use.

This 'LCL-Carbon Calculator' was completed by August 2018 (Fig. 26.3), allowing participating businesses to gain simple 'snap shots' of their carbon footprint and guidance for first stage carbon reductions.

The tool also accommodated the longer term objective of including householders in the program, thus building wider community support for it. This was critical, because it made it more likely that residents participating in the program would also use the website to select local services, thus increasing incentives for businesses to further reduce carbon to better compete for customers.

While the growth and diversification in this program have surpassed expectations, a critical question is just how much carbon this program might reduce long term. The tourism industry produces around 5% of carbon emissions in Australia. A 2015 project report estimated that carbon reduction in the national tourism industry, based on projections from the Blue Mountains program, could include around 1800

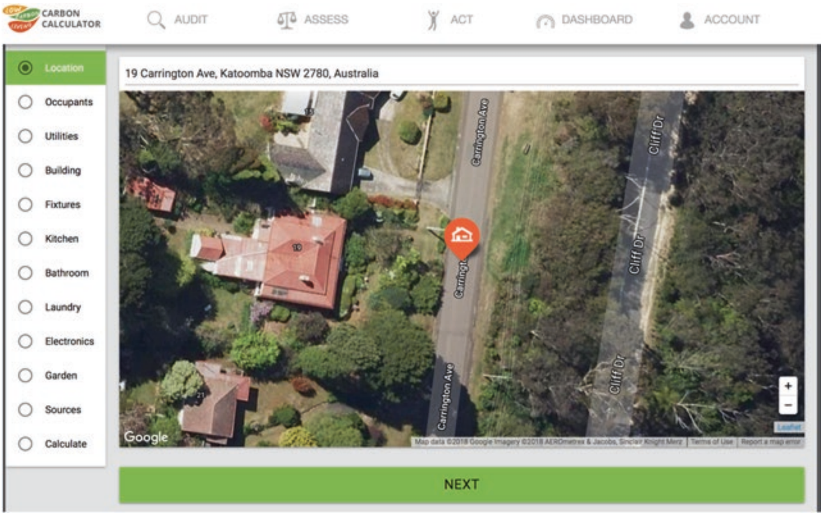

Fig. 26.3 Front page of the LCL Carbon Calculator version 1.0

participants by 2027 and avoid about 230,000 tonnes of CO_2-e per year beyond business-as-usual reductions.

This is of course indicative only, but if we add in households, the program's uptake could significantly help reduce Australia's carbon footprint.

So the program's evolution continues. Land-based transport is now included. Carbon offsets, initially excluded in order to drive carbon reductions though behavioural and technical change, are now included, partially to cover situations were carbon reduction may not be practically possible for businesses, particularly in relation to transport. Given these offsets, the Blue Mountains Bus Company is the first carbon neutral bus company in the country.

It is planned that Port Douglas and Byron regions will be supported to adopt the program in late 2018 and, with involvement from partners like Ecotourism Australia and sponsorship from Scenic World, Bendigo Bank and Powershop, the goal of spreading this program across Australia is becoming a reality.

Decarbonising Schools and Their Communities

There are abundant opportunities to reduce carbon emissions within the built environment, with school buildings being among the most rapidly ageing and increasingly inefficient building stock (Rauland et al. 2014). This issue is compounded by increased utility consumption, particularly energy, due to greater reliance on new classroom technologies and the expectation that schools will be temperature controlled. Nevertheless, school buildings have been identified as offering some of the most cost-effective carbon abatement opportunities in the economy (ASBEC 2018).

Reducing school buildings' emissions can not only contribute significantly to the nation's carbon reduction efforts; it can also reduce carbon far beyond the school walls. Not only can schools help to educate and upskill the next generation to be more resource efficient, but they can also facilitate intergenerational and societal change as children take knowledge home and educate their parents and families.

This case study examines the results from a two-year Low Carbon Schools pilot program in Perth, Western Australia (WA), and highlights opportunities to scale up the impact of this through its application in schools and their communities around the nation.

In 2012, a Fremantle high school become the first certified Carbon Neutral School in Australia. The school saved thousands of dollars on their utility bills and hundreds of tonnes of carbon emissions, while engaging and upskilling the students, staff and local community around resource efficiency. This inspired the development of the Low Carbon Schools Pilot Program (LCSPP), launched in Perth in 2016. The program was delivered by a small consultancy, SimplyCarbon, in collaboration with Curtin University and supported by the CRC for Low Carbon Living, with Dr. Vanessa Rauland, Ph.D. student Portia Odell and Kathy Anketell as the project personnel. The LCSPP aimed to create a replicable process to enable and empower more schools to quantify and reduce their carbon emissions.

Fifteen primary and secondary schools participated in the two-year pilot program, which included five workshops and 15 monthly meetups hosted by participating schools, where participants shared their progress, feedback and ideas. The results presented here are from the 13 schools that agreed to participate in the research.

A total of 266 tonnes CO_2-e was saved across the 13 schools between 2015 and 2017 from carbon reduction activities. As nearly 80% of the schools increased their student numbers over the two-year period, results were also analysed on a per-student basis. This is important from a funding perspective, as many Australian states, including WA, use funding models with budgets based on the number of students enrolled (Rauland et al. 2014). The average emissions per student across all 13 schools fell from 0.37 tonnes of CO_2-e to 0.29 tonnes, a drop of 20%. Of the 13 schools, 70% reduced utility costs by over $30 per student representing a 15% reduction in costs for these schools. Across all schools, an average of $16 per student was saved. Figure 26.4 shows the percentage change in carbon emissions and utility costs per student per school. A positive percentage indicates an increase in cost or emissions, and a negative percentage indicates a decrease.

Most emissions reductions came from reduced electricity use, followed by gas and then water reductions. Utility consumption and costs as well as the associated carbon emissions were calculated and tracked using an Excel spreadsheet, where each school entered their consumption and cost data for electricity, gas and water for 2015 (baseline year), 2016 and 2017. Each school also created an action plan using Google Docs, which the program delivery team could view to assist with accountability.

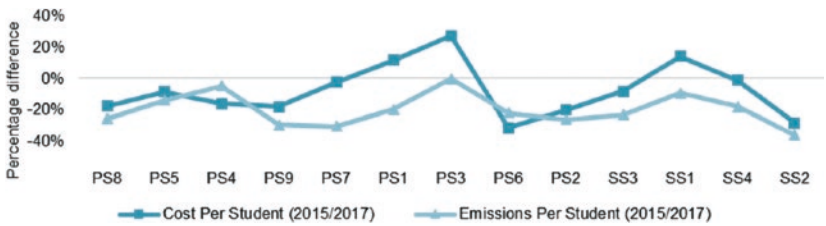

Fig. 26.4 Percentage change in utility cost per student and percentage change in emissions per student between the baseline year (2015) and 2017 for each school. Schools are ordered left to right from the least to most students

A total of 636 actions were identified in the action plans of 12 schools (one school did not complete an action plan, although it did reduce consumption). The largest number of initiatives (36%) targeted energy consumption, while 26% targeted waste and 19% targeted water. While the LCSPP only collected consumption data for electricity, gas and water, schools also identified many other initiatives. Actions responsible for major carbon reductions included optimising a building management system so that appliances and systems were turned off outside of school hours, switching off electronics over school holiday periods, counting the number of school refrigerators and removing unnecessary ones, and identifying hidden water leaks. The schools also implemented many smaller scale actions, such as signs to turn off lights and unplugging refrigerated water fountains. Most actions identified were low or no cost (60%) and almost 50% involved students in the process.

Students of all ages felt empowered to act on their school's carbon reduction goal. Over 70% of schools surveyed also believed students can participate in more aspects of carbon reduction, which highlights the benefits and potential of student and teacher involvement in carbon reduction, rather than leaving it to Education Departments or consultants.

Participants noted the sense of community created through the program's monthly meetups, and the importance of this in maintaining motivation and inspiration. There was significant collaboration between the schools, and a feeling that 'we're in this together'. One high school also mentioned how the LCSPP acted as an umbrella program, and united all the school's existing sustainability programs, giving them a goal to work towards together. A passionate parent at one school initiated a tree planting program to offset the baseline carbon emissions of all schools participating in the program (3800 tCO_2-e). Hundreds of students from 13 schools planted over 50,000 trees in 2017, more than offsetting the baseline emissions.

All schools in the program were responsible for paying their own utility bills, which created a direct incentive to reduce these costs, which could then be used in other areas. If, as sometimes happens, utility costs are paid centrally by education departments, this incentive is lost.

Investigating bill data also enabled schools to better understand consumption patterns and anomalies, particularly by comparing themselves with similar schools, which most of the participating schools believed was a highly useful exercise. Having a standard and consistent approach to measuring resource consumption helped with comparability.

A growing interest in the program from schools around the country has seen the development of an online version of the program launched in 2018. This next version, The ClimateClever Initiative, distilled the most effective components of the two-year pilot to create a highly intelligent, engaging, data-driven App. Based on feedback from the pilot, this App is designed to be predominantly student-led, enabling students to easily measure, track and compare their school's carbon footprint and costs online, conduct online audits of their buildings and identify inefficiencies, and create and manage personalised, evidence-based action plans. Waste is also included in the 2018 program, creating a holistic and comprehensive carbon reduction tool. To further increase the potential for intergenerational change, a version of the ClimateClever App for homes will be developed in 2019. This will allow schools, for the first time, to easily and accurately measure the impact they have on their communities in reducing emissions and preparing for a low carbon future.

Overall, the LCSPP demonstrated that there are abundant opportunities for schools to reduce resource consumption and carbon emissions and save money, largely for little or no cost, highlighting the importance of quantifying sustainability and adopting a strategic approach to implementation. Given that schools act as a focal point in every community, there is significant potential not only to reduce emissions from the school buildings themselves, but to empower schools to build low carbon communities.

Decarbonising Through Neighbourhood Groups

The aim of the 'Livewell Yarra' project was to trial the effectiveness of engaging average Australians in reducing their carbon emissions by assisting them to come together in small carbon reduction groups whose members met regularly to support each other in making these reductions. Project participants also had access to practical information on how to do this, through a website, workshops and emailed information.

The project took place in the City of Yarra in inner Melbourne in 2014 and 2015. It was supported by Yarra Council and the Yarra Energy Foundation, who provided advice, publicity and free venues.

There have been other types of groups in Australia that have encouraged personal carbon reduction, often among other objectives, such as 'Transition Towns', 'Sustainability Streets' and 'Living Smarties' groups, but this project focused specifically on carbon reduction and offered a model of group interaction that could be set up relatively easily and operate independently of any course or program.

In early 2014, the project leader, Dr. Robert Salter, recruited local community members to form a voluntary committee to help to run the project, as well as a Ph.D. student researcher, Darren Sharp, later that year. Throughout 2014 and early 2015 the project leader, the Ph.D. student and the committee prepared for the project's commencement, and this included the creation of a website in late 2014, which, among other things, contained 'How to Guides' advising on carbon reduction in areas such as energy use, home insulation, transport and consumption (see www.livewell.net.au).

The project was launched at a public meeting at Fitzroy Town Hall in March 2015. Those interested were then formed into 'Decarb Groups', groups of five to twelve people who met monthly to discuss how they could reduce their carbon emissions, to report on their progress and to support each other. There were six groups initially (plus the committee, which itself functioned as a Decarb Group). The original plan was that people would join groups close to where they lived, but instead they tended to join groups that met at a time they were free. One of these initial groups, and three more that started later, were formed by particular individuals, all women, who got together people in their neighbourhoods. So there were ten Decarb Groups in all.

As mentioned, the committee was also a Decarb Group, which meant that from its inception, about half the time in each meeting was taken up with members telling the group what they had each done since the last meeting to reduce their emissions, or what they planned to do, and this usually led to discussion about how best to go about these actions, the pros and cons of different approaches, where to source products and so on. It proved to be an effective and enjoyable process of social learning in which to share information, encourage each other, model actions that others might follow, and make informal commitments to take certain actions.

Most groups' early meetings were facilitated by a committee member, but aside from this groups functioned quite autonomously. They were encouraged to take the approach, described above, of having each participant discuss what they were doing or planned to do to reduce emissions, and other activities were also suggested, such as having guest speakers or discussing particular topics. The researchers were only present at a minority of their meetings, and participants were not asked to report on what occurred in the meetings, but information about their perceptions of the project (of which these meetings made up a big part) was obtained through interviews with selected participants, described below.

Groups met in premises of their choice, usually participants' homes, and meetings were accompanied by refreshments and sometimes meals.

A range of workshops were arranged over the course of 2015, including two orientation workshops, a series of 'First Thursday' workshops, two talks, and workshops on asset mapping and co-design by Ph.D. student Darren Sharp. The First Thursday workshops covered topics of interest to participants, namely reducing home energy use, waste reduction, how to discuss climate change with peers, the sharing economy, and divesting from high carbon investments. Almost all these workshops and talks were attended by a broader group of people that just those in the Decarb Groups. A periodic newsletter and a further list of tips for reducing carbon were circulated to participants and others via email.

It was not intended that the groups would necessarily be ongoing, and so they continued until group members decided to disband them. For some groups this was towards the end of 2015, while others continued into 2016 or 2017, and at the time of writing in 2018 one is still going. Groups tended to wind up for several reasons: when the momentum of action slowed because members had made the changes they were prepared to make, when (for various reasons) some members left and the group became too small to be viable, and because of a perceived lack of direction or structure.

Based on 'Most Significant Change' interviews (Dart & Davies 2003) conducted by Darren Sharp with a selection of participants, some common themes emerging from participant responses were as follows:

- The great majority valued the social support they received in the Decarb Groups and workshops.
- In most cases, participants reported that this social support spurred them on to take actions they would, or might, not have otherwise taken. Even though most who got involved were quite environmentally aware and had already taken steps to reduce their carbon emissions, participation helped them to take further action.
- Most also greatly valued the information they obtained in the workshops.
- A number commented on how they enjoyed the social aspect of meeting together.
- Some felt that insufficient structure or direction in their group made it less effective.

Comments made by smaller numbers included:

- Appreciation of the emphasis on maintaining quality of life while reducing carbon
- Appreciation of the written material provided, on the website and through mailouts
- Concern that the project was mainly 'preaching to the converted', and not reaching others
- The view that the project leader might have devolved more responsibilities to others
- A desire to go beyond personal carbon reduction to advocacy for policy change (which did happen to some extent).

In conclusion, a moderate level of success was achieved in this project. It revealed that there is potential for increased action to reduce personal carbon emissions when groups of people get together to support one another in this process, even when they are already quite aware of the need to reduce carbon and have already taken some action. These groups will usually have a limited lifespan, but this does not imply a lack of effectiveness (just as people take courses for a limited period but still generally benefit from them). A second important ingredient of success in this project was having sources of information outside the groups, and the workshops were the most popular source, with the website and other distributed information also proving useful.

Conclusion

There are many challenges in reducing carbon emissions, but there are also many ways in which these challenges can be addressed, and this chapter has described three of these. The projects all provided a structure that encouraged and facilitated action to reduce carbon. Within this structure there was leadership, the provision of necessary information, the generation of expectations about participant action, and help where necessary, and these things were strengthened through interaction among program participants.

Moreover, each program created, or made participants aware of, specific incentives to reduce carbon. In the first program, carbon reductions led to lower business costs, and helped in promoting low carbon credentials that generated further business. In the second program, carbon reductions lowered school utility costs, and the project provided students with real-world sustainability projects to learn from. In the third program, the project provided enjoyable social contact and a focus on how reducing carbon can enhance wellbeing.

Thus, in order to move to a zero carbon world as quickly as possible, we need—alongside the right technologies at affordable prices—carefully designed programs to help specific sectors of society make the necessary changes, given the diversity of situations they find themselves in and the range of challenges they face.

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Part V

A Future Perspective

27

Visions, Scenarios and Pathways for Rapid Decarbonisation of Australian Cities by 2040

Chris Ryan, Paul Twomey, Idil Gaziulusoy, Stephen McGrail, Seona Candy, Kirsten Larsen, Michael Trudgeon and Philippa Chandler

Introduction

Over recent decades it has become clear that any successful move towards decarbonisation of the global economy (and any enduring shift towards low-carbon living) will require significant *transformation of existing cities* (Barber 2017; CRISP 2014; Eames et al. 2017;

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Frantzeskaki et al. 2017; Webb et al. 2017). A new focus on cities in global action on climate change reflects their *role*:

- in *economic* development (from production, innovation and services[1];
- as *engines* of greenhouse gas *emissions* (both from consumption and production)[2];
- as potent *agents of change* (an emerging political force), reflecting rapid urbanisation, where over 68% of global population is projected to live in cities by 2050 (UN DESA 2018);
- as shapers of *cultural allegiance* and *belonging* (with successful cities generating a potent sense of social identity);
- as generators of *creativity and innovation* (related to the density and diversity of social interaction).

Cities are also increasingly vulnerable to climate change impacts, both chronic (progressive shifts in weather patterns) and acute (extreme weather events).

Low-Carbon transformation will be hugely challenging for Australian, fossil-fuel-dependent, cities. The co-benefits of such action could be significant, creating opportunities to simultaneously improve

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the quality of life, social creativity and innovation, livelihoods and opportunities for all, as well as ecological diversity and vitality (Philip, Taylor & Thompson 2015).

The Visions and Pathways 2040 (VP2040) project is an exploration and investigation of possible and plausible pathways for the transformation for the southern capital cities of Australia, aiming for an 80% reduction of their 2013 greenhouse gas contributions by 2040.[3] The four-year project was designed as an interlinked research and engagement process to develop, analyse and communicate visions, scenarios and pathways for such transformation.[4] VP2040 involved three universities (University of Melbourne, University of NSW and Swinburne University of Technology) and a range of government and industry partners including the cities of Sydney, Melbourne, Adelaide and Perth. Its research objectives included:

- tracking international research and coordinating with related international projects;
- identifying emerging technological and social innovations that could disrupt current trajectories of development;
- developing and refining a set of visions and scenarios for low-carbon resilient cities;
- communicating and translating those scenarios to stimulate engagement of CRC partners and the general public; and
- back-casting from those future visions to develop potential pathways for their realisation.

Throughout the four years, the research team worked alongside a panel of around 250 experts—professionals from the built-environment, planning and design sectors, university researchers, representatives of all tiers of government, social entrepreneurs and relevant NGOs. Those experts volunteered their time. Panel members later acted as a sounding board for the research-led process of generating initial 'proto' scenarios, which attempted to codify divergent trajectories of transformation for the cities.[5]

A set of narratives of four scenarios and possible pathways were produced, again linking research with expert panel feedback. Finally, 'carbon modelling' was undertaken using the Australian Stocks and Flows Framework.

The VP2040 Project: Visualisation, Scenarios and the Wicked Challenge of Complex City-Transformation

As global action on climate change has progressed, researchers, governments and citizen groups have increasingly focused on the importance of *low-carbon transitions* for cities, adopting terminology from the growing field of analysis of disruptive shifts in the history of socio-technical change (Geels & Schot 2010; Twomey & Gaziulusoy 2014). The VP2040 project adopted the term *transformation* rather than *transition,* partly to reflect its etymology as 'changing shape', but also to emphasise the necessary scale of change (beyond incremental change) as well as the principal objective of the project: to *investigate the potential form of radically decarbonised urban futures*—the future to which we might transition.[6] Cities are complex adaptive systems; as they grow, specific technical, social, economic and cultural systems are entangled with their physical fabric, shaping their urban morphology (Ryan 2013; Twomey & Ryan 2013). 'Carbon dis-entanglement'[7] becomes a truly transformational challenge for a city; it requires a significant shift in its 'metabolism' (Bai 2016), a realignment of all its systems of provision, its established and interconnected infrastructures of life that make the city productive and habitable.

VP2040 focused on eight systems of provision: energy, water, food, transport, buildings and open-space, waste disposal, information, products and services. For every city those systems are developed in response to different resource contexts (regional eco-systems, arable land, seasonal weather, rainfall, rivers and so on), different spatial conditions, different economic histories and utilising different technologies. Systems of provision become deeply interconnected in different ways, around different physical morphologies. Because of that interconnection, transforming the city to achieve an 80% reduction in emissions cannot be approached through a reductive process taking each of the systems of provisions in turn; they are not independent variables. A living city is even more complex; its metabolism is not merely a function of its ecological-technological-physical systems, it reflects human agency. Architectural and urban history demonstrates how profoundly economic systems, cultures, rituals, practices, aspirations, lifestyles, power structures and so on, are intermingled with the physical form of our constructed world (Harvey 2012; Jacobs 1961; Mumford 1961; Sorkin 2011).

Transforming these intermingled *technical-physical-ecological-social-cultural systems* represents an archetypically wicked problem, where an effort to solve one aspect of the problem may reveal or create others. For this reason the approach taken in this project emphasised transdisciplinary research (Gaziulusoy et al. 2016), the co-design and testing of alternative system configurations, the visualisation of transformed system conditions and patterns of urban living and a multiple scenario approach. The scenario approach reflects what Sondeijker (2009) defined as the 'third generation' of scenario thinking, moving beyond the question of 'what will we do if something happens?' to 'what do we actually want the future to look like?' This idea of the scenario, as producing ideas of the future that we collectively want, has become important in participatory futures design (e.g. Quist & Vergragt 2000, 2006; Ryan 2013; Vergragt & Quist 2011).[8] The lead institution for VP2040, the Victorian Eco-Innovation Lab (VEIL) at the University of Melbourne has more than a decade of action-research projects that involve processes of co-envisaging future urban systems and modelling those changes to evaluate their potential for decreasing carbon emissions and increasing resilience.[9]

Methodology and Process

Figure 27.1 depicts the sequencing of research and engagement tasks throughout the project.[10] To focus the research and workshop processes, a simplified schema of a city was developed with a focus on elements involved in transformation (see Fig. 27.2). With this schema, VP2040

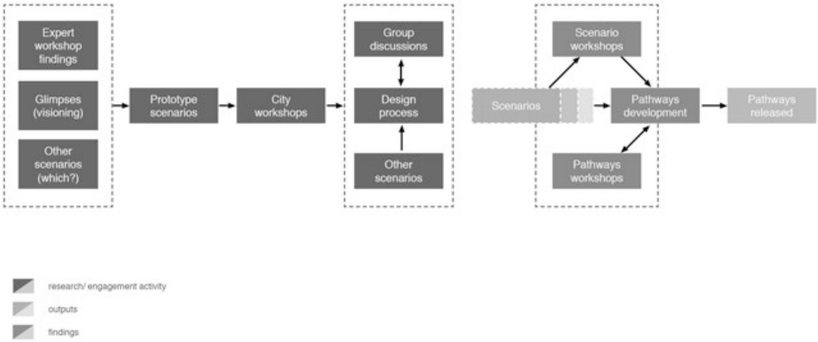

Fig. 27.1 The VP2040 process

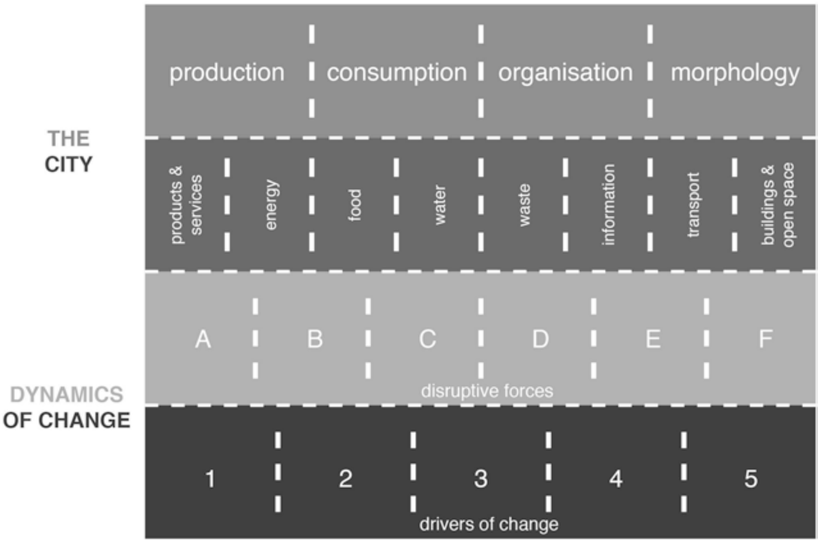

Fig. 27.2 A simplified schema for understanding the complexities of transformation for the city

research began with analysing the *dynamics of change*; both the 'drivers of change' as well as 'disruptive forces'. In this work, and the later scenario generation process, the researchers were able to draw on related projects in the UK and Europe.[11] Representatives from those overseas projects formed an international scientific committee for the project.[12]

The knowledge base for the 'dynamics of change' was regularly reviewed by the panel of experts (as part of their workshop process).[13] This data on the dynamics of change covered disruptive shifts in technology, socio-cultural dynamics (including values and behaviour), organisational developments (from governance to new business models) and external forces (essentially environmental and physical limits).

A similar process of research and expert feedback was used in the mapping of change in the city, modelled as the eight systems of provision, each considered in terms of their role in production, consumption, organisation and physical morphology ('the city' component of Fig. 27.2). In a series of workshops, members of the expert panel considered each of the systems of provision using the 'layered system mapping' methodology of VEIL (Ryan 2013; Ryan, Gaziulusoy, et al. 2016). They were asked to speculate on possible changes to production and consumption that could lead to lower carbon emissions. The output of this process became briefs for a series of *design charrettes*.[14] The charrettes visualised future glimpses and, later, early visualised scenarios; these can be considered as 'dialogic objects' (Manzini 2013; Ryan, Gaziulusoy, et al. 2016) through which the possibility and desirability of projected future states (and their potential contribution to decarbonisation) were debated in the expert workshops. When any dynamic appeared particularly critical or controversial, additional topic-focused expert round-tables were convened as a sounding board for the research team (Gaziulusoy & Ryan 2017; Gaziulusoy et al. 2016).[15]

Scenario Generation

The scenario generation processes used by the research team generated early 'proto' scenarios. In research conducted in 2014–2015, the project considered a range of possible, challenging, divergent and plausible futures. This work involved combining multiple elements[16] into a coherent description of plausible futures of sustainable and resilient Australian cities and drew on the early visualised futures glimpses as well as research on trends (see Ryan, Twomey et al. 2016). All this was informed by other sustainability-related scenarios work internationally.[17]

The proto-scenarios were refined in workshops with panel members in Adelaide, Perth and Sydney, extending to considerations of the impact of different scenarios on the urban morphologies of Australian cities (low and high density, residential and mixed use). The potential uptake of social and technological innovations in each scenario was considered according to the core scenario 'logic' (Ryan, Twomey et al. 2016, Appendix 1), with the research team drawing on the workshop discussions when refining the scenarios, in particular when considering major sectors like energy, transport, buildings, food, information, water and waste. Again, a design charrette developed scenario visualisations. Finally, an additional set of experts were interviewed in order to better understand aspects of the scenarios (Ryan, Twomey et al. 2016).

Scenario Pathways

As workshops and research progressed, the scenario refinement extended to deliberations on pathways—plausible and internally consistent narratives of how each scenario of a 2040 future could have unfolded from baseline conditions in 2013. A refined version of these pathway narratives was published in 2017 (Candy et al. 2017, p. 19).

Modelling of Future States

The final stage of the project concerned the measurement of the scenario changes through quantitative modelling. In low-carbon transitions work, emissions accounting is often used to determine baseline emissions and their distribution across goods and services to identify key intervention points for mitigation. To simulate emissions reductions between a baseline level in 2013 and four different end states in 2040, each scenario narrative and summary table was translated into a set of specific modelling assumptions ('settings') across six sectors (electricity/energy, transport, food, goods, water and waste) and 11 core variables (proportion of renewable energy generation, energy consumption, transport mode distribution, number of vehicles, need to travel, diet profile, consumption of processed foods, amount of food waste, consumption of goods, changes in urban water infrastructure).

Dynamic modelling methods are typically employed to simulate the effects of low-carbon initiatives implemented over time. The potential non-linearity and non-continuity of change can make quantitative modelling difficult, particularly in accommodating fundamental shifts in the structure and dynamics of systems. This challenge was faced in this project, as the first input–output modelling method used was limited to quantifying carbon emissions reductions from changes to demand and carbon intensities, governed by linear equations and with no interaction with other domains. This consumption-based environmentally extended multi-region input–output (MRIO) model was used initially—provided by the Integrated Carbon Metrics research programme within the CRC LCL (Teh et al. 2015). In addition to the indirect emissions calculated using MRIO analysis, the household direct emissions were also estimated on the basis of spending on energy derived from household survey data.

The limitations of the MRIO method for modelling low-carbon interventions, particularly due to the complex nature of cities and the systemic challenges implied by decarbonisation, became apparent. It was decided to change the modelling of the pathways utilising the Australian Stocks and Flows Framework (ASFF). The ASFF is a scenario modelling platform for integrated analysis of the physical economy of Australia (Turner et al. 2011). It is a process-based simulation model of all sectors of the Australian economy, tracking the dynamics of major capital and resource pools, and the flows associated with these stocks such as productive output, resource inputs, changes in capital and carbon emissions. Emissions calculated within the ASFF at a state or national level were attributed to cities based on methods developed for a previous project by VEIL (Turner et al. 2017). For VP2040, city consumption factors were calculated based on data from household expenditure surveys, similar to the MRIO method. The ASFF method proved more transparent, providing the ability to examine detailed mechanisms to reduce emissions in alternative scenarios, and to determine flow-on effects such as material implications or economic impacts.[18]

With the modelling from ASFF, there was the potential to iteratively refine each scenario (adjusting the settings) to ensure they deliver the projected 80% reductions by 2040. Per capita reductions in greenhouse gas emissions (CO2e) for each unrefined 2040 scenario (based on the 2013 emissions profile for Sydney) ranged from 66 to 70%. That modelling showed that achieving the additional 10–15% reductions would require substantial adjustment of many settings.

Due to resource constraints, iterative refinement of all four scenarios (see below) was not able to be attempted; instead the four futures were combined into two 'Action Pathways', that made it possible to address some questions of plausibility and desirability of the four scenarios. Most importantly they simplified the process of adjusting settings to approach the 80% carbon mitigation target.

Results

With its scenario approach, the most important contribution of VP2040 has been to demonstrate, for its city partners, that radical urban decarbonisation is possible, but that a performance target does not define the conditions of its realisation. This is particularly relevant as it runs counter to the often prevailing idea that the realisation of low-carbon futures is essentially a technical challenge, with the outcome more-or-less technically determined. VP2040's set of four scenarios describe urban/city futures that differ significantly in the way that energy, food, transport and built-form are provided for citizens; they also differ in the way that information is utilised and in the way that the city is governed. Most critically, the four futures differ significantly in *the nature of their social, cultural, political and economic life*. These four scenarios are schematically mapped in Fig. 27.3.

The Four Scenarios

The scenarios mapped in a two-axis space is shown in Fig. 27.4.

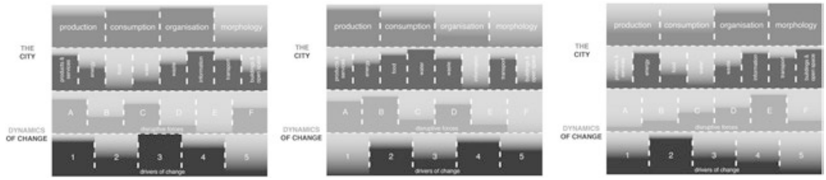

Fig. 27.3 A schematic representation of different scenario choices for the simplified city schemata (different combinations of the dynamics of change lead to different effects on the systems of provision and their production, consumption, organisation and morphological structure)

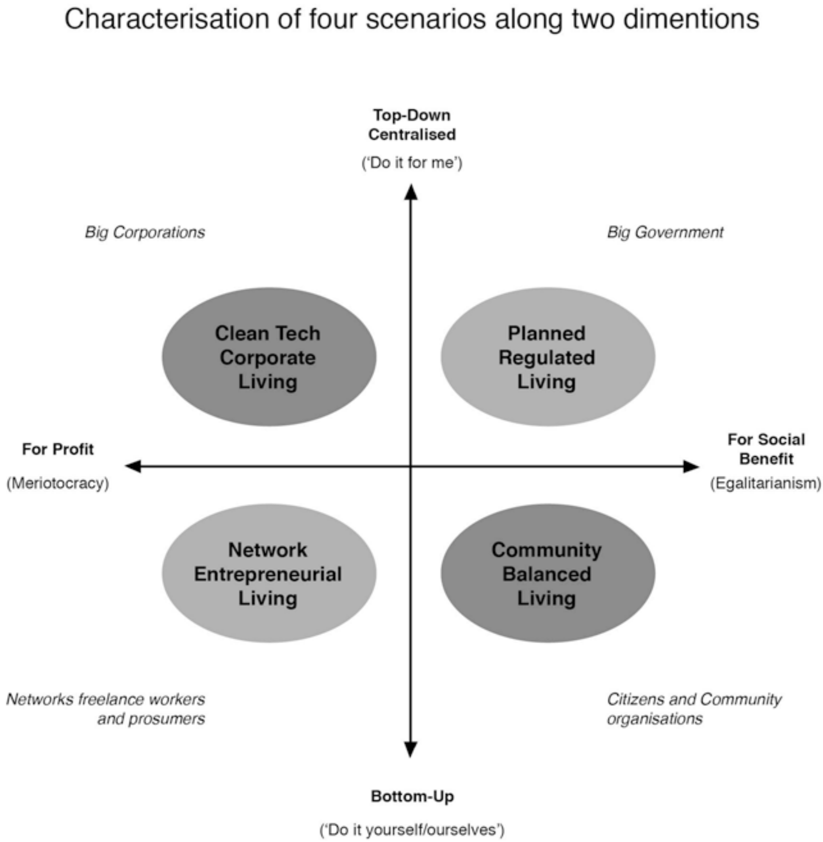

Fig. 27.4 The scenarios mapped against two axes—profit to social benefit and top–down to bottom–up

Clean-Tech, Corporate Living

This is a city of clean and efficient production, a model for the application of circular economy principles and clean-tech innovation. International agreements have redirected market competition towards innovation for triple bottom line success. Large, for-profit companies with the resources to invest in innovation are the primary actors in the economy. Significant decarbonisation has been achieved through a focus on changing production systems and product design and the adoption of low-carbon clean technologies, rather than limiting consumption. The private sector owns and manages most of the city infrastructure from energy supply to transport and building technologies, to food and water. Services and public space (even green spaces) are privately owned, deriving revenue from fees for access as well as public funding for ecosystem services delivered. Competing corporate services is a feature of life for citizens. Information technology has created a city that is smart and efficient; corporate investment in the 'internet of things' is significant with the sale of privately held data now an important contribution to corporate profits and overall GDP. Robots and automation have reduced labour costs in many areas of production and service provision, generating significant unemployment, increasing social inequality. A significant proportion of the population has very low income and (consequently) low consumption.

Planned Regulatory Living

This is a city of planned order where a democratic consensus has concluded that the challenges posed by a carbon and resource-constrained world are best addressed through public planning, public investment in green infrastructures and tighter regulations that limit behaviour and practices to an acceptable environmental norm. Rational and technocratic approaches guide all areas of development and the use of public assets and capital. Private sector activity is limited and regulated; taxation levels are high. There is great public trust that the balance between corporate profits and public needs is best managed by government.

Environmental and social ethics is accepted as a guide all decision making, for maximum societal benefits. Greenhouse emissions reduction has been achieved through: reduced per capita energy and material consumption; changes in social behaviour; public investment in renewable energy supplies, grid-connected storage, production of biofuels and hydrogen and improvement of building stock. Planning has delivered a 'twenty minute city', with comprehensive and integrated public transport systems, including bicycling, walking, driverless electric taxis and small community shuttles. Business premises are more dispersed; teleworking accounts for almost half of working hours. New behaviours and limitations on consumption align with up-to-date monitoring of environmental conditions. City information systems are ubiquitous and publicly owned; they provide feedback on consumption levels, for individuals and for communities.

Networked Entrepreneurial Living

This is a city where large corporations and government are less influential but where the economy has developed around nimble, self-organised entrepreneurial activity, particularly for the sharing and exploitation of excess capacities of various assets. It is a future characterised by a dynamically changing economy, experimentation and innovation and the development of networked platforms that are open source and open data. Many workers are freelancers. There has been a rapid growth in agile microbusinesses that produce innovative technologies, products and services to exploit renewable energy and to increase resource and material efficiencies. All new businesses are supported by informal, digitally connected networks. Individuals have also taken up such technologies to become 'prosumers' and actively engage with businesses in the design of products. In this new market context the value of information is rising rapidly compared to materials. Many material products are now manufactured within a distributed system involving open source design studios and an extensive network of local 3D printing fabrication workshops. While non-profit social entrepreneurialism is strong, small business is primarily profit oriented.

Community Balanced Living

This is a city of low consumption that promotes a socially and environmentally meaningful life, including shared wellbeing, high liveability and (face-to-face) socialising. There is still a market economy, however, there is a thriving and diverse set of alternative forms of enterprises that are not profit-oriented, including cooperatives, B-corps and other types of social enterprise. A high proportion of the population works only part-time in the mainstream economy, with time freed for other pursuits that range from creative activity to cooperative work contributing to building community resources. Communities generally have much greater responsibilities for the creation, improvement and maintenance of commons spaces or essential resources, including food production, renewable energy generation, rainwater collection, storage and distribution, the maintenance of built infrastructure, urban forestation, education and training, aged care and so on. Recycling and repair of goods is an important service for small businesses and cooperatives. A high proportion of new building and building refurbishment depends on the contribution of cooperative, community labour. Decarbonisation has resulted from lower consumption and reuse of materials.

Pathways, Action Scenarios and Modelling

The initial pathways for each of the above scenarios, depicting plausible and consistent narratives for the trajectories from 2013 to the four 2040 states, were developed for the 2016 project report (Ryan, Twomey et al. 2016) and later refined with a more detailed critique of their plausibility and desirability in the final phase of VP2040 (Candy et al. 2017). Two combined 'Action Scenarios' were developed that allowed some of the artificially exaggerated dimensions of the four scenarios to be relaxed. The exaggeration of trajectories of change had been necessary to define critical decision points as the paths unfolded.[19] The development of the two combined Action Pathways allowed for more coherent and multi-faceted activities and responses to drive climate mitigation; they were also more amenable to modelling and refinement (Candy et al. 2017, pp. 56–69).

The Two Action Pathways

Commons Transition

The City is a network of 'commons' where local communities organise themselves to manage key resources and systems of provision in collaboration with business and government. It is distinguished by peer-to-peer collaboration and community ownership; it is 'post-growth', 'post-smart', 'post-hierarchy' and 'post-pollution'. The will of the 'people' has been clearly and loudly expressed in actions to reduce greenhouse gas emissions by over 80%, creating common value for everyone, rather than private value for a few. People consume less material goods, work for themselves and their communities, and use much less energy. Infrastructure is managed through cooperatives, public utility trusts and public buy-backs of formerly privatised assets. Renewable energy infrastructure is distributed across networks spanning households, neighbourhoods, cities and beyond, and the benefits flow back into the communities that own and run them (Candy et al. 2017, pp. 56–61).

Green Growth

This is a city of clean and efficient production following circular economy principles and clean-tech innovation. Large corporations, with the resources to manage infrastructure and rapidly scale innovations, are the driving force of the economy. The private sector owns and manages most of the city infrastructure, from energy supply to transport and building technologies to water. The 80% reduction in greenhouse emissions has been achieved through decarbonisation of the electricity system, the substitution of electricity for other forms of energy, high energy efficient products and a relative increase in the service sector. A strong regulatory framework ensures carbon and resource costs are passed through the market. Competition in smart city technologies saw early proliferation of systems but these have given way to a few market monopolies. Some local governments have public–private partnerships with those monopolies accessing and using citizens' data for public policy. Robots and automation have reduced labour costs in many areas of production and service provision. There is a large shift towards casualised labour, decreased job security and increased disparity in income (Candy et al. 2017, pp. 62–67).

Based on new quantified 'settings' (Candy et al. 2017, pp. 68–69), both low-carbon pathways show a sharp reduction in emissions after 2020 compared to BAU. The total emissions for the Green Growth (GG) pathway drop lower than for CT initially, but then converge again after 2030. Both low-carbon pathways effectively achieve an 80% reduction in emissions compared to 2013 levels by 2040. The reduction is sustained after 2040 even with rising urban populations. However, zero-net carbon is not achieved until just before 2100. The differences in the two low-carbon trajectories are a result of the dynamics of emissions generated over time from various sources.[20] The final report of the project (Candy et al. 2017) shows the distribution of greenhouse emissions reductions by category, from the output of ASFF modelling. The results for both pathways require carbon sequestration to achieve the 80% target.

A switch from forest clearing to significant forest replanting leads initially to substantial carbon sequestration in the agri-forest sector for both pathways. The amount of sequestration required in the Commons Transitions (CT) pathway is less than for the GG pathway because overall emissions in other sectors are lower due to reduced consumption and reduced exports of emissions-intensive products. Sequestration is a short-term mechanism, as the net effect in a given area will rise to a peak and then decline due to the physical profile of carbon sequestration as trees mature. If no additional land is available, there is a physical limit to the total carbon abatement potential from revegetation. This suggests that reforestation can only provide a temporary reduction in emissions to buy time for long-term low-carbon structural changes in the energy sector and broader economy.

For both low-carbon pathways it is clear that the greatest reductions can be achieved by focusing on activities that typically occur outside city boundaries but support urban lifestyles and consumption patterns. This extends beyond sequestration and involves the embodied energy/carbon in the multitude of products and services that are imported into cities and represent the largest percentage of a city's carbon footprint (see Teh et al., this volume).

Notes

1. For example, Melbourne and Sydney each generate around 75% of their state's economic output [17].
2. The per capita emissions for Sydney and Melbourne have been calculated at 24.7 and 29.1 tCO2 eq, respectively, which are 7–27% higher than the national per capita emissions and around triple global per capita emissions (Candy et al. 2017).
3. That target was set from a review of city and national emissions reduction programmes at the time this research project was initiated (2014) (Candy et al. 2017, pp. 7–13).
4. Although it was formally out of scope for this work, it was accepted that scenarios and pathways for decarbonisation had, at the same time, to increase the resilience of the cities to cope with anticipated climate impacts.
5. They were providing critical feedback as to the internal logic of scenarios as they were developed.
6. Hölscher, Wittmayer and Loorbach (2018) discuss the differences in terminology between 'transition' and 'transformation', principally used to differentiate system foci.
7. To use the term adopted by the OECD as the climate challenge. See for example OECD (2018).
8. The emphasis on 'designing' a future reflects a literature on design and wicked problems where the involvement of a diversity of stakeholders is a way of addressing problems that cannot be solved by the application of standard methods but are amenable to creative speculation.
9. That work sits within an international network of 'designing the future' projects. In these projects, visions of possible futures are seen as a way of opening up alternative discourses on the nature, culture and dynamics of city development and planning, to break from existing institutionalised discourses that underpin regimes of planning and urban design (Hajer 1995; Hajer & Dassen 2014; Ryan 2013). The process of generating visualisations of changed urban conditions—and the visualisations themselves—can be considered as a feedback loop within

the multi-level transitions theory model, highlighting tensions at the socio-technical landscape level, portraying alternative (future) regimes in operation and defining potential new areas for innovation at the niche level.

10. Along with the academic researchers, three Ph.D. students worked in each of the three universities. Although the time lines for their research was not a good match for the project's program, they were involved in much of the early research team meetings and visioning workshops. At best this meant that the directions of the project had some influence on the specific thesis topic for each student. Their results however were not incorporated into the VP2040 final outcomes.
11. See note 17 below.
12. See Ryan et al. (2015) report, page 2.
13. The researchers also used 'polling' of the audience at a number of CRC related conferences and symposia, using 'tag cloud' software to stimulate some public debate in those meetings.
14. See, for example, the visualisations from Sydney and Melbourne: VP2040 2015 report 2015, pp 13–29, and http://www.visionsandpathways.com/research/visions/.
15. For example, workshops explored current theory and practice of 'the sharing economy', new business and financial models, and new models of governance (Gaziulusoy & Ryan 2016).
16. Elements such as: whether changes in production are dominant, or changes in consumption patterns (e.g. for energy); rate of technology development; centralised versus decentralised systems; access and use of data across urban systems of provision; high or low GDP growth; degree of social equality; carbon emissions priced or not.
17. Projects such as the Global Scenarios Group (gsg.org), EPSRC Urban Futures project (http://imagination.lancs.ac.uk/activities/Urban_Futures), RETROFIT 2050 UK (Dixon 2011; Eames et al. 2017), SPREAD (http://www.sustainable-lifestyles.eu) and the EPSRC Realising Transition Pathways (http://www.realisingtransitionpathways.org.uk).
18. For a detailed description of this process see Candy et al. (2017), pp. 21–26.
19. For the city partners in the project there was great interest in capturing those decision points so they could monitor 'signals' as an input to current and future debates about their own future pathways.

20. Consumption-based greenhouse gas emissions attributable to cities include both those emitted directly within the city (scope I), from production of electricity used in the city (scope II) and from production of goods and services consumed in the city (scope III).

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