RACE for 2030

RELIABLE
AFFORDABLE
CLEAN
ENERGY

B1 Opportunity Assessment

Transforming energy productivity through value chains

Final report November 2021

Australian Government
Department of Industry, Science, Energy and Resources

AusIndustry
Cooperative Research Centres Program

RACE for Business Program

Transforming energy productivity
through value chains
Final report of opportunity assessment for
research theme B1

Project Code: 20.B1.A.0129

ISBN: 978-1-922746-03-0

November 2021

Citation

Denham, T., Xing, K., Dodson, J., Pears, A., Agrawal, H., Azar, B., Hossain, J., Indrawasi, K., Katic, M., Liu, M., Rajakaruna, S., Shawon, M., Shi, L. and Susilawati, C. (2021). Transforming energy productivity through value chains. Final report of opportunity assessment for research theme B1. RACE for 2030 CRC.

Authors

- Todd Denham
- Ke Xing
- Jago Dodson
- Alan Pears

Section authors

RMIT

- Todd Denham
- Jago Dodson
- Alan Pears

QUT

- Connie Susilawati
- Karlina Indraswari

Curtin University

- Sumedha Rajakaruna
- Himanshu Agrawal
- Mohammad Shawon

UTS

- Jahangir Hossain
- Andrea Trianni
- Kaveh Khalilpour
- Bahareh Berenjforoush Azar
- Mile Katic

UniSA

- Linda Shi
- Ming Liu

Project partners

What is RACE for 2030?

The Reliable Affordable Clean Energy for 2030 Cooperative Research Centre (RACE for 2030) is a 10-year, $350 million Australian research collaboration involving industry, research, government and other stakeholders. Its mission is to drive innovation for a secure, affordable, clean energy future.

racefor2030.com.au

Executive summary

Purpose

The purpose of the project was to identify research priorities through investigating opportunities to reduce energy use in Australian industry, beginning with analysis of trends in productivity and energy. The research was based on the concepts of:

- **energy productivity**—the amount of value added by industry per unit of energy, and
- **value chains**—a method for analysing entire systems of production.

When applied to industry sectors and value chains, energy productivity provides a rationale for business to address energy use within their systems of production.

The project was also informed by considering the role of society, government, institutions and economic factors in the mainstream adoption of innovations. These factors are set out in theories of socio-technical transitions, which provide a framework for understanding how changes to socially dominant systems, processes and actions occur. In the context of the project, these theories indicate that more than technological developments are required for a shift to more energy-productive industry. Business models, policy, education systems, societal preferences and supporting infrastructure may all need to change to enable transitions to occur.

Research process

The research priorities identified in the project were a result of beginning with a survey of energy use and productivity across seven key value chains in the Australian economy, as identified through consultation with RACE for 2030 partners: (1) data, (2) education, (3) food, (4) health, (5) infrastructure, (6) shelter and (7) water. The following flow chart illustrates the research process undertaken and the evidence and assessments used to refine the opportunities.

Chapter purpose	**Pre-project: Sector identification**	**Chapters 2 & 3: Concepts & methods**	**Chapter 4: Industry sector analysis**	**Chapter 5: Priority clusters & oppportunities**	**Chapter 6: Discussion & reflection**	**Chapter 7: Outcomes**
Research method	Identified by RACE for 2030 partners.	Discussion papers on energy productivity and transformations.	Desktop research: • value chain reviews • market status • technologies • transformations • energy productivity opportunities.	Presentation and prioritisation of cluster by IRG. Additional analysis of priority clusters and key energy productivity opportunities. Stakeholder interviews.	Research team review of methods, concepts and project outcomes.	Summary of outcomes and recommendations from Chapters 5 & 6.
Evidence & validation		IRG validation of project plan, concepts and methods	Energy productivity opportunities identified. Assessment based on energy use and production data. Ranking of opportunities by research team. Research clusters formed	Research clusters prioritised by IRG. Outcome review by Project Steering Committee.	IRG discussion.	Validation of report and recommendations by the IRG.

Energy productivity opportunities

Identifying the productive and energy-intensive aspects of these sectors through desktop research, as well as the prospective of meeting consumers' needs through alternative and less energy-intensive means, provided the following initial list of 15 energy productivity opportunities for assessment and prioritisation.

Food Systems cluster

Robotic harvesting feasibility study → Robotic harvesting transitions study → Robotic harvesting expansion & adaptation

Circular & shorter food systems feasibility analysis → Circular & shorter food systems transitions study → Circular & shorter food systems expansion & adaptation

Bio-packaging feasibility analysis → Bio-packaging transitions study → Bio-packaging expansion & adaptation

Shelter cluster

Shelter innovation situation analysis → Shelter innovation absorption capacity study → Accelerating change in the shelter sector

Building performance transparency situation analysis → Building transparency & monitoring systems transition analysis → Building transparency expansion & adaptation study

Key methods for the assessment of the energy productivity opportunities were a multi-criteria analysis undertaken by members of the research team, a standard method for informing decision-making based on qualitative assessment, and validation of research clusters and proposals by the Industry Reference Group.

Focus on policy

The project recommends that RACE for 2030 continue to engage with policy questions arising from energy productivity and socio-technical transitions, through:

1. **Including policy and market analysis within the scope of industry-specific research projects.**
2. **Establishing an ongoing program to address issues of policy**, including regulatory and industry engagement with energy productivity and value chain transformation, and the market transformations necessary to enable this conceptual shift.

Market transformation

The project revealed significant gaps in theoretical and conceptual understanding of value-chain transformation of end-user services, and of energy productivity both within the research literature and within current market practice. In particular, there is very limited market understanding of what productivity means when applied to energy or of what a value chain comprises and how end-user services provided by value chains might be transformed. This lack of knowledge is a major impediment to application of these concepts within the energy and wider industrial and service sectors.

Accordingly, the report proposes an ongoing research and action agenda around market transformation, including developing a National Plan and Implementation agenda. This is needed to build and disseminate knowledge of these concepts within the market and to develop shared understanding of how they can be applied at the national scale through a transformative planning process, to prepare and position the Australian energy market for value-chain transformation.

Research roadmap

Priority areas

The project identified two priority areas for further research—food systems and shelter—and the following four opportunities:

1. **Food transparency**—Use of digital information gathering for consumers and participants in the industry to improve traceability through supply chains and transfer production information to consumers. This will increase produce value an1d reduce energy use through supply chain efficiencies.
2. **Reducing food waste**—Increased energy productivity in the food sector can be achieved by reducing the lost productivity due to waste, either through improved processes in food handling, or for more productive reuses of food currently going to waste.
3. **Innovative building materials and design**—Improvements in building materials, such as Structural Insulated Panels (SIPs) and engineered timber, indicate that there are energy benefits to be realised in the shelter value chain. The adoption of innovative materials and design is needed to realise the benefits of this opportunity, supporting other research and policy initiatives focusing on technologies in this sector.
4. **Building performance transparency**—Building energy performance information is not systematically collected or made available to participants in housing markets. This lack of disclosure means energy efficiency in housing is not adequately considered in housing decisions, either by consumers or the building industry. RACE for 2030 can complement existing initiatives in this area (e.g. the Green Building Council of Australia’s Green Star rating system) through applying value chain analysis and a focus on energy productivity to identified issues.

Research agenda

The above two priority research clusters translate into the following recommended research agenda for RACE for 2030. The sequential project streams progress from feasibility and detailed scoping studies to provide an evidence base for industry by 2023, through supporting industry transitions to facilitate industry adoption to realise potential by 2030. For the food systems cluster, the initial feasibility studies should address the need to undertake trials of technologies and systems to build the evidence base as a foundation for the development of business cases and industry adoption. For the housing systems cluster, situation analysis projects are required, as the primary objective is to restructure the value chains and the ways of working within them to realise energy productivity benefits. The subsequent project recommendations follow the same structure for both clusters.

To 2023

- **Feasibility studies**—Testing technologies and innovative production systems to provide proof-of-concept and an evidence base for further development.
- **Situation analysis**—Establish a stronger evidence base and detailed understanding of the industry and its value chains, including transformation capacity.

To 2025

- **Transition studies**—Address key barriers to implementation and industry uptake, including social, technical and regulatory impediments identified in the feasibility or situation analysis studies.

To 2030 and beyond

- **Expansion and adaptation studies**—Facilitate the transition of industry to new and more energy-productive ways of working.

Contents

List of figures

List of tables

Glossary

A2EP	Australian Alliance for Energy Productivity
ACOSS	Australian Council of Social Services
COAG	Council of Australian Governments
DISER	Department of Industry, Science, Energy and Resources
GBCA	Green Building Council of Australia
GDP	gross domestic product
GHG	greenhouse gas
HVAC	heating, ventilation and air conditioning
IEA	International Energy Agency
IoT	Internet of things
MWh	megawatt-hour
NABERS	National Australian Built Environment Rating System
NatHERS	Nationwide House Energy Rating Scheme
NEPP	National Energy Productivity Plan
PJ	petajoules
PV	photovoltaic
TNE	Transnational Education

1 Introduction

This report provides the outcomes of desktop analysis of Australian industry to identify priority projects for RACE for 2030 to pursue. The analysis drew on, as well as extended, the concepts of energy productivity and value chains. Beginning with seven value chains identified as having potential for energy productivity improvements by RACE for 2030, priority opportunities were identified through desktop research and analysis.

Energy productivity captures the total economic value generated from each unit of energy, whereas energy efficiency focuses on the product output from a unit of energy input. Shifting the focus from energy efficiency and intensity to energy productivity is transforming the focus of energy conservation and emissions reductions. Improving energy productivity captures the additional economic benefits of energy use through considering the value outcomes of productions, rather than only focusing on saving energy. The social outcomes include enhanced employment, stronger government finances and improved infrastructure and trade (A2EP 2017; COAG Energy Council 2015).

Value chains, as applied to energy productivity, are an analytical framework for assessing systems of production and the relationships across industries and business units, based on the form of business analysis developed by Porter (2001). The application in this context draws out how energy use and value need to be considered as a result of systems, including consumption, rather than discrete steps from raw materials to final product. The focus on industry also raises questions of the adoption of technology into systems of production, as well as the displacement and disruption of incumbent industries.

This project investigates opportunities to reduce energy use in Australian industry, while at the same time transforming energy productivity through innovative technologies and business models, through value chain analysis.

1.1 Project team

The project has been a collaboration between RMIT University, University of South Australia (UniSA), Queensland University of Technology (QUT), Curtin University and University of Technology Sydney (UTS), with industry partners Australian Alliance for Energy Productivity (A2EP), Climate-KIC, Simble and Sydney Water. RMIT University and UniSA co-led the project, with RMIT University as administering institution. This report has been prepared by Todd Denham, Ke Xing, Jago Dodson and Alan Pears. Ming Liu and Linda Shi have contributed to the discussion on energy productivity in Section 2.1. Linda also provided editing and feedback during the preparation of the report.

1.2 Industry Reference Group

The research team worked with industry partners Climate-KIC and A2EP, along with RACE for 2030, to identify suitable industry partners to participate in the Industry Reference Group (IRG) for the project. The purpose of the IRG was for the project team to obtain feedback on the approach taken, including assessment of current status, opportunities, barriers and priorities in relation to energy productivity transformation. The three meetings with the IRG were:

1. **Scoping workshop**—To understand and inform the direction of the research, identify any uncertainties or issues with the research program and to advise on project activities, engagement and communications.
1. **Research clusters and energy productivity opportunities workshop**—Outcomes from the industry sector analyses undertaken by the research team was presented, to test and prioritise the proposals identified.
2. **Draft report workshop**—Testing of recommendations and priorities for future research tested with the IRG.

Table 1 presents the members of the IRG, as constituted by project partners Climate-KIC and A2EP at the start of project. Not all members were available for the three meetings, however each member received copies of the reports and discussion papers for the meetings, in order to provide feedback and input to the project as it proceeded.

Table 1. IRG membership.

Value chain	Company	Name
Food	FIAL	James Krahe
Food	AMPC	Matthew Deegan
Food	Dairy Australia	Ian Olmsted
Food	Queensland Farmers Federation	Andrew Chamberlin
Food	Glaciem Cooling	Alemu Alemu
Water	Sydney Water	Greg Appleby
Water	BlueScope	Andrew McClure
Shelter	Property Council of Australia	Francesca Muskovic
Shelter	SmartCrete CRC	Zoe Schmidt
Enablers	Mov3ment	Mark Gjerek
Enablers	Simble	Bill McGhie
Health	Mater Health Services	Ngaire McGaw
Energy	ARENA	Peter Haenke
Energy	Department of Industry, Science, Energy and Resources (DISER)	Matt Clarke
Energy	Department of Industry, Science, Energy and Resources (DISER)	Christine Croke

1.3 About this report

After this introductory chapter, the report is organised into the following chapters:

- **Chapter 2** sets out the conceptual foundations for the research, including energy productivity, innovation and disruption theories, and the analysis of production systems.
- **Chapter 3** describes the approach and methods for this project in more detail.
- **Chapter 4** provides the outcomes of the investigations into value chains and the associated opportunities for energy productivity
- **Chapter 5** organises the outcomes of the research into research clusters that share thematic or methodological synergies.
- **Chapter 6** discusses the outcomes from the research, including insights to inform further projects that aim to identify energy productivity benefits.
- **Chapter 7** is the conclusion.
- **Chapter 8** lists the references used in this report, organised by chapters and value chains.

2 Conceptual foundations

Energy productivity and theories of change in, and the analysis of, economic systems provide the conceptual foundation for this research. Improving energy productivity is the central goal of the project, therefore this chapter begins with a definition and how it is measured, followed by Australian trends and international comparisons of energy productivity. The second section introduces innovation theories, including disruption and socio-technical transformations, which provides insights into how interactions between technology and society result in changes to incumbent systems of production and consumption. The third section lays out the approach to production and consumption systems analysis, including value chains and end use services. The final section within this chapter brings together the three underlying concepts, to highlight how energy productivity, innovation and socio-technical changes, and systems of production interact, which informs the investigations into value chains.

2.1 Energy productivity

Energy productivity is the primary metric used in this analysis. Energy productivity is a measure of economic output per unit of energy used, and as such value creation is included within the analyses in addition to cost reduction and energy efficiency. This section outlines the purpose of using energy productivity as the goal in this research project, its definition and national and international trends.

2.1.1 Approaches to energy use in industry

The aim of this research is to identify ways that Australian businesses and industry can contribute to the reduction of energy use and carbon emissions in line with our current commitments under the Paris Agreement to reduce greenhouse gas emissions by 26–28% below 2005 levels by 2030 (DISER, 2021) and RACE for 2030's goal of *Accelerating the transition to Reliable, Affordable, Clean Energy for 2030*. Therefore, we need to consider how make and provide goods and services, how energy use is factored into business decision making processes, and how to approach the relationship between energy use, profits and productivity.

The problems are that energy efficiency is not a primary concern for many businesses and is not a major factor in the costs of production in many value chains, and that methods for a full accounting of the range of benefits are still in development (Ürge-Vorsatz *et al.*, 2016). In many cases the lifecycle energy impact of production decisions occurs outside the boundaries of businesses making these decisions: referred to as Scope 3 emissions. Also, much of the discussion regarding industrial productivity focuses on labour and capital (e.g. Productivity Commission, 2020) and in some instances Australian industries have responded to international competition and globalisation by increasing capital intensity at the expense of labour (Productivity Commission, 2017), which is likely to result in higher energy use. However, relationships between energy use, capital intensity and productivity are not clear-cut (Elkomy *et al.* 2020), even if central to recent economic policy discussions in Australia (e.g. Morrison, 2020). It is also important to point out that capital investment is central to improving energy use and improvements in energy efficiency, for example new equipment is likely to be more efficient than what it is replacing.

In essence, the problem is to connect the public or social good of reduced emissions and energy use and the private or commercial good of competitiveness and productivity. The concepts of bounded rationality and satisficing rather than optimal decision making are also important, indicating that there is room for improvement and that industry is making rational decisions limited by their understanding of what is possible and most beneficial (Visco & Zevi, 2020). Therefore, addressing energy use in industry needs to seek ways to address public and private good in industrial energy use, and consider investment barriers such as upfront cost and other resources, information and other market effects (Impact and Reason, 2015).

This is the underlying reason for the energy productivity approach taken in this research paper, based on previous studies by A2EP where the concepts of energy productivity, value chains and end use services are used to identify opportunities to simultaneously improve business outcomes and contribute to reducing energy use and carbon emissions in Australia (A2EP, 2017d). As an example, in recent work on compressed air in industry it was found that most decisions regarding compressed air systems were taken by maintenance or production managers, who were under pressure to maintain production and had limited capital budgets. They often saw the time and effort required to prepare, and submit to the finance team and management, a strong business case for funds as too onerous. Further, they often were not aware of high efficiency options that differed significantly from the equipment they usually dealt with. Senior management were often unaware of the potential for significant financial and productivity benefits (A2EP, 2020).

Another approach to this issue is the multiple benefits approach to energy productivity as outlined by the International Energy Agency (2015), as depicted below, and the Multiple Benefits of Energy Productivity project in the EU, known as Mbenefits (2018). MBenefits argues that there are benefits to industry from reconsidering their methods of production to reduce energy use that outstrip the cost savings resulting from reducing energy consumption.

Energy productivity, when applied to industry, starts with understanding the value of what is being produced, and then considers whether there are other means to realise that value. As a result, MBenefits is more suited to process improvements and refinements of existing systems, while energy productivity includes the prospects of more profound changes such as disruptions and demand diversions and market transformations. Both need to be based on an understanding of the barriers to including energy use concerns in industrial decision making and planning processes.

2.1.2 Definition

There is only a very limited research literature that offers guidance on the definition and measurement of energy productivity for industry sectors and value chains, as it is generally used as a comparative measure of national energy performance. Hence this project is working from a limited basis and should be considered novel in the context of wider discussions about energy and economic activity. Working from basic economic principles, energy productivity can be understood a measure of the economic productivity gain from each unit of energy input. At the macro-economy level, a common international measure of energy productivity is defined as the ratio of national gross domestic product (GDP) and primary energy consumed. It indicates the extent to which the traditional correlation between economic growth and energy use is being broken, that is, as economies become more efficient they can generate greater volumes (or value) of economic output per unit of energy consumed in production. There is an increasing focus on energy productivity as many governments are boosting economic growth while committing to reduce carbon emissions.

As the National Energy Productivity Plan (NEPP) sets out:

> *Improving energy productivity requires more efficient investment across both the supply and demand side of energy markets, including: primary energy sources (such as coal, gas, oil, solar and wind); energy supply assets (generation and networks); assets related to energy use (such as more efficient equipment, buildings and vehicles); and avoided energy use (COAG Energy Council 2015, p.7).*

For Australia, energy productivity improvement is an essential factor for economic growth. Energy productivity of an industry is closely aligned with the concept of energy efficiency, as both are measures of energy performance (A2EP 2018).

Measurement

At an elemental level, energy productivity may be calculated by the following formula:

$$\text{energy productivity} = \frac{\text{value of output}}{\text{energy input}}$$

This provides average energy productivity. Other measures used in the analysis of production systems include marginal energy productivity and marginal value productivity. Energy is also an element of multi-factor productivity, where the value of output is measured across the entire system and its inputs, rather than the specific contribution of energy to output (Panesar & Fluck 1993). Energy productivity may result from a range of changes to production systems, such as improved labour productivity, improved safety, reduced health costs, increased product quality and value, reduced energy supply infrastructure costs, improved reliability and reduced use of resources. It deserves mention however, that calculating the energy productivity of any given good or service will be highly complex because of the extensive inputs that go into those goods or services as implied by both the concept of Scope 3 emissions and value chain theory. Accounting for these is a highly complicated process and, in many instances, sufficient data may not exist to allow full energy productivity calculations.

Energy efficiency and energy productivity

As the equation above implies, energy productivity is a result of both value-added and energy used. Therefore, energy productivity can increase through lower energy use for the same output, increased value created for the same energy input, or changes to both energy and value. This means energy productivity encompasses energy efficiency outcomes, as well as wider or more extensive innovations that result in improved or higher value goods and services, as indicated in COAG's NEPP (2015, p.8).

The size of each of the columns aligns with projections for energy productivity gains made by ClimateWorks and included in the NEPP (COAG Energy Council, 2015, p.13). The separation between energy cost savings and market benefits in this diagram is of note, indicating that at least in the view of ClimateWorks and the COAG Energy Council they are separate approaches to increasing energy productivity, rather than an integrated approach that addresses both energy cost savings and market benefits in a single initiative.

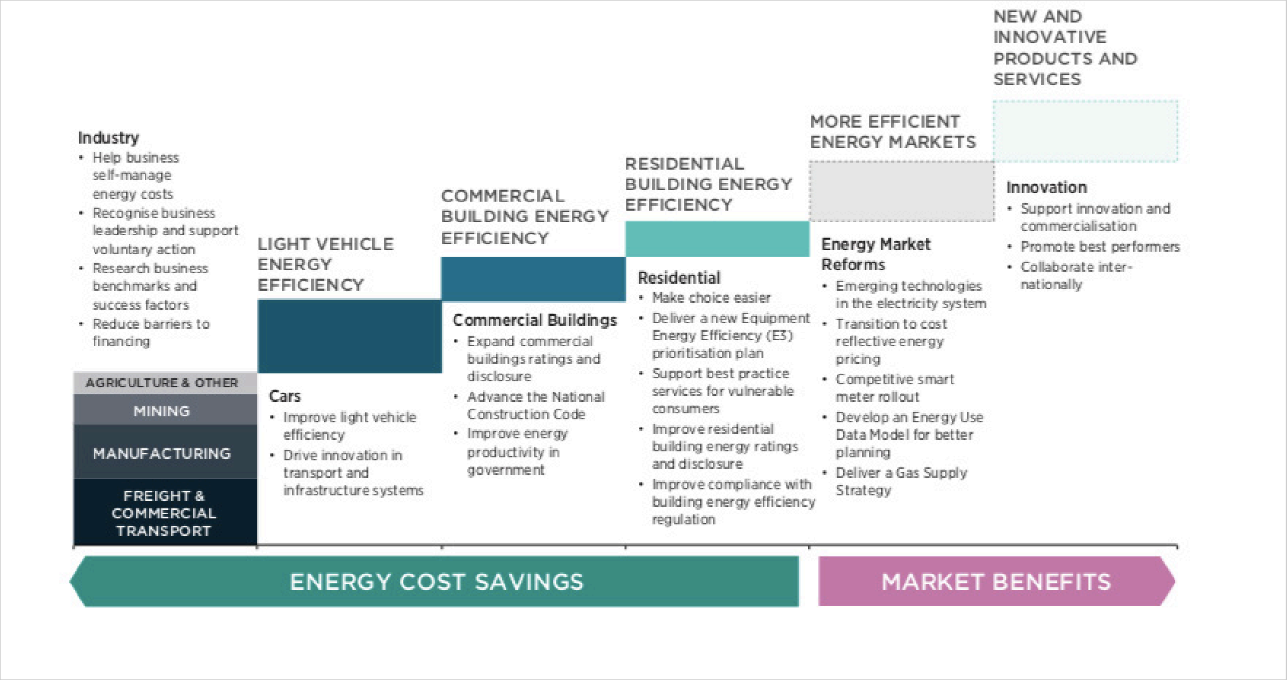


Table 2. Examples of energy productivity measures. Source: COAG Energy Council, 2015, p. 8.

2.1.3 Energy productivity in Australia

The Australian Government committed to an economy-wide target to reduce greenhouse gas emissions by 26–28% below 2005 levels by 2030 at the United Nations' 21st Conference of Parties (COP21) in Paris (DISER 2021). Approximately 80% of Australia's present emissions are associated with fossil fuel production and use (ABS 2020). Recognizing the importance of energy productivity to the Australian economy and carbon emission reduction goal, the Council of Australian Governments (COAG) Energy Council took the first step by developing the NEPP (COAG Energy Council, 2015). The NEPP consists of 34 measures and set a target of energy productivity improvement of 40% from 2015 levels by 2030, which is equal to an annual target of 2.3% increment. A2EP analysed the NEPP in detail and concluded that it lacks details and there is inadequate progress due to the insufficient resources and the negligence of both the state and federal governments (A2EP, 2015). NEPP 2.0 proposed to double energy productivity by 2030 from 2010 levels, by addressing whole-of-economy issues including a framework and target, a focus on a top ten list of priority measures, new sector-specific approaches, and back-of-envelope program costings (A2EP, 2015).

Australia's energy productivity has increased over time and has particularly accelerated since 1998 (COAG, 2015). This outcome is because the economic growth rate was higher than the energy consumption growth rate, particularly since 2008. The overall improvement was 19% over the last ten years, averaging 1.9% per annum (COAG, 2015). To achieve the goal of NEPP 2.0 to double energy productivity by 2030, the average increase rate needs to be 4.4% per annum (A2EP, 2015).

Energy productivity gains are attributed to the cumulative improvements in energy efficiency, sectoral shift from highly energy-intensive industries such as manufacturing towards less energy-intensive industries such as services (Australian Government, 2020).

2.1.4 International comparisons

Driven by technological progress, the average improvement of energy productivity was 34.6% between 1990 and 2010 across 123 countries (Australian Government, 2020) and the improvement varies between countries.

Australian ranked 22 of 35 countries in the OECD in 2011 (IEA, 2015). Ireland and Switzerland had the highest energy productivity. While Australian energy productivity increased between 2000 and 2011, it fell behind most OECD members and the energy productivity was slightly below the average OECD level, and also 14% lower than the G-20 average (Atalla and Bean, 2017).

2.1.5 Trends and potential for energy productivity improvement

By extrapolating the recent rate of improvement, Australian energy productivity would improve by 44% between 2010 and 2030 as shown in Figure 1. ClimateWorks' analysis indicated that Australia has the potential to increase its energy productivity by 97% between 2010 and 2030 (Doojav and Kalirajan, 2020).

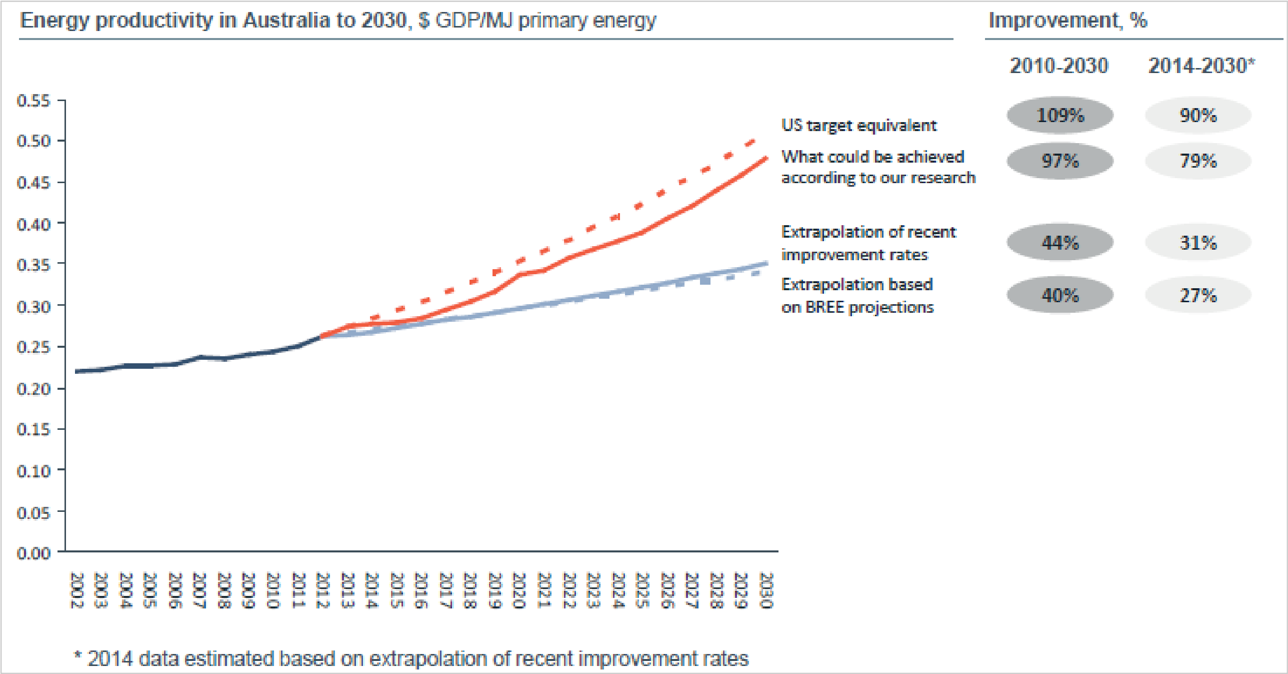


Figure 1. Recent and projected energy productivity in Australia between 2002 and 2030. Source: ClimateWorks, 2015.

The projected range of changes to energy supply, demand and consumption to meet the target of doubling energy productivity in Australia by 2030 indicates that efficiency improvements and renewable energy have potential to play major roles, as well as structural changes in the economy (ClimateWorks, 2015 p. 19). The reduction in mining energy productivity is related to reduced ore quality over time, and the extraction of deposits in more difficult locations as existing, more accessible sites are mined out.

Figure 2 shows the change in equivalent energy productivity in the major energy-using sectors from 2008 to 2013. The overall improvement of energy productivity was slow, with only a 3.05% improvement the seven selected sectors, with wide variation across sectors. In order to achieve the NEPP 2.0 target, A2EP has developed roadmaps for the six major end-use economic sectors including agriculture, built environment, manufacturing, mining, freight transport, and passenger transport (A2EP a, b, c, d, e, 2016; 2017). Even though a separate roadmap was produced for each sector, they should be seen as a joint pathway for all Australian business to improve their energy productivity.

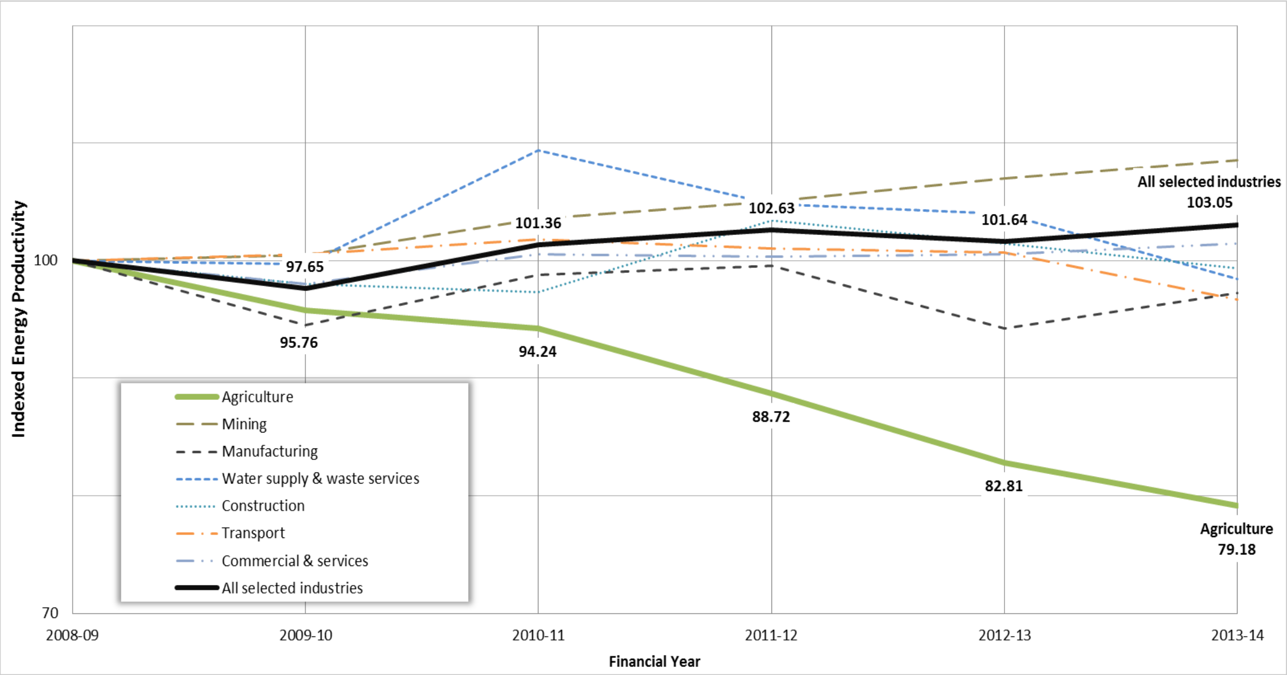


Figure 2. Equivalent energy productivity in different Australian value chains. Source: A2EP, 2016a.

Doojav and Kalirajan (2020) analysed the factors that influenced the energy productivity change in 10 Australian sub-industries over the period 2003 to 2015. The factors investigated included technical efficiency change, technological change and changes in labour-energy and capital-energy ratios. In general, the technical efficiency change was the main positive contributor to energy productivity changes, except for the coal mining industry. The energy productivity growth in the oil & gas extraction industry is a result of the increases in capital-energy and labour-energy ratios. Decreases in the rate of technological change were the main reason for year-to-year energy productivity reduction between 2003 and 2015. This study emphasised the need to promote technological growth and improve technical efficiency, which could be done through government incentives to employ new technologies and on-the-job training, respectively.

Technological change was also found to be the main contributor to change of energy intensity between 1995 and 2007 in most countries (Voigt *et al.* 2014). However, Australia, the United States, Japan, Taiwan, Mexico and Brazil are the exceptions, and the change of industry structure played a more important role. This conclusion is different for some countries such as Australia, the United States and Mexico from that by Atalla and Bean (2017) due to the use of two different World Input Output Database (WIOD) energy datasets. The latter study found the improvement was due to the increases in sectoral energy productivity for most countries.

Bhattacharya *et al.* (2020) suggested that one common energy policy would be sub-optimal for the whole of Australia. By using the club convergence approach and after examining the energy productivity in seven Australian states and territories over years 1990–2015, they identified two convergence clubs of energy productivity with NSW, South Australia and Victoria being in the high energy productivity club. It was concluded that energy productivity was primarily affected by industry structure and automobile fuel prices. This study also forecasted the energy productivity to 2030 at the state-level under a business-as-usual scenario. NSW and South Australia have the highest predicted energy productivity, followed by Victoria and the Northern Territory. However, energy productivity growth is between 14% and 22% for different states and territories from 2015 to 2030, which is far less than the NEPP 2.0 target.

2.1.6 Productivity and costs

As an observation, this project comes at time of transitions in the Australian energy sector. Many fossil fuel-based generators are reaching the end of their productive lives, and renewable energy capacity, both distributed and large scale, is increasing to meet demands, and at the same time the demand for grid-supplied energy has stagnated (Clean Energy Council, 2021; Cranney, 2020). At the same time, energy market prices are in decline, a trend likely to continue with the ongoing development of storage and renewable energy generation systems (Blakers, 2021).

While relationships between productivity and energy use are unsettled and contingent (Elkomy *et al.*, 2020), declining energy costs with increasing renewables will counter initiatives to increase energy productivity and efficiency in Australian industry, unless other forms of value from energy efficiency and productivity are recognised. And EP/MB provide ways of valuing EE benefits in a more comprehensive way. The increasing share of renewables in the national energy market does not mean that energy productivity and efficiency measures are no longer important goals. Reducing demand can hasten the demise of inefficient and high emissions older generators in the supply network, as well as the costs of energy supply (IEA, 2018).

A major challenge in energy-related improvements in industry is that for many sectors energy is already a minor contributor to industry costs and so is not included within the rationale of decision making. Further cost declines will only reduce the impetus for industry to take up energy measures, unless we focus more on the non-energy cost value.

2.2 Innovation, disruption and socio-technical transitions

The purpose of this section is to provide insights into how inventions and innovations arise and transition into new products and practices in the functioning of society. The multi-level perspective of socio-technical transitions provides a basis for understanding how transitions occur as an interaction between innovations, social norms and practices, and broader influences such as government policies. These insights will underpin subsequent studies of how such transitions can result in increased energy productivity in economic sectors within Australia.

Transitions, or changes in the way society operates, can be seen as a contest, based on the “multi-dimensional interactions between impulses for radical change and the forces of stability and path dependence” (Köhler *et al.* 2019, p. 2). It is the social, economic and political systems, the inertia of current practices, that resist the adoption of new technologies and systems, as:

> … these innovations require breaking down the routine behaviour that is daily reproduced by individuals, groups, business communities, policy actors and society at large. For this reason, the introduction and scaling-up of such innovations are not completely under the control of a single actor (or a small network of actors), because changes in the factors that form the boundary conditions (i.e., existing organisations, institutions, networks, dominant practices, interests etc.), are as well required (Ceschin 2014, p. 2).

This also means that transitions are difficult and are not always met positively by all sections of society—they are associated with *disruptions*.

2.2.1 Innovation

The purpose of discussing innovation is to outline its importance as the foundation for socio-technical transitions, which can be understood as the social changes that result from an alignment of innovations (Geels 2002). Innovation is the basis for dynamic economies and competitive advantage in business and also between nations and regions: it is a vehicle for change and transformation (Hospers 2005; Fagerberg 2018).

It is important to set out the differences between inventions, innovations and how they contribute to socio-technical transitions. Fagerberg (2018, p. 6) provides definitions and distinguishing features:

> *Invention is the first occurrence of an idea for a new product or process, while innovation is the first attempt to carry it out into practice.*

Innovation emphasises social and economic aspects of the adoption of technology, it is the “development of technology in interaction with the system in which the technology is embedded” (Hekkert *et al.* 2007, p. 414).

Schumpeter identified five forms of innovation, providing an early recognition of innovation being more than technological development: new products, new methods of production, new sources of supply, the exploitation of new markets, and new ways to organise business (Hospers 2005). Much of the subsequent research into innovation has focused on the first two, referred to as ‘product innovation’ and ‘process innovation’; distinctions are also made between technical process innovations and organisational process or business model innovations (Fagerberg 2018). The different types of innovation indicate how new ways of working are as important as technology in market competition. Business process and technological innovation regularly occur in tandem, as technologies can require or allow new organisational structures and institutions to be implemented. For example, Tesla combines new automotive and battery technologies with innovative methods of marketing and distribution (Shipley 2020; Wright 2020) and as usage increases transport taxation systems are adapting (VicRoads 2020).

As innovation includes implementation, it occurs over time and is a process that may require trial and error. As Kline and Rosenberg (1986, p. 283) warn:

> *...it is a serious mistake to treat an innovation as if it were a well-defined, homogenous thing that could be identified as entering the economy at a precise date—or becoming available at a precise point in time... The fact is that most important innovations go through drastic changes in their lifetimes—changes that may, and often do, totally transform their economic significance. The subsequent improvements in an invention after its first introduction may be vastly more important, economically, than the initial availability of the invention in its original form.*

Innovation is a process and the result is an outcome of the organisations and social structures within which it occurs, providing the basis for the extensive literature on innovation systems. The use and uptake of technologies are linked to social, political and economic systems and structures. This is a key reason for the slow rate of the take-up of innovations (Hekkert *et al.* 2007). This also means the ways we consider it possible to provide a service, or imagine an alternative, are based on our past experiences.

This also means that current market operators have the advantage of having responded to and shaped market demands over time, both in quality and production efficiencies, as well as the system aspects such as “accumulated knowledge, capital outlays, infrastructure, available skills, production routines, social norms, regulations and lifestyles” (Kemp 1994, p. 1027).

While innovation is a fundamental component of socio-technical transitions, the literature is mainly concerned with innovation as a driver of and response to economic circumstances. The longer-term development and implementation of technologies to reduce greenhouse gas emissions and shifting energy production to renewable sources has been a public good rather than driven by profit motivations. While this situation has changed, it indicates the need for policy interventions to provide directions for fostering innovations (Markard 2018). These interventions may be complex and have multiple elements and evolve over time. If innovation can be seen as providing a social and economic context for inventions, then socio-technical transitions is a further widening of the development framework to consider iterative and aligned innovations in response to social, political and economic contexts and the resulting change in the way societies operate.

2.2.2 Disruption

Disruption is a widely used term, typically referring to the replacement of incumbent industries and service providers by new firms who obtain advantage, and eventually market dominance, through innovations. In many instances, disruptions are associated with major changes in profitability and value of businesses and value chains as old models of production and business lose their competitive position. As a result, the focus in the many studies of disruption is why successful firms fail to see the disruptive potential of innovations and market entrants.

One explanation for disruption is that the benefits from innovation follow as 's'-curve, as shown in the figure below. Initial efforts realise limited benefits in performance until a point is reached where rapid improvements are made, but as the product matures the marginal benefits from effort also decline.

Figure 3. Disruptions, performance, effort and discontinuities (Gans 2016, p. 19).

The inclusion of the 'New' development in Figure 3 indicates one explanation for disruption, as leading businesses in the sector ignore new development during of the expansion phase of the development cycle, which provides space and opportunity to develop and eventually overtake incumbents (Gans 2016, p. 19).

Disruptions may also occur in different ways, providing better value for users or attracting new customers to the market through product innovation (Christensen & Raynor 2013), as well as through innovation in components, or design solutions (Henderson & Clark 1990). For a disrupter like Uber ride sharing, the essential service provided has not changed, but the method of booking and the organisation of the business provides the basis for disrupting the taxi industry.

A key aspect of explanations of disruption is that it is a rational path for incumbent firms, as Gans explains:

> *Successful firms that are disrupted are not complacent or poorly managed. Instead, they continue on the path that brought them to success. It is precisely because this is an appropriate thing for them to do that they are disrupted* (*Gans 2016, p. 30*).

An important criticism of disruption studies, as well as socio-technical transitions theories, is that they are better at helping us understand what has happened than what disruptions are likely to occur in the future (Sood & Tellis 2011). That is, it is not clear at the time which, if any, innovations will displace incumbents, as "disruptive technologies can be revealed as being disruptive only in hindsight" (Kostoff, Boylan & Simons 2004, p. 142).

Disruptions can be seen as a result of changing the way that end-use services are provided, which has impacts through the value chain that produces those services. Contemporary disruptions are associated with digitisation and the use of technology in the interactions with customers as much as the system of production: for example, peer-to-peer services such as Uber and Airtasker.

2.2.3 Socio-technical transitions and the multi-level perspective

Socio-technical transitions are major changes to the ways that industries operate, and the services and goods provided as a result. The inclusion of 'socio' is of note, as it indicates that it is an extension of earlier innovation theories that primarily focused on technological regimes, without considering how the adoption and acceptance of new technologies and innovation is a result of social and political processes (Geels & Schot 2007; Rip & Kemp 1998). The multi-level perspective of transitions provides a framework for understanding how innovations are taken up by wider society, as well as how society shapes and filters them as well, all within the broad context of social and institutional structures.

Socio-technical transitions are shifts from a set of technologies and formal and informal rules and norms, referred to as a socio-technical regime, to another. A prominent framework for analysing socio-technical transitions is the multi-level perspective, which considers how "system innovations come about through the interplay between processes at different levels" (Geels 2007, p. 1414). The socio-technical landscape creates pressure for change in the socio-technical regime, particularly as it changes through new government policy or community preferences: examples include a carbon emissions tax, subsidies for renewable energy generation, or increasing demand for organic and sustainably produced food. The need for aligned niche-innovations also distinguishes multi-level perspective from technology-focused theories, as it indicates that society-wide transitions in production and end use services result from a series of innovations, that align in response to the landscape and regime, rather than single 'eureka' moments. As Figure 4 on the following page indicates, the multi-level perspective on transitions is concerned with changes to the socio-technical regime as a result of the pressures created by the socio-technical landscape and the alignment of niche innovations.

The term 'structuration on the vertical axis refers to the interaction between people's capacity to act and the wider social, economic and political constraints (Giddens 1984): the role of wider elements of society increases and individual action decreases upwards along the axis. At the niche-innovation level actors are relatively unconstrained by society in developing ‘novelties’, as markets and social structures around the innovation are weakly developed. At the socio-technical regime level, actions are more influenced by social norms, institutions and rules, which also indicates that change at this level meets greater resistance.

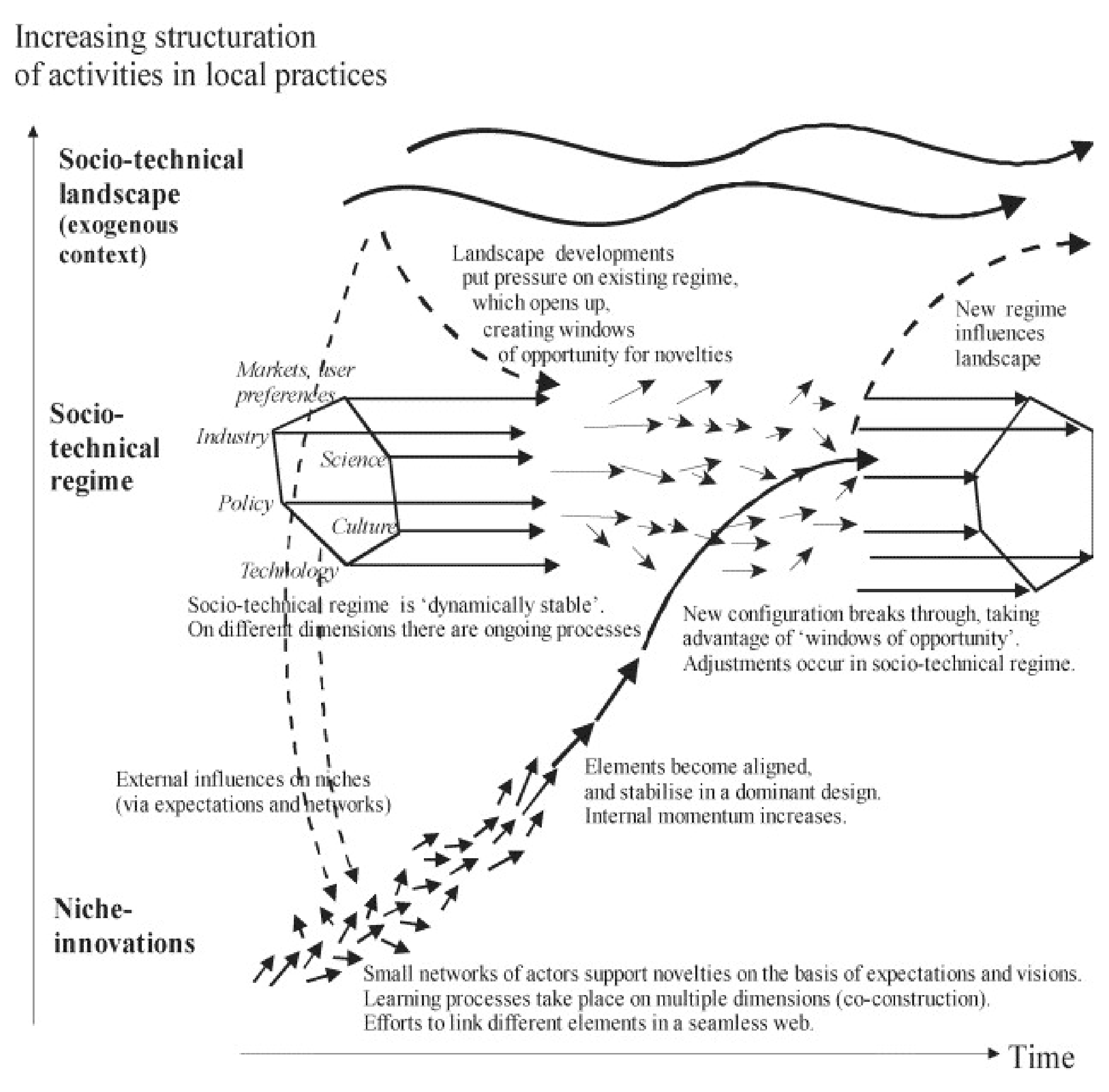


Figure 4. Multi-level perspective on transitions. Source: Geels & Schot (2007, p. 401).

The three levels of the framework are discussed in more detail below.

Socio-technical regime

The socio-technical regime, and how it can move from one state to another, is the primary focus of multi-level perspective analyses. It is an extension of technological regimes, which are:

> *… the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures (Rip & Kemp 1998, p. 340).*

The inclusion of the social in this description reflects the influence of agents external to technology and engineering, such as scientists, policy-makers, end users and special interest groups (Geels & Schot 2007).

The confluence of policy, standards, markets, technology and society within the regime makes it stable, as each aspect reinforces the status quo, or tends to restrict change to incremental advances (Geels 2002). This resistance to change, or lock-in and path dependency, associated with socio-technical regimes can act to resist the adoption of new and better innovations (Klitkou *et al.* 2015). For example, socio-technical transitions have been used to analyse the continuation of coal-fired energy systems in Japan (Trencher *et al.* 2020). Therefore, socio-technical transitions can be seen as a framework for understanding how to overcome locked-in regimes through the adoption and absorption of niche innovations and pressures resulting from the socio-technical landscape. However, what constitutes a regime is not clearly defined, as a regime change at one level may be an incremental change at another (Berkhout, Smith & Stirling 2004).

Niche innovations

The niche innovations level is where radical novelties are developed and incubated, supported and protected from market forces due to their potential longer-term benefits. As Figure 4 indicates, niche innovations respond to the socio-technical regime and landscape, initially operating outside the regime and responding to specialised requirements as the innovation develops in response to user requirements but relying on enabling hard and soft infrastructure and enablers. Niche innovations influence the regime when "elements become aligned and stabilise in a dominant design" (Geels & Schot 2007, p. 401).

Socio-technical landscape

The landscape level is different to the others, it is an analogy of physical landscapes, and sets the environment that the regime moves through over time (Rip & Kemp 1998; Geels & Schot 2007). The socio-technical landscapes are the wider, macro-level factors that influence the direction of socio-technical transitions from beyond the regime, such as macroeconomics, cultural patterns and political developments.

Landscapes do not directly determine the socio-technical regime, but "provide deep-structural 'gradients of force' that make some actions easier than others" (Geels & Schot 2007, p. 403). While landscapes are often slow to change, when they do it creates new pressures on the socio-technical regime, which provides an impetus for innovations to be adopted within the system.

2.3 Production, value chains and end use services

The objective of this project was to identify opportunities for increasing energy productivity in key Australian value chains. The investigations started with identifying the end use service being provided and considering more productive ways of providing that service as well as potentially redefining the way the service was perceived. As a result, the research enabled opportunities for industry disruption and restructuring of production systems to be identified, as well as incremental changes to existing production.

This section of the report proceeds by outlining the approach taken to the value chains and analyses of the systems of production, the application of value chain analysis and the reconsideration of end use services. This is followed by a description of the four phases of the methods used to collect and analyse the data to identify opportunities for energy productivity improvements.

2.3.1 Systems of production

Production systems can be seen as the process of converting raw materials into goods and services for consumption. Each stage of the production system is associated with flows:

- Forward flows of the end product or service through the system towards consumption
- Backwards financial flows, indicating the value at each step of production
- Forwards and backwards flows of information about product quality and quantity, as well as operational factors.

These flows are depicted in the figure below.

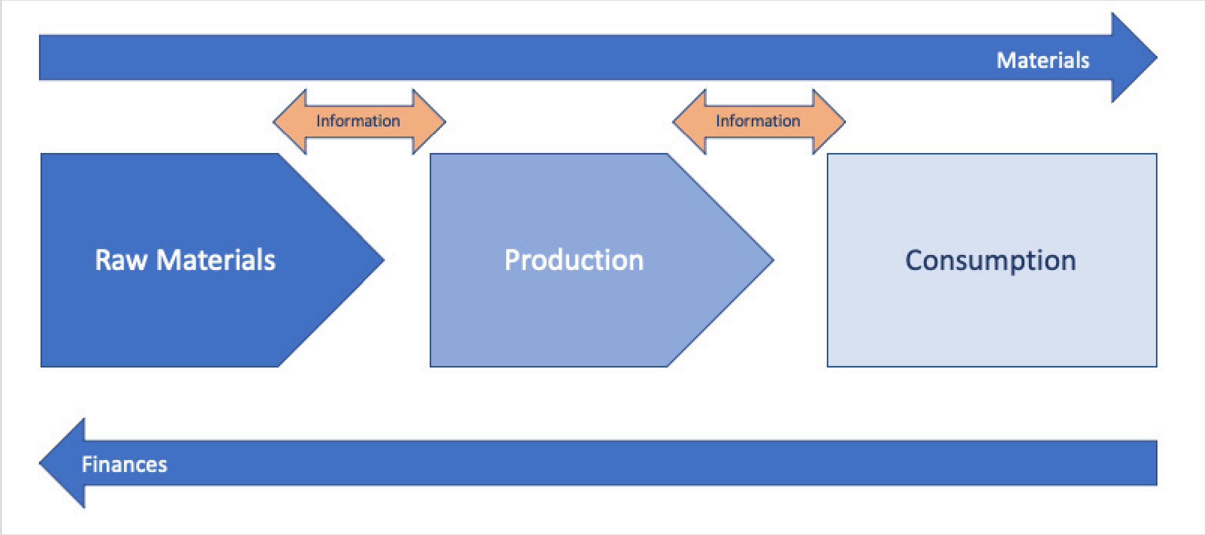


Figure 5. Production systems and flows. Source: Authors.

Value is produced at each stage of the process, while waste is generated and energy used. Frictions and inefficiencies occur within and between the elements of the process which impact on the productivity.

The multi-directionality of these flows is the basis for analysing methods of production with system-wide perspectives. These forms of analysis include:

- Supply chain analysis, which considers the flow of materials through the system.
- Value chain analysis, which adds considerations of value and profit to supply chain analysis in both international development and single product contexts (Gereffi & Fernandez-Stark 2011; Porter 2001).
- Life cycle analysis, which takes a detailed approach to environmental impacts of a good or service from raw materials through to the end of use and disposal.

The flows of materials, money and information through a system of production, including consumption, are also central to energy productivity analysis as it is important to arrive at net productivity improvements in the system. Many decisions and activities that impact on energy use are strongly influenced by productivity and other outcomes, and perceived value of services and risks for each decision-maker. For example, these forms of analysis may arrive at circular economy systems, that encourage transformation of waste from one activity being utilised as resources by others and thus in turn change the production system.

Supply chain analysis does not include the complexities of relationships between elements in the production, and while lifecycle analyses can provide a complete picture of energy use within a production system it is data and resource intensive to implement, and typically focuses on existing production systems, not future possibilities. Value chains provide a middle ground, including the governance, profit and relationships within the analysis, without the resources required for lifecycle analysis.

2.3.2 Value chains

Value chains are a way of looking at systems of economic activity and how the relationships between the nodes within the system. Broadly, value chains can be seen as:

> *... the series of activities involved in delivering useful products and services, through transforming major raw inputs, with economic value being added at each step* (*A2EP 2017d, p. 8*).

There are two related uses of the value chain concept, which share a conceptualisation of systems of production as a series of connected nodes. First, international development scholars use multinational chains of production for identifying opportunities to attain economic benefits in developing countries (Gereffi & Fernandez-Stark 2011; Humphrey & Schmitz 2000). The second stems from Porter's (2001, p. 52) value chain, which considered how industries can assess the system of production, including outsourced aspects, to attain competitive advantages, as depicted in the figure below.

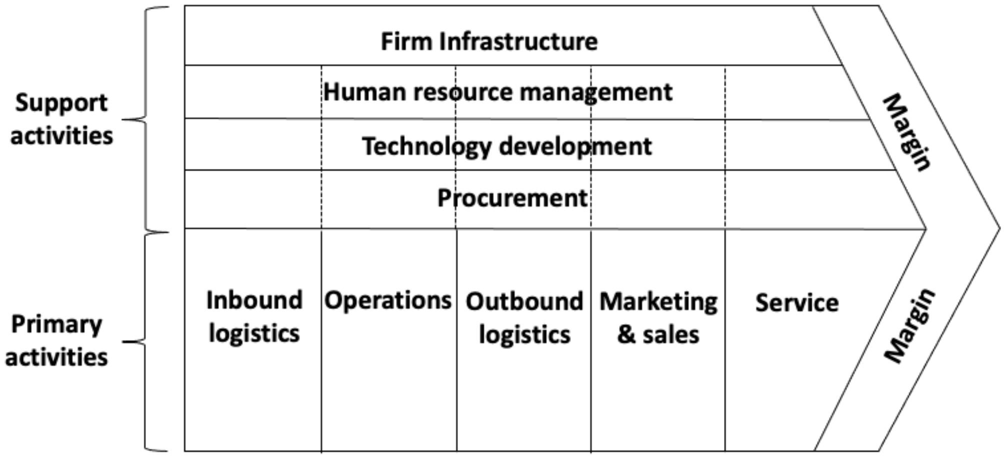


Figure 6. The generic value chain. Source: Porter (2001, p. 52).

Porter refers to the above model as a *generic value chain*, noting that in practice a "firm's value chain in an industry may vary somewhat for different items in its product line, or different buyers, geographic areas, or distribution channels" (2001, p. 52). That is, within a firm there may be multiple value chains, and also each input to production sourced from outside the firm has a value chain. Porter's model focuses on a single firm and its interactions with inputs and upstream/downstream, so a broadly framed value chain could be seen as a series of Porter's firm-based nodes. For analysis, this means that if the outcomes of a value chain analysis are to be generalisable and applicable to types of products or value chains then aspects of production also need to be generalised. This is important for two reasons:

- Generalisability is a key distinction between value chain and lifecycle analysis in this context—it enables sector- and industry- wide analytical scope; and,
- It implies that value chain analysis is subjective. Choices need to be made about what are the important aspects of a production system in terms of their energy use and value-add, and how those aspects are represented and perceived.

Subjectivity means that value chains are best defined as a methodological tool, or analytical framework, rather than a clearly defined object that exists and can be studied.

Further complexity arises from the understanding that value chains are not discrete: their systems, energy use and value added occurs in relation to other sectors. These relations are the basis for both input-output analyses in the national system of accounts (Gretton 2005), as well as the focus on Scope 3 emissions in supply chain emissions analyses (WEF & BCG 2021). The indeterminacy of value chains has been raised in association with another of Porter's theories, industry clusters, where defining the industrial boundaries of what is included in a cluster is a 'creative process' (Porter 2008, p. 202). The inter-relatedness of sectors is also evident in the research undertaken for this project: for example, energy productivity in agriculture is connected to water supply, and how education and health care are provided has implications for the transport sector. As the IEA's (2015, p.129) observed:

> *A key challenge is that industry is highly heterogeneous. There are thousands of industrial processes and countless ways in which energy efficiency projects can be designed and implemented.*

From a practical viewpoint, the subjectivity of value chains and industry boundaries means that the assumptions made that underpin the analysis need to be made clear, including the scope of the system under investigation and its structure and why particular elements of the system are at the focus of the investigation. The flexibility of industry boundaries in conjunction with the definition of value chains as a tool means that it is a flexible and widely applicable approach to identifying energy productivity opportunities: the boundaries of industries and their associated production systems and consumption outputs can be set to reflect the focus of the analysis.

Value chains also pose methodological problems for investigations of energy productivity. Production systems generally draw inputs from a range of sources and sectors which are then transformed to deliver the product used by the end user. For example, food manufacturing may draw on farm produce, water, electricity, packaging, machinery and other inputs in order to generate the final product, be it a packet of breakfast cereal or a frozen meal. It is possible to obtain energy use data at the industry division level to understand the energy inputs to production at course scale, however there are few existing datasets that operate across sectors at the value-chain level anticipated by this project. This is a major problem for innovative analysis which this project will need to address.

Value chains and services

The view of production in a chain is more applicable to material systems of production than services and knowledge work. The Porter concept of value chains in Figure 6 has also proven less applicable to services (Nooteboom 2007).

As discussed above, value chains describe how raw materials progress through production processes and as a result are transformed into final goods (A2EP 2017d; Porter 2001). Material goods are more likely to move through distinct phases of production and are repetitive processes. While some manufacturing and the preparation of products has changed markedly from the conveyor belt system of the Fordist era due to the unbundling of industry and the development of global supply chains (Dicken 2003).

In contrast, services have been defined by product and production occurring at the same time and in many instances the same place, the customer contributes to the production process and that services cannot be stocked (Grönroos 1990). Digitalisation has meant that an increasing number of services can be delivered at the same time but in different places, but the essential differences remain. Another important trend in the services sector is their 'projectification'. For knowledge-intensive services in particular, temporary teams of specialists form to undertake complex and specific projects and then dissolve and reform in different combinations as the demands change, often in multi-firm combinations (Grabher 2002; von Danwitz 2018).

For services, the value chain concept still applies. It is important to understand how the systems and processes of the production of a service interact, use energy and create value. However, service production systems are not as amenable to the linear depictions of value chains as systems of material production.

Box 1. What is a curry?

In many cases simple goods have many uses and provide different end use services depending on the contexts that they are produced and consumed in. For example, a curry may be home cooked, eaten in a restaurant or café or home delivered. The first question is whether they are all providing the same end use services. At a basic level they are all providing nutrients as an end use service, but they can also be seen as different. Home cooked curry provides nutrition and, in some circumstances, may also provide some enjoyment for those who like to cook. In addition to nutrition, a home delivered curry also provides time to do something other than prepare nutrition—relax, continue working, spend time with friends and family—the end use service includes time and convenience. Cafes may include end use services of social engagement and amenity on top of the nutrition.

The production process of each curry would also have distinct value chains for providing essentially the same nutrients and can be analysed as a production and consumption process in different ways. A home delivery analysis may include two distinct value chains, the production of a curry and the home delivery service, which would each have different opportunities for energy productivity. It is also worth noting that from the perspective of the food transport provider, both the curry house and the consumer are customers. Even a home cooked curry varies depending on whether the home cook is preparing from raw materials or using pre-prepared ingredients. As the previously cited quote from Porter indicates (2001, p. 52), value chains reflect the objective or output being analysed, and are likely to be different for each product, market or even purchase.

It is not just basic consumer goods that are open to different interpretations: other seemingly straightforward goods and services can be perceived, and value chains constructed, in different ways. Water has domestic and commercial uses, including for consumption, cleaning, waste disposal and as an input to production for both primary and manufactured goods. Housing investors may be seen as consumers of the constructed housing unit or as producers of housing services for renters, and investors may have different end use services and energy use and productivity objectives than owner occupiers.

2.3.3 Disruption and end use services

The analysis of systems of production does not tend to provide insights into diverting demand and market disruptions, rather is more likely to be concerned with refinements of the incumbent systems. Diversions increase productivity by shifting demand to less energy intensive forms of end use delivery, such as replacing travel with internet conferencing. Disruptions dislodge and replace incumbent producers and systems of production. Disruptions can result in significant improvements in energy productivity, for example dematerialisation and the shift from individual ownership to services. Therefore, the analysis of energy productivity needs to start with a consideration of the end use service provided to include the prospects of diversion and disruption. The diagram below shows how changing the provision of end use services flows through the production system to result in alternate value chain systems. The diagram also indicates how the end use service and the value chain are related within a system.

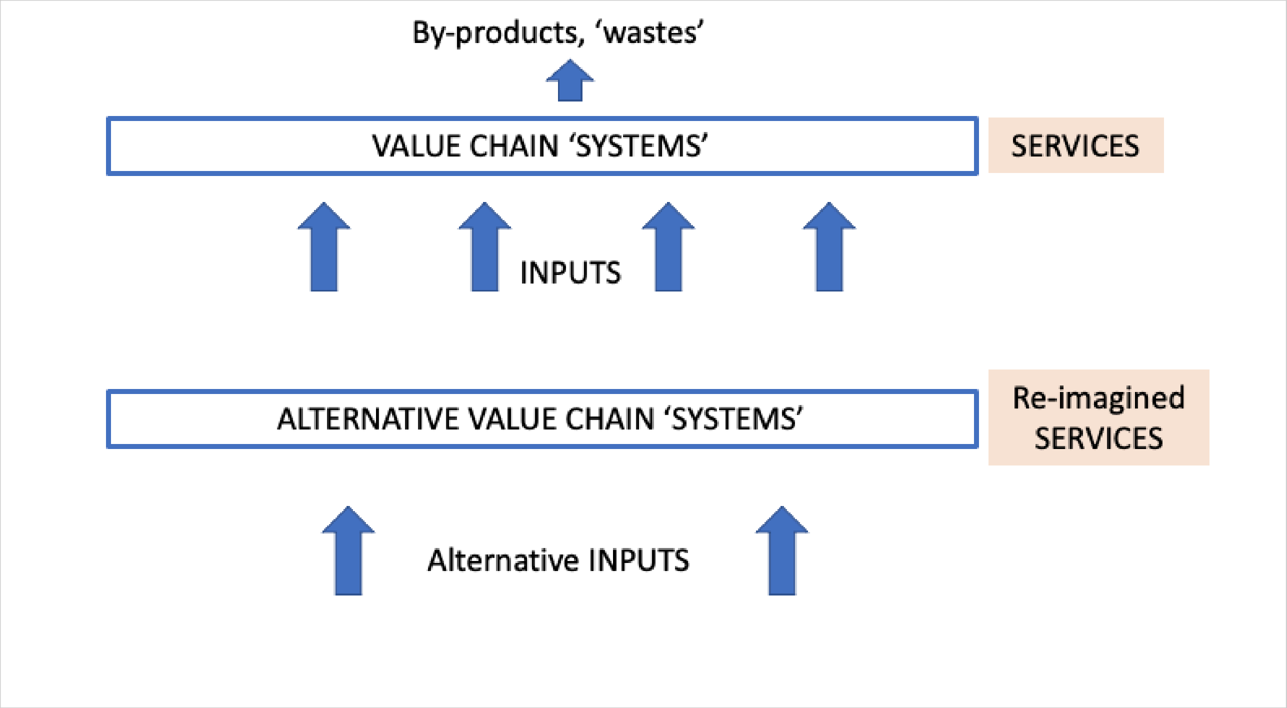


Figure 7. Re-imagining services and the effect on inputs. Source: Authors.

End Use Services reflect the functions that arise from the use of the good or service: the medium of delivery is a secondary consideration. It is comparable to the classical micro-economic concept of utility, the "property in any object, whereby it tends to produce benefit, advantage, pleasure, good, or happiness … or … to prevent the happening of mischief, pain, evil, or unhappiness to the party whose interest is considered" (Bentham, 1823, cited in Broome, 1991, p.1). For example, the end use service of the recorded music or film industry is to provide entertainment to people. The shift from physical storage mediums such as records, DVDs and compact discs to streaming services did not change the end use service of the industry but has had significant ramifications for manufacturers and creators in these fields, as well as behaviour and perceptions of consumers. Another example is the prospect of mobility as a service through driverless cars and peer-to-peer service platforms: the end use service of mobility is provided through on-demand providers instead of individual car ownership. Also, if this 'mobility' service is redefined as access to a service, then physical mobility could be replaced by virtual service delivery, such as tele-health or virtual meetings.

These examples illustrate the usefulness of considering, or re-imagining, consumer value of goods and services through the lens of end use services. By excluding systems of production and how the good or service is currently manifested, opportunities for diversions and disruptions that result in increased energy productivity in providing the same end use, as distinct from the same product, can be explored.

2.4 Bringing it together: Energy productivity, transformation and value chains

As noted earlier, energy productivity improvements can result from process innovations through to disruption and the transfer of entire production systems to new processes and goods and services. Therefore, changes that impact on multiple nodes within value chains that improve energy productivity can be seen occurring on a spectrum or within a hierarchy, including refining of processes, displaced demand, alternate provision through to disruption. The extent of energy productivity benefits will depend on where and how energy is used in value chains, and how changes affect value creation. It is also the case that not all changes to systems of production will result in energy productivity benefits, and some changes that result in energy productivity benefits may also increase energy demand. As the socio-technical transitions theory in Section 2.2.3 implies, the greater the scale and scope of the possible change the more resistance from the incumbent industries, social practices, and institutions that have coalesced around the existing regime also increases, unless they can adapt to a viable model or absorb the disruption. In these ways, disruption can also drive reactive innovation.

The relationships between types of production and consumption changes, the scale of benefit and whether the change, is predominantly technical or social in nature are depicted in Figure 8. As indicated by the discussion above, this is a generalisation of these relationships, with the scales of outcomes identified through value chain analysis dependent on the structures of the industries and systems of production under investigation.

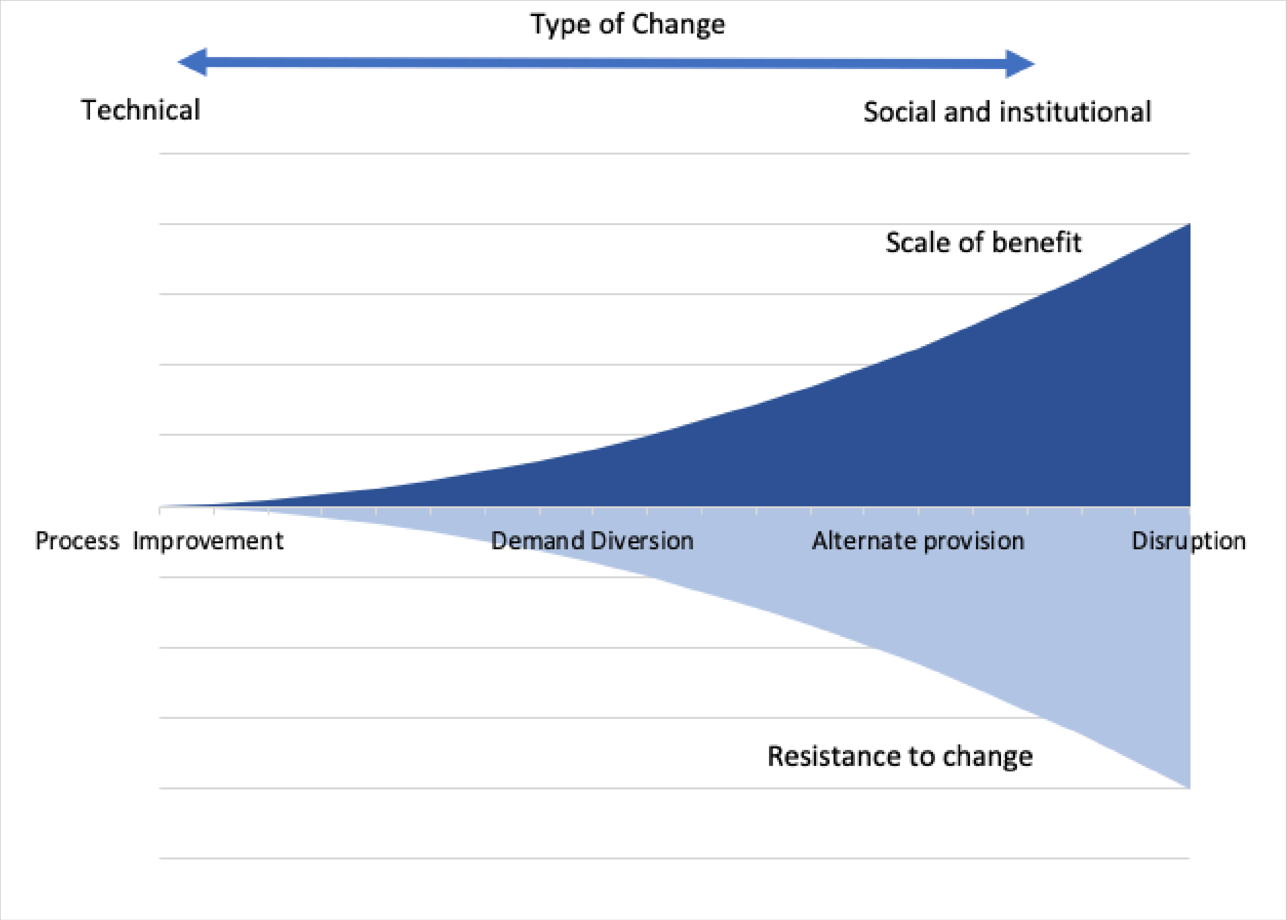


Figure 8. Energy productivity and process changes. Source: Authors, adapting Geels & Schot (2007).

With these qualifications considered, the purpose of the diagram is to highlight the trade-offs in energy productivity improvements that are implied in socio-technical transitions theory. The transition of niche-innovations into the mainstream socio-technical regime requires a range of social, institutional and market actors to adjust to the new paradigm. Therefore, as the large-scale changes to systems of productions and socio-technical regimes, that impact across multiple nodes in value chains, may result in greater benefits but also face greater resistance to change (e.g. Arthur 1989). Greater resistance to change also implies that there is a greater risk that innovations and changes to production and consumption will not be taken up. This links the diagram to socio-technical transitions theory, as the *type of change* arrow at the top correlates to the structuration access included in Figure 4 (Geels & Schot 2007). System and society wide changes that result in energy productivity improvements are increasingly likely to be more dependent on non-technical interventions such as policy, economics of production and understanding the inertia of social incumbency. As the discussion of cement in Box 2 Box indicates, as the proposed scope of change increases so does the organisations and institutions affected.

Box 2. Cement, energy productivity and process changes.

Cement is an energy intensive product that within concrete is widely used in building and infrastructure construction, and provides an example of the different process changes:

Process Improvement—More efficient grinding and kiln technologies for use in cement production (Hasanneigi *et al.* 2012).

Demand Diversion—Use of sand, blast furnace slag, fly ash, geopolymers and other additives to replace part as a partial replacement for cement in concrete—for example glass waste (Taha & Nounu 2008).

Alternate Provision—Development of engineered timber products to replace concrete in construction (Kremer and Symonds 2015).

Disruption—Reduce demand for infrastructure and buildings through increased working from home, on-line shopping and tele-health, a possible result of the pandemic (Autor & Reynolds 2020).

The increasing focus on an array of non-technical aspects of the changes to the production system is evident in the examples, although they rely on alternative technologies which may exist, emerge, or adapt to new roles. Changes associated with the process improvement impact predominantly within the batching plant, the inputs to production and outputs from production are the same. For demand diversion, there are changes to the production value chain as the reuse of waste resources enters the system. The resulting product may also have different use and deployment characteristics that need to be reflected in education and training systems. Alternate provision through the replacement of concrete with timber products extends these changes to the systems and processes of production further, likely impacting on design and engineering in the sector. The example of disruption is entirely social, albeit with the potential for further development of internet communication systems.

2.5 Summary

This chapter has summarised the foundations for this research: energy productivity and innovation, disruptions and socio-technical transitions, and systems of production.

For energy productivity, the key points are:

- **Australia's energy productivity baseline**—Overall, Australia's energy productivity has improved by 1.9% per year over the past 10 years, but is required to double for NEPP2.0 goal by 2030.
- **International comparison**—Australia's energy productivity is largely lagging most of OECD countries and was 14% below the G-20 average (based on 2011 data)
- **Potential**—Australia is on track for a 44% improvement between 2010 and 2030 and could increase by 97% up to 2030, driven by energy efficiency and electrification. Opportunities lay in managing behind-the-meter demand related to supply and consumption of products and services.

Improving energy productivity can capture broader social and economic benefits beyond only focusing on saving energy, including increased energy security, business competitiveness, resource efficiency and carbon emissions reduction. How to assess and improve energy productivity often presents as a quest for industries. This section reviewed the conventional and alternative metrics of energy productivity, including total factor energy productivity measures:

- **Conventional measure of energy productivity**—Traditionally, energy productivity is measured as the economic benefit gain from each unit of primary energy used. This needs to expand 'per unit of energy use' to the wider impact of energy generated, distributed and used in delivering the value added.
- **Alternative energy productivity metrics**—Options include: value created per unit of final energy, useful work produced per unit of energy, total output per unit of total energy (operational and embodied). There is also a need to embrace total-factor energy productivity rather than single-factor measures, including economic and resource efficiency factors. This is a particular challenge in sectors producing 'public goods' such as health and education where the value may not be quantified, and may be spread across multiple beneficiaries.
- **Energy productivity and carbon reduction**—Energy productivity improvement is coupled with carbon emission intensity reduction and decarbonisation target. To increase the energy productivity, businesses and organisations need to move to cleaner energy.
- **Transformation of energy productivity**—To transform energy productivity for value chains, key determinants for improvement should be considered, which include energy management enabled by Industry 4.0 digital technology, system optimisation, business model transformation and value creation or preservation. Mechanisms that facilitate fair allocation and sharing of benefits and costs across boundaries, such as blockchain, are also essential.

Australia has the potential to achieve the target of doubling energy productivity by 2030 through improving energy productivity in different value chains. Thus, specific approaches for measuring the energy productivity for each value chain need to be applied, particularly for those such as water and education services that have not been deeply analysed.

The second section introduced innovations, value chains, end use services, disruption and the multi-level perspective of socio-technical transformations. The central theme is that innovation and change is a result of social and economic processes and practices as much as it is technical. Innovation is defined as the adoption of inventions, the absorption of new technologies into the ways that societies and businesses operate.

Definitions of key aspects of the project are also set out, including:

- **Innovation**—The putting of inventions into practice, may include new products, new methods of production and new ways of doing business and new ways of interpreting and allocating 'value'.
- **Value chains**—A framework for analysing systems of production—based on the value added through the 'chain' of activities and inputs to production.
- **End use services**—The functions that deliver value, and arise from the use of goods or services, as opposed to considering the good or services as the end result of its provision.
- **Disruptions**—The rise of new providers in established markets at the cost of established companies or incumbents, often associated with innovation.
- **Socio-technical transitions**—A framework that explains major shifts in technologies and how society uses them through three interacting layers:
  - The **socio-technical regime** is the dominant technical and social practice.
  - **Niche innovations** are new developments that operate on the fringe of the main market, and at times align to shift the socio-technical regime.
  - The **socio-technical landscape** includes factors such as government policy and consumer preferences that shape the direction of change and the adoption of innovations.

Value chains are defined here as a framework or method for assessing systems of production. This definition is founded in the observations of Porter (2001) on the generalisability of value chains, as well as reflections on the previous studies of value chains, where assumptions and decisions as to what is important for the study distinguish the analysis from lifecycle approaches to energy research. In combination with the reconsideration of end-use services—what is the purpose and underlying value of the good or service consumed—provides a scope for considering both energy efficiency through process improvements as well as disruptions and demand displacement.

3 Approach and methods

The approach and methods used in this research stem from the concepts from the previous chapter i.e. by value chain analysis and the consideration of end use services, opportunities from energy productivity through to transformation. The method for this project began with broad sector overviews of energy use and productivity within the seven value chains identified for analysis, and then worked through a process of refinement and further research to establish recommendations that were prioritised by the IRG and through multi-criteria assessment by the research team.

3.1 Analytical approach

This analysis of production systems and consumption applied in thus project can be summarised in the following four questions:

1. What is the end use service provided and how is its value perceived?
2. What is the current value chain, or chains, that results in the service?
3. Are there alternative ways to produce the same end use service?
4. Are there new systems of production that are more productive from an economic and energy perspective?

These questions position research within the conceptual framework discussed in the previous chapter.

3.2 Methods

The method used for this research consisted of three phases, which reviewed and synthesised knowledge of transformative innovation to scope potential value chains that offer high potential for energy productivity transformation. The research outcomes from the method are:

3. Define energy productivity and end-use service transformations;
4. Map value chain energy productivity transformation opportunities; and
5. Prioritise transformative solutions for value chains.

The approaches, tasks and key deliverables of the four phases proposed for the project are detailed below.

Phase 1—Define end-use service transformation

This phase investigated how end-use services can be transformed to realise major energy productivity gains through the development of discussion papers and frameworks that were presented to the IRG. This included synthesis of research and sector knowledge and understanding of energy transformation in relation to end-use services as a foundation was undertaken to inform the assessment of opportunities to increase energy productivity undertaken in Phase 2 of the research.

The framework included potential for transforming technology, business models, and end-use services, as well as wider socio-technical transformation and market disruptions.

The outcomes from Phase 1 were:

1. A high-level conceptual framework for ‘end-use services transformation’,

2. An overview of energy productivity in Australia, and a definition of a future desirable state as a result of transformations and increased energy productivity; and
3. A ‘value chain transformation’ framework, that is set out in this chapter and informed the scoping of high transformation potential value chains in *Phase 2*.

Phase 2—Map energy productivity transformation opportunities for value chains

This phase undertook value chain analysis to identify those that offer large-scale opportunities for energy productivity transformation. The energy and productivity overview and framework were used to assess the current state of energy productivity within industry sectors and value chains in Australia, and energy transformation opportunities within them.

Phase 2 included collaboration with industry partners and stakeholders in an IRG workshop, to build a common understanding and map transformation opportunities for energy productivity.

The value chains investigated were nominated by RACE for 2030 industry partners, and were food, water, health, education, data, infrastructure and shelter (including construction materials such as cement and steel).

The tasks undertaken in this phase were:

1. **Value chain review**—Research and industry reports on the current state of energy use within value chains were analysed, focusing on end-use services. This included existing value chain analysis, energy use reports, and examples of energy productivity transformation potential in relation to end-use services. Opportunities for process transformation including digital innovation were included as part of this review.

Research teams identified opportunities within each value chain based on their expert knowledge and application of the following criteria:

- Energy productivity outcomes, focusing on value creation and the alternative provisions of end-use services. Given the definition of energy productivity set out in Section 2.1, projects that were assessed to provide value outcomes were prioritised.
- The high-level and aggregate productivity and energy use data available from sources, provided mainly as industry divisions and international case studies. In most cases, detailed data for projects is not available.
- Prospects for value chain and industry transformations.

2. **Develop assessment methodology**—This task applied the transformation framework developed in Phase 1 and insights from the value chain analysis to produce an assessment methodology for identifying energy transformation and innovation potentials. A multi-criteria assessment methodology completed by representatives from the project team was used for the analysis, which drew on the following key criteria:

- Goal Alignment
- Scale of Benefit—direct and indirect
- Application/implementation limits
- RACE for 2030 role in opportunity
- State of research and development
- Other/Overall

The assessment was qualitative, due to significant gaps in the available data and existing evidentiary base to assess energy productivity outcomes for project recommendations, as discussed further in Chapter 6 of this report.

The outcomes of the assessment indicated that there were benefits in combining the energy productivity opportunities into thematic clusters, which would form the basis for sequences of research projects for RACE for 2030 to pursue, rather than proceed with prioritisation of individual research projects with limited overlap.

3. **Validate assessment methodology**—The energy productivity assessment outcomes and proposed research clusters were presented to the IRG, for feedback on the approach and identification of the priority projects and clusters for further analysis.

The outcomes from Phase 2 were:

1. Fifteen energy productivity opportunities across the seven value chains.
2. An assessment of the opportunities, based on multi-criteria analysis.
3. A summary of analysis and prioritisation of value chains with energy productivity transformation potential.
4. A draft report that presents the industry stakeholders' perspectives regarding opportunities and priorities for energy transformation of end-use services and in value chains, which is included in Chapters 4 and 5 of this report.

Phase 3—Prioritise value chains for transformative solutions

This phase assessed the energy productivity opportunities within the two priority research clusters: food and shelter.

Twelve members of the IRG were invited to participate in interviews regarding the priority clusters and value chains identified in Phase 2 of the project, with an email follow-up sent to non-respondents after 10 days as allowed in university ethics requirements. This resulted in four interviews being undertaken. Ethics requirements preclude the provision of any identifiable details from the participants.

An IRG workshop was conducted to engage with key stakeholders to test project outcomes and the mapping of energy productivity opportunities into research clusters, identify potential project partners, aligned research and further opportunities and priorities.

4 Value chain analysis

The investigation of opportunities for energy productivity gains in value chains through value chain analysis, was described in Chapter 3. This chapter provides the energy use and productivity contexts for the seven value chains investigated: data, education, food, health, infrastructure, shelter and water, which results in the identification of projects for increasing energy productivity. This information provides the evidence base on which these value chains were identified for investigation by RACE for 2030 CRC partners.

The review of value chains includes summaries of productivity and energy use to inform the identification of energy productivity opportunities to be appraised for further analysis and as prospects for implementation as part of the RACE for 2030 research agenda. The energy productivity opportunities recommended for further analysis included in this chapter were selected based on the assessment of the research teams undertaking the sector analysis. The foundations for prioritisation were to identify opportunities that reconsidered the end use services provided, provide energy productivity outcomes through value creation, and considered outcomes from a value chain perspective. As a result, technology projects such as heating, ventilation and cooling (HVAC) systems were not promoted as opportunities as they typically present incremental and efficiency-based outcomes by intervening at specific instances in value chains, rather than addressing transformative energy productivity aims and benefits as defined in Section 2.1 of this report. From a quantitative perspective, the assessments were based on industry division scale evidence derived from the Australian Bureau of Statistics and Energy Australia data, and other indicative data sources of energy use with the sectors included in the scope of this project. The emphasis on transformative and innovative projects at the core of this project also means that detailed assessments of energy productivity outcomes have not been undertaken, particularly in the Australian context. As a result, the 15 energy productivity opportunities selected were based on the expert and informed opinion of the project team and via engagement of the IRG within three project workshops.

The energy productivity opportunities are summarised below in Table 3. The following sections in this chapter provide the basis for why these opportunities were selected as result of the research processes set out in the previous chapter.

Table 3. Summary of energy productivity opportunities.

Value chain	Opportunity title
Data	Data monetisation Blockchain for data provenance
Education	Digitisation of education delivery Travel minimised Transnational Education
Food	Carbon footprint tracking Food transparency Cold chain for food
Health	Public health Telehealth
Infrastructure	Improve telecommunications productivity Make better infrastructure decisions
Shelter	Innovative building materials and design Building performance transparency
Water	Agriculture and industry Water for Community

These opportunities are introduced here, and the priorities as identified by the project team and IRG are discussed in more detail in Section 5.

4.1 Data

4.1.1 Introduction

Today data is considered as the 'new oil' for the digital economy and revolutionising the global society. With the fourth industrial revolution data is a driving force for the circular economy. The European Commission has identified the data value chain as the 'centre of the future knowledge economy", shaping the opportunities for digital developments in a number of sectors including food, transport, financial services, health, manufacturing and retail (Connect 2013). According to International Data Corporation (IDC), there is rapid growth of digital information, from 10 Zettabytes in 2015 to an estimated rise up to 180 Zettabyte by 2025 (GSMA June 2025). The data value chain also offers potential to support energy productivity gains through enabling digital tracing of energy use in production systems. This report is reviewing the existing best practices in data-value chain and presenting further opportunities in this sector.

4.1.2 Value chain context

The rapid progress of digital technology has enabled the data sector to play a pivotal role in the national economy of Australia and in many value chains. Businesses have the chance to use data to create new products, processes, and services by increasing access to data and converting data into useful information while preserving privacy and security. In key industries including agriculture, mining and health, Australia has opportunities to build on industrial strengths by using the power of data to further drive productivity gains and deliver world class innovations. The number of Internet subscribers in Australia rose by 3.6% in a period of six months from December 2017 to June 2018 (ABS 2019).

As shown in Figure 9, the data value chain portrays the transformation of data from collection to publication, uptake and finally the importance of data for decision making (Watch Open Data 2018). In a data-driven industry, the value of data is enormous and should be used ethically and effectively. As reported by (Alphabeta Advisors 2018), the gross economic value for data-driven digital innovations in Australia had an estimated market size of A$315 million. In the past five years, Australia has shown progress in the data sector Data61, a digital research group within CSIRO, is transforming data into useful information to optimise energy use and cost through R&D programs such as data analytics, cyber-physical systems, decision, software, and computational systems (ATIC Report 2018).

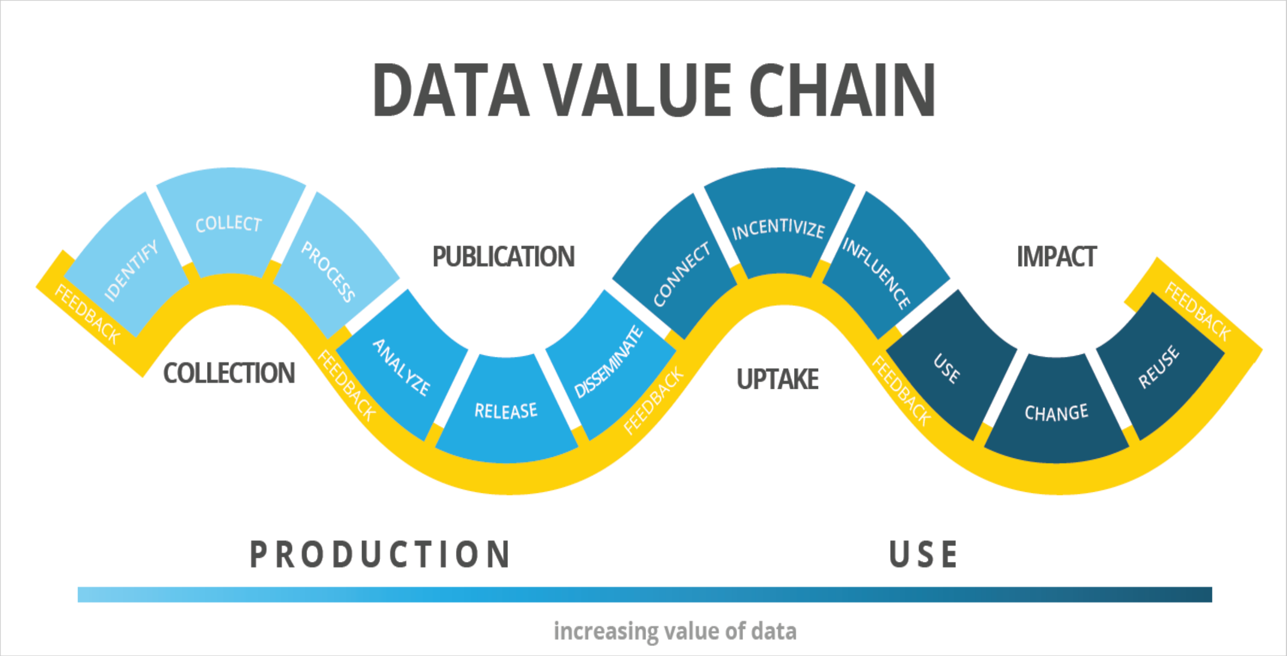


Figure 9. Data Value chain. Source: Watch Open Data (2018). © 2014–2021 Open Data Watch. Licensed under a Creative Commons Attribution 4.0 license.

End-use services

While data services are a growing industry in themselves, data is also an essential element of many contemporary social and economic activities undertaken in contemporary Australia. Therefore, data can be considered infrastructure, similar to water or energy, providing underlying support for other industries by generating useful information or actionable insights and communicating them in appropriate form to appropriate recipients (human or machine).

Data services and innovations have also been at the forefront of increasing energy productivity in other value chains, supporting dematerialisation and transitions from ownership to service provision, particularly in peer-to-peer services. Development of remote sensor networks, in combination with low-cost data communications such as LoRa, are opportunities that align with the Internet of Things, increasing real time data collection and analysis. Such technologies permit the recording of energy use along the value chain, allowing energy productivity of value chains to be calculated more efficiently.

Data is also an industry in itself, with the rise of peer-to-peer platforms, and the high value placed on information.

Energy usage: data

There are two aspects of energy usage in data sector. Firstly, there is energy consumption associated with data generation, transmission, and analytics. Secondly, the energy consumption by the end-use equipment usage. But the influence of information on the utilisation of resources of all kinds (energy, people, etc) is far greater than these, as demonstrated by International Energy Agency studies of digitalisation.

Energy usage in data production

In the process of data generation and transmission, data centres are considered as primary energy consumers. The Australian data centre sector is responsible for more than 4% seems high of national primary energy consumption, with more than 50,000 data centres registered in Australia (IT Brief 2020). Energy consumption also depends on the size of the data centre as a data centre can be classified from small to medium and mega data centre (ranges from 10 kW to more than 2500 kW). Also, small data centres consume almost 39% of total data centre energy consumption in Australia (Consumer Research Associates 2014). The AGC Coombs Group (2018) reported on the energy consumption pattern in a data centres: 45% energy is consumed in HVAC, power, and lighting and 55% energy is consumed in IT equipment (servers, energy storage, transmission of data). The IT equipment itself generates much of the heat that must be removed by HVAC equipment, and the environmental conditions required for reliable operation of the IT equipment also affects HVAC energy use.

Energy usage in end-use equipment

With cutting-edge technology such as Micro/Nanofabrication techniques to On-Chip Molecular Electronics and energy efficiency measures, the energy consumption at the end user, is getting reduced. Costenaro & Duer (2012) reported that for the utilisation of every GB (Gigabyte) of data, the internet consumed an average of 5 kWh electricity, approximately equivalent to US$0.51 of energy costs. The end user share is only 38% of those costs, while the remaining cost is shared by data generation and transmission through which the data travels; (in switch-hubs, routers, ethernet, optical fibres, servers, and data centres).

Data Productivity

In the context of the data value chain, it is imperative that the data sector productivity can be increased either by increasing the dollar value (revenue) while keeping the existing infrastructure or using modern digital technology during the data generation-transmission process (Latif *et al.* 2009). Also, increasing the use of data by converting it into useful information delivered in a timely manner and user-friendly format to a person or equipment that can make use of it can dramatically increase the value or reduce energy use in other equipment, buildings etc. As the majority of the energy is consumed in the data generation-transmission process (in data centres), there have been several metrics proposed (Avgerinou *et al.* 2017) and already applied into the efficiency practices in this sector. These metrics include power-performance benchmarks such as power efficiency of IT equipment (Computer Power Efficiency), Power Usage Effectiveness (PUE) (Grid 2007) and its reciprocal Data Centre infrastructure Efficiency (DCiE), Data Centre Productivity (DCP) (Anderson *et al.* 2008). The data centre energy efficiency is discussed in various reports (Bose *et al.*) which include data centre infrastructure efficiency, improving the efficiency of IT equipment, and renewable energy integration.

4.1.3 Key transformation opportunities

The transformation opportunities identified through the research are: data monetisation, blockchain for data provenance, digital twins for end use, and data centre energy efficiency. Key challenges with data value chains are traceability and transparency of the data. Blockchain data provenance can address to these challenges. Digital twins are an analogue of real-world systems and environment, and so can also transform any data-driven applications. Nonetheless, blockchain and digital twins are useful but many forms of data analytics and design of interfaces that communicate or drive actions are also potentially big contributors to value adding and optimisation of energy use for many activities, not just energy use within the data management system.

These transformation opportunities focus on the data sector because they underpin its potential to enable transformation across value chains, as well as within specific sectors.

Data monetisation

Data monetisation is the process of utilizing data for increasing the revenue in any specific industry such as Facebook, UBER, Google, etc. It increases certainty and demonstrates value regarding any activity, so that financial (or other) transactions can be based on it. Additionally, the data monetisation influences all stakeholders including engineers, financial advisers, production staff or other workers who analyses data. At present all the big brands and fastest-growing companies have considered data monetisation as their crucial strategy (Fred 2017). The 'Data Value Chain,' can help industries to use data as new ways of revenue generation thus enabling circular economy or can be utilised for the reduction of operational cost. There are five key elements of the data value chain which include data capture, data quality and integration, data enrichment, analytics, and monetisation (Rado Kotorov 2018). A report (Knowledge Sourcing Intelligence LLP 2019) indicates that the Australian data monetisation market can achieve an annual growth rate of 6.0% between 2019 and 2024. The global data monetisation market is estimated to witness a growth rate of 47.9% between 2019 and 2025 (Gowri 2019). Tech giants such as Google and Amazon have already adopted data-based platforms and provided convenient shopping experience for their customers globally (Gleeson-Long 2019). However, there is an ongoing debate regarding data monetisation, such as the accusation of unauthorised data selling on Facebook in the US election (New York Times 2018). To summarise, monetising data is an effective way of adding value, but caution needs to be taken as to the outcomes and privacy concerns.

The Blockchain is a distributed platform with a focus on enhancing security and transparency. While digital currencies are energy-intensive, blockchain for data provenance does not necessarily use much energy and if it supports higher energy savings across a value chain its energy use is offset. The difference between a typical database and block chain is that it stores information in a data block which is chained together (Bodkhe *et al.* 2020). Different categories of data can be stored on a blockchain, with the most common uses banking and finance, health care, infrastructure and food. Data provenance is a process of tracking changes made to data, the origin of data and the authority who makes changes to it over time. This has a significant impact on the industries including retail supply chains, academic research, legal video evidence, user authentication (Medium, 2018). Supply chain industries can have accurate provenance information for monitoring the whole process and thus seamless movement of material is accomplished in each stage of distribution from manufacturing units to the wholesale distributors, retail shops, the consumers, and thus benefitting customers through offering traceability. Australia's finance and banking industry has been the dominant user of blockchain technology so far, accounting for nearly 40% of blockchain activity in the country, but other sectors have also adopted it. For example, Adelaide-based ag-tech start-up, T-Provenance has developed a smart tracking software that records transactions on fresh produce from paddock-to-plate using Blockchain technology (CSIRO, 2021). Blockchain data provenance can track and improve process control and audit throughout their supply chains, enabling to greater supply chain productivity.

Digital twins for predictive data analysis

Given the end-user service as knowledge in data-value chain, data analytics is one of key elements in the entire data-value chain. Digital Twins are considered as key enablers for data value chain offering predictive data analytics. Digital Twins use a digital replica of a physical world using Internet of Things (IoT) and Artificial Intelligence (AI), and providing a virtual replica of the physical entities such as devices, people, processes, or systems. This technology provides a powerful visualisation platform and predictive maintenance capability for any industry to monitor and control operations remotely. As reported by (Shamgunov, April 2020), digital twins can be an opening door for 'data economy' by leveraging data for a customer's convenience, ease of use and to increase productivity. Research firm Gartner (Costello & Omale 2019) identified a digital twin as "a software design pattern that represents a physical object or system (e.g. a building and its HVAC systems) with the objective of understanding the asset's state, responding to changes, improving business operations, and adding value." (MKM Report April 2018) reports the growth of the digital twin market up to $16 billion by 2023 with 38% growth rate. Digital twin application can be adopted in manufacturing, healthcare, supply chain and retail industries and energy use. In Australia, the NSW Government recently partnered with CSIRO's Data61 to release its Digital Twin of the Western Sydney City Deal that can be used by planners, infrastructure owners, builders, policymakers, and residents to build and manage the natural environment around them (CSIRO Digitial twin). The barriers for digital twins can include cost, security risk, ensuring interoperability (Advisors 2018). They also need multiple data streams from which they produce 'actionable insights.'

Data centre energy efficiency

With the rapid increase in the usage of data, the Australian data centre market is expanding at a fast pace. A report highlighted a 16.8% annual growth in the national data centre market totalling to a market revenue of $998.4 million in 2017 (Deloitte Access Economics, 2019). As the data centre is a heavy energy consuming industry, the focus of the existing industry is on improvement of data centre efficiency and thus to improve the energy productivity in the data sector. The measures can include changes in government policy to adopt energy efficiency protocols inside data centres, reduction of numbers of small data centres, improving the efficiency of data centre infrastructures and IT equipment, renewable energy integration, reuse of waste heat. Data centre infrastructure improvement can be accomplished by designing air management, cooling system and electrical system inside data centre whereas IT efficiency improvement requires implementation of technology such as virtualisation of servers, Energy Star program certification to aid adoption of high-efficiency servers, Hyperscale servers, optical fibre implementation. The challenge lies within the implementation cost and adoption (Jones 2018), therefore is not closely aligned with research and development and RACE for 2030.

Energy storage offers potential to ensure system resilience, while also opening opportunities to offer energy services to stabilise electricity grids. There is also research indicating that data centres can become more energy efficient through flexible supply systems (Cioara *et al.*, 2018).

4.1.4 Energy productivity opportunities

In line with the goal of RACE for 2030, two opportunities have been selected and these are data monetisation and blockchain for data provenance. These opportunities have been prioritised as based on research into the value chain analysis, they represented the main opportunities for realising energy productivity gains, through increased value through data monetisation and provenance systems.

Opportunity 1: Data monetisation

Considering the end use services for the data sector, the focus is placed on creating a measurable, positive impact on business revenue through the usage of data to optimise and ensure value, and quantify the outcomes. There are two primary ways for data monetisation. The first one is internal (Najjar & Kettinger 2013), which includes using data for improving any business's service and productivity. This is a clear opportunity for future value-chain productivity improvement as obtaining greater value from an existing value chain for the same level of energy input implies greater productivity. External monetisation (Fred 2017), through the process of making data available to customers, creates a new revenue stream for a business or industry and thus increases overall productivity of the value chain from which the data derives. The components of data monetisation are customer intimacy, operational efficiency and risk management and new revenue system. This focus delivers far more value added than simply optimising energy use of systems, so it dominates improvement in the energy productivity metric. However, this opportunity may contribute to energy productivity in the data sector, it may not result in energy savings.

Opportunity 2: Blockchain for data provenance

Data provenance is one of the key components of the data value chain (Data Economy). Data provenance refers to a process of cloud data auditing by enabling data tracking from the source of data (Simmhan *et al.* 2005). Today consumers are more digitally savvy and are more demanding regarding information about the products and services they buy, such as food stuffs. Recent studies on data provenance have revealed that one challenge is establishing trust between data users and cloud services while preserving the privacy of sensitive data. Blockchain can offer transparency, traceability and trust (Liang *et al.* 2017). Blockchain as a technology has been known for some time, but its use for data provenance is still in its infancy. It has potential to be transformative for business process changes and thus improve overall energy productivity in the data value chain and across many value chains.

Other projects

There are several other possibilities for data value chains, including digital twins for improving energy productivity in the health and shelter sectors. Digital twins are an innovative data-driven real-time modelling tool. One can leverage digital twins for business process automation and predictive analytics, which influences energy productivity. However digital twins did not emerge as immediate priorities within the project deliberations.

4.2 Education

4.2.1 Introduction

Education is considered as one of the 'central pillars' of Australia's economy as well as a core contributor to Australian society, as well as internationally. Australia has a well-developed education system that consists of preschools, primary and secondary schools, universities, vocational institutions, self-learning and professional development institutes. In 2020, there were four million students enrolled in our schools, out of which 65.6% were in government schools (ABS, 2020). Furthermore, over 1.4 million local and international students choose to study in Australia's universities each year. Australian university education contributed an estimated $140 billion to the economy in 2014 (Universities Australia, 2021).

The Australian Budget Report (Budget 2019) suggests that government education expenditure alone in 2019–20 was $36.4 billion, representing 7.3% of the Australian Government's total estimated expenditure and 1.8% of estimated GDP. The framing of this expenditure as a cost highlights a dilemma flagged in Section 2.1: we need methodologies to incorporate the value of educational outcomes into economic analysis, so that appropriate priority is placed on spending—and the value of improving energy productivity and broader productivity in education can be balanced against the costs of capturing benefits. Nationally, the education industry creates employment opportunities for approximately 1,094,400 persons (ABS seasonally adjusted data), which accounts for 8.5% of the total workforce including a 1.7% growth rate over the past five years (Australian Government 2020). Also, international education, which is one of the core parts of Australia's education industry, is the fourth largest export for Australia and has contributed $40.3 billion to Australia's economy in the year 2019–2020, making Australia as one of the most popular study destinations after the USA and Canada (DESE 2020).

4.2.2 Value chain context

End use services

The end use service of the educational sector is 'facilitating learning' (McLaughlin and Talbert 1993) leading to personal enrichment and better employment, as well as underpinning productivity improvement across the economy, among many possible benefits. Through the careful design of learning method at educational institutions, productivity gains can be achieved. Different institutes offer services in a number of possible approaches such as teaching, research, training, and innovation.

Energy use

Energy usage in education mainly occurs due to travel, building heating, cooling and lighting infrastructure, computing and the use of papers and printed matter for course preparations. As illustrated in Figure 10, a UK based study of environmental impacts of campus-based and distance higher education systems shows that 50% of energy consumption of campus-based full-time students is due to travelling (Roy, Potter *et al.* 2005). Further, campus infrastructure related energy consumption accounts for only 20% of energy use, while 26% of total energy is consumed for residential heating and cooling in on-campus accommodation.

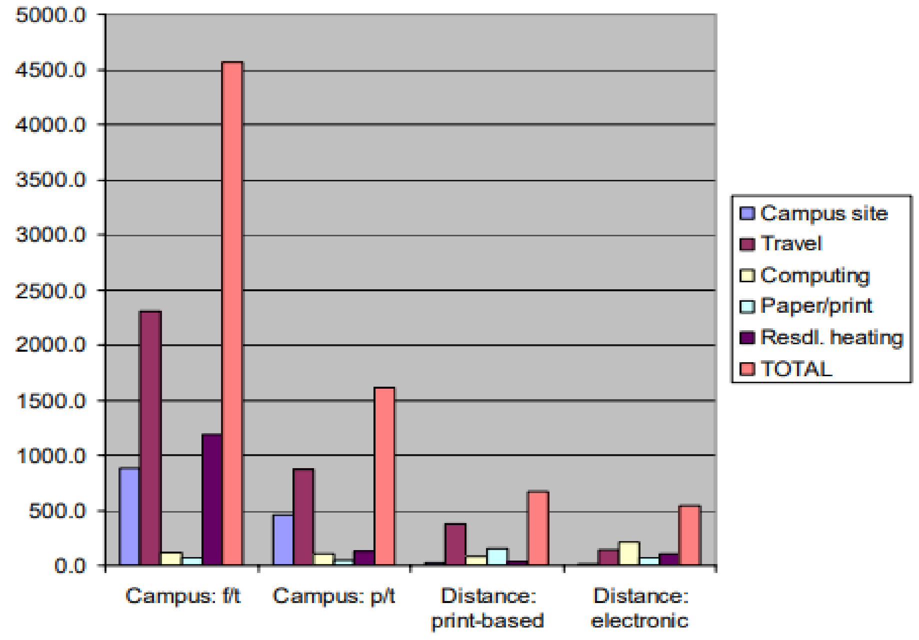
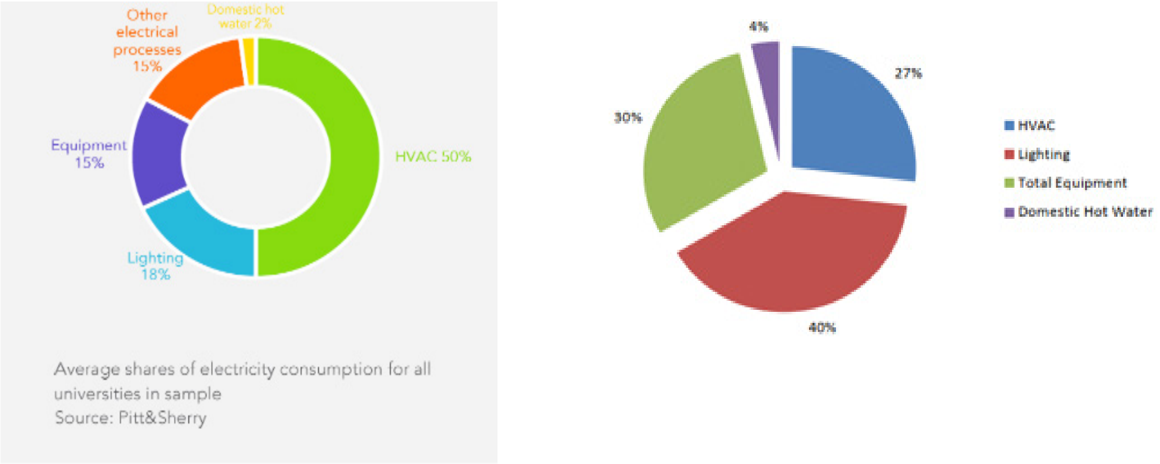


Figure 10. Energy consumption distribution for different learning methods in higher education (average MJ per student per 10 CAT points). Source: Roy, Potter *et al.* (2005).

Education infrastructure energy usage in Australia is included in the 'commercial and services' group, which collectively consumes approximately 5.4% of Australian industry primary energy consumption in the year 2018–19 with only 1.8% annual consumption growth (DISER 2020). For the case of Australian schools, a comprehensive overview of energy use is difficult to come by—particularly for private institutions (COAG 2012). It has been estimated that the highest building energy intensity (energy use per square meter) among all the educational institutions is at universities (CEFC, 2016). Additionally, the energy intensity for the educational sector buildings is comparable to that of hospitals and shopping centres.

Regarding energy consumption patterns, Figure 11 shows that nearly 70% of energy consumption in a university is consumed in HVAC (Heating, Ventilation, Air and Cooling) and lighting (UTS Energy 2016). Schools have also observed a similar pattern of energy consumption, mostly in heating and cooling consuming almost 67% of energy (ACT School Report, 2009–2012). Travel to and from schools may also be a major contributor, as mentioned earlier for education more broadly. Time spent by parents transporting students to schools, and by older students travelling and owning cars is likely a very significant cost and energy consumption that is rarely considered.

For transport related energy, it is associated with staff and student mobility, as travel accounts for more carbon dioxide (CO_2) emissions. For example, the University of Tasmania (UTAS) has initiated a sustainable transport program which has resulted in an estimated reduction of 512 t CO_2-e in relation to staff and student commuting (UTAS GHG Report 2018).



Average shares of electricity consumption for all universities in sample
Source: Pitt&Sherry

Figure 11. Energy consumption pattern: (a) Universities; (b) Schools. Source: Pitt & Sherry 2012. © Commonwealth of Australia 2012, Creative Commons Attribution 3.0 Australia Licence.

Measuring of energy productivity in education

Generally, the output and productivity of education are measured by way of inputs including, for example, labour costs and capital (McGivney and Fonda 2018). As teaching and learning institutions, this measure of productivity indeed leaves much to be desired. From an energy productivity perspective, its measurement is also not that clear-cut. As Education is a service sector, the measurement of productivity is more challenging than for the goods sector because of the difficulty to define a standard ‘unit’ for that service (Productivity Commission, 2021), as discussed in Section 2.1. However, Hanushek and Ettema (2017), have proposed metrics including pupil/teacher ratios and pre-pupil spending as possible options. Other more complex metrics defined by them include grades, employment prospects, college (university) enrolment, test results and so on. In the context of energy consumption, data are typically sliced according to the school type (primary, secondary), geometric characteristics and age (Katić, Krstić *et al.* 2021), to name a few. Chung and Yeung (2021) also shed some light onto the plethora of metrics that can be used to characterise energy efficiency in education settings including kWh/m^2/year, kWh/student/year, kWh/m^3/year, kWh/person/year, MJ (or GJ)/m^2, and kBtu/ft^2. Regardless, there is not an established method to measure energy productivity in education sector and its actions that contribute to higher productivity over a person’s working life and health should be considered, not just the effects within the education system.

4.2.3 Energy productivity opportunities

Based on the analysis of productivity and energy use in the education sector, the two primary energy productivity opportunities identified were related to education delivery systems. The impact of building systems efficiencies on energy productivity in this sector is important, but is not included as a priority as it is not considered specific to education delivery, or address value aspects of energy productivity.

Opportunity 1: Digitisation of education delivery

Similar to the health sector, education in Australia underwent a rapid transfer to online teaching delivery systems in 2020, which if continued would reduce transport energy usage for school commuting (UTAS GHG Report 2018). There are also prospects of reduced energy use, and thus productivity gains all else being equal, through the reduced demand for university facilities. Improvements to digital methods of education delivery may also reduce the demand for international students to travel to Australia to study. However, it is important to maintain quality of educational outcomes.

Opportunity 2: Travel minimised transnational education

Other than the energy use by education buildings, international student travel is a major contributor to the energy usage in the tertiary education sector in particular. Australian universities have offered transnational education (TNE) study programs to international students in countries in Asia for some time, with more than 100,000 students engaged with Australian education providers in other countries in 2018 (HESC 2018). Extensions of and additions to these programs may lead to energy productivity benefits for the Australian tertiary education sector.

Other opportunities

In addition, some of the other energy productivity opportunities that could be investigated are as given below:

- Designing a framework to measure value addition in the education sector
- Intelligent spaces to minimise energy use
- Effect of climate settings of learning spaces on productivity
- Carbon emission education through the live display of emission statistics
- Distributed learning centres to reduce local travel
- Optimised use of buildings to reduce carbon emissions.

4.3 Food

4.3.1 Introduction

The food value chain involves activities from food production, food manufacturing, food storage, food transportation, food provision (either as a service or a product), food preparation (within the supply chain and in homes) and finally ends in consumption (either as a service or a product) and food waste management. In 2018, Australia's GDP was $1.8 trillion and the food and agribusiness industry, including all wholesaling, retailing and services, contributed $138 billion, representing 7.6% of the GDP (Wynn, K., & Sebastian 2019).

To keep the quality and freshness of perishable food, a substantial amount of food, including vegetables, fruits, meats, seafood and dairy products, need to be chilled or frozen during the entire supply chain. Refrigeration is very critical to preserve the food at correct temperature within allowed limit to ensure its optimum safety and high-quality shelf life. The value of food waste in Australia is estimated to be $3.8 billion at farm gate values due to breaks and deficiencies in the food cold chain, among which the waste fruit and vegetable worth $3 billion (Brodribb and McCann, 2020). Since much food waste occurs within the value chain (including at homes), not on farms, the actual value of this waste is much greater. Australian households waste about $10 billion on perishable food due to short shelf life (A2EPc, 2017). Meanwhile, consumers must also be considered as part of the food value chain, as they use transport and energy for food, as well as act as key decisionmakers and the source of money who drive the whole system. Their perceptions of value and service requirements are influential. Food quality for the end user is a key factor impacting health.

4.3.2 Sector context

The energy use for the food value chain in Australia differs throughout the food supply chain and among consumers. For every 1,000 PJ (primary energy) used, 13% is used in the production, 28% in the manufacturing system (18% for processing and 10% for storage), 14% in transportation, 11% in retail and display, 29% in preparation of food for commercial and households and 5% in waste management. In addition to the energy used for the supply chain, there is also a large amount of food loss in the supply chain. Each year Australia wastes 7.3 million tonnes of food, which equates to around $20 billion in loss (A2EP, 2017b). Note that earlier estimates of food waste costs were based on farmgate prices, whereas this is household waste.

Energy use in the food cold chain

The food cold chain is highly involved in manufacturing, storing, transporting, and retailing. It maintains the appropriate temperatures to protect the perishable food products throughout its various processes until reaching the end-customers (either commercial or private). According to the Australian Food and Grocery Council (2017), on average food is moved in and out of refrigeration control 14 times before consumption. Depending on size and purpose, the refrigeration facilities employed in the food cold chain can be cold storage rooms, refrigerated display and storage cabinets, large, centralised supermarket refrigeration system and refrigerated transport (Brodribb and McCann, 2019). This multiple handling introduces significant potential for food loss and loss of quality. Further, if food temperature increases, additional energy must be used to re-cool it later.

Worldwide, the food cold chain is reported to account for 30% of total final energy consumption (Adekomaya *et al.*, 2016). It is estimated that the equipment in the Australian refrigerated food cold chain amount to 1.7 million items and the electricity consumption is 19,600 GWh in 2018 (Brodribb and McCann, 2019). The annual primary energy use for refrigeration in the Australian cold chain is estimated to be about 255 PJ, which accounts for 25–30% of total primary energy in the food chain, and the related greenhouse gas (GHG) emission is approximately 30.3 Mt (A2EP, 2017a). These estimates do not include residential refrigeration use, indicating the total costs of the cold chain are significantly higher.

Australian cold chain from farmgate to consumption has five sectors, including domestic refrigeration in the household, retail refrigeration, refrigerated distribution, cooling of raw material in the primary industries and chilling and freezing of products during the secondary processing stage. Although now dated, previous studies indicate that the refrigeration energy consumption increases dramatically in the final stages of the value chain (Estrada-Flores and Platt, 2007). Domestic and retail refrigeration are the major energy users and accounted for 49% and 44% of the energy use of the cold chain. Thus, the cold chain should include consumers, who do a lot of the storage and 'processing' (i.e. cooking) as well as being the consumers of the fundamental services (nutrition).

In 2018, more than 23 million tonnes of food worth $42 billion based on farm gate values and much more at retail sale value passed through the Australian food cold chain (Brodribb and McCann, 2020), and failure of temperature management (e.g. temperature variation between truck and storage facilities) in refrigeration systems and cold chains has caused approximately $3.8 billion of food waste at farmgate values and worth much more if the lost retail sale value is considered (Brodribb and McCann, 2020). And the energy waste is substantial, as food that warms up must be re-cooled at the next stage of the value chain.

Measuring energy productivity

Innovations are required to enhance the food supply chain to create higher energy productivity. Energy productivity improvement in the food chain is either an increase in value within the supply chain given the same energy and/or cost used, or production of the same value but with a decreased use of energy and/or cost. Measurements of energy productivity will be based on what is the input of a system and what output is achieved. Focusing on innovations or transformations that increases energy productivity, this report will look at how an input of a proposed innovation can create an output that creates a positive transformation in end-user value resulting in added end user value and therefore an increase in energy productivity. A total factor energy productivity (TFEP) approach could be used to measure the energy productivity of food value chain. TFEP includes all the factors related to energy use and created values (Honma and Hu, 2009). Such measurement can also be used to compare with business as usual and what would potentially happen (or what energy would be lost) if energy productivity transformations (through proposed innovations) are not implemented.

This section will focus on three main umbrellas of value chain transformations and innovations to create optimal energy productivity. These include focus on innovations to prevent food loss and reduction in shelf life, innovations to increase food transparency and innovations to improve the performance of food cold chain.

4.3.3 Energy productivity opportunities

Three main opportunities are identified for improving energy productivity of food value chains by transforming food loss, increasing food transparency, and enhancing the efficiency and effectiveness of the food cold chain. These opportunities from part of Priority Research Cluster 1: Food Transparency and Distribution Systems and are discussed in more detail in Section 5.1.

Opportunity 1: Reducing food loss

Two types of waste in the food supply chain are food that is lost due to the inability to harvest, and food that is not sold into the market due to imperfections. The financial loss from waste resulted from food loss or food waste from the food supply chain can reach $ 20 billion annually. This project would address these issues through:

- Improving harvesting productivity through automated picking systems
- Creating a circular economy for food production, by reusing waste products
- Increased support for businesses with shorter supply chains
- Campaign for the use of cosmetically non-conforming food.

Opportunity 2: Food transparency

Improving the transparency of food supply can result in less food loss to problems in production and supply systems, as well as increase value through provenance and providing information to consumers on product quality. This may be done through sensors, QR codes, chemical identifiers, blockchains and packaging systems.

This project can improve energy productivity through reducing waste and increasing the value of the end product to consumers.

Opportunity 3: Cold chain as a service

Refrigeration accounts for between 25 and 30% of the energy use in the food supply chain. Energy productivity in the cold chain can be achieved through increasing product value and shelf life, and reducing product loss. These benefits can be realised through monitoring and control systems, improved energy efficiency of thermal energy storage, and reducing the loss of refrigerants which affects performance. The Internet of Things and data analytics provide the basis for these systems improvements.

The opportunities in the cold chain include improving system effectiveness through packaging that extends product shelf life and reduced refrigeration demands, a greater focus on freshness in the supply chain, reducing the length of the supply chain between producer and consumer, and developing digitally-enabled business models.

4.4 Health

4.4.1 Introduction

The health sector in Australia is important due to its role in promoting and providing wellbeing, as well as providing jobs for an increasing number of Australians, and more jobs than any other sector. The sector comprises a number of different facets, including general practitioners, specialists, mental health practitioners, hospitals and public health.

4.4.2 Sector context

Health care is a major industry in Australia. It is predominantly a public sector industry, and total government spending on health in 2019–20 was estimated at $81.8 billion, equivalent to 16.3% of commonwealth expenditure. The Health Care and Social Assistance sector is also the largest employer in Australia, employing more than 1.3 million people in 2016, as shown in Figure 12.

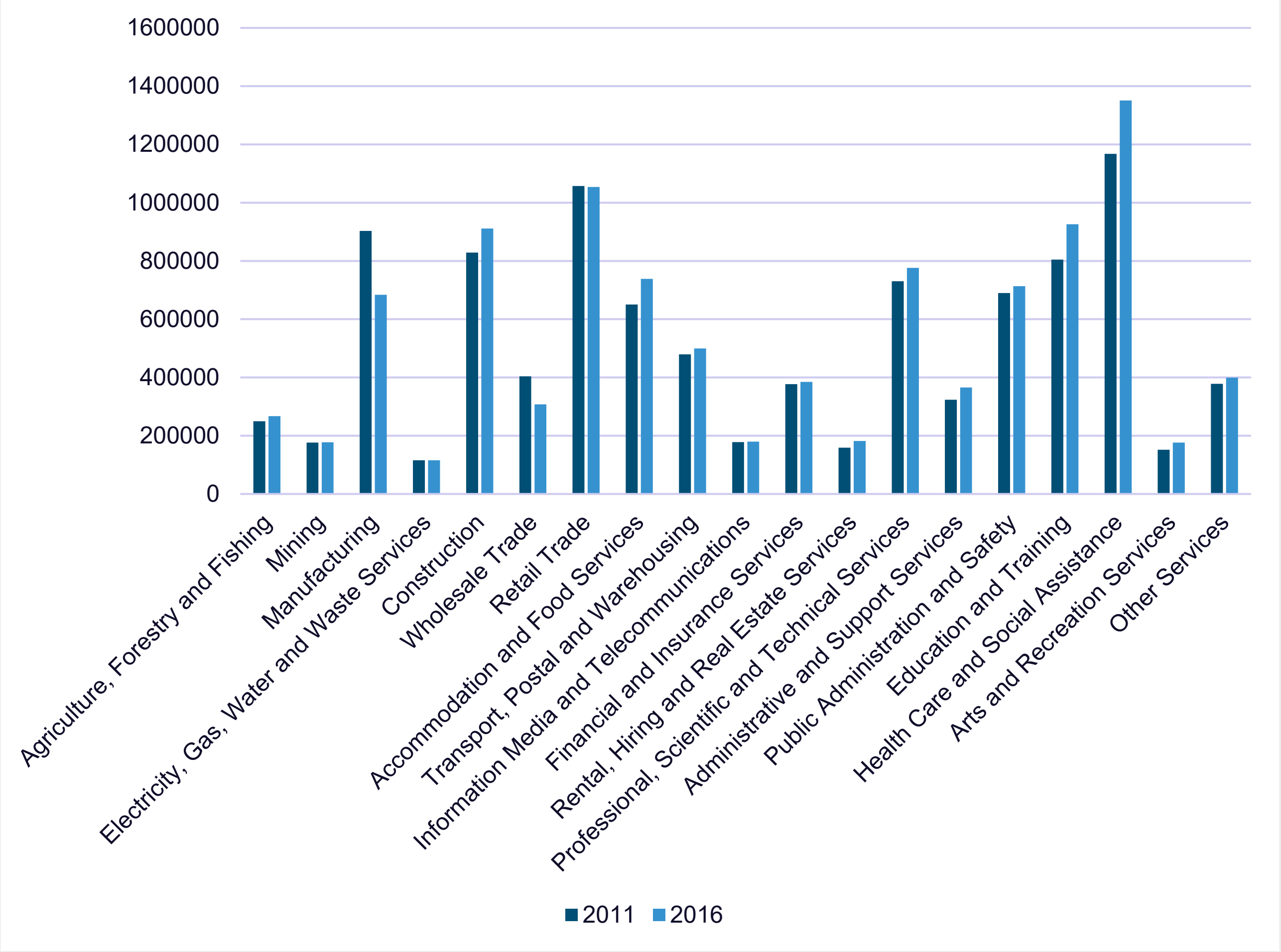


Figure 12. Employment by ANZSIC 1 industry sector, Australia 2011, 2016. Source: ABS (2011, 2016).

Of the additional 384,000 jobs created in Australia between the 2011 and 2016 censuses, 183,000 were in Health Care and Social Assistance, reinforcing its position as the major employer in the country.

The Health Care and Social Assistance sector is not a major consumer of energy in Australia. In the reporting of energy use by sector, it is bundled in with 13 other sectors in the broad category of ‘commercial and services’[1] which in total accounts for approximately 8% of national final energy consumption (DISER 2020)—a higher proportion of primary energy due to its electricity intensity. Transport and time spent travelling associated with health care significantly add to this. However, given that energy productivity is defined as value added/unit of energy, the substantial scope to enhance and reframe perceptions of value, and to use energy more efficiently, it is a key value chain. For example, absenteeism has been estimated to cost over $30 billion per year in Australia. If energy productivity measures drove healthier buildings and influenced other factors driving absenteeism, it would provide substantial ‘multiple benefits’ on this indicator alone.

---

[1] This also includes Wholesale Trade; Retail Trade; Accommodation and Food Services; Information Media and Telecommunications; Financial and Insurance Services; Rental, Hiring and Real Estate Services; Professional, Scientific and Technical Services; Administrative and Support Services; Public Administration and Safety; Education and Training; Arts and Recreation Services; and, Other Services.

Energy use

Australia's health care system, including the pharmaceuticals sector, was estimated to be responsible for 19% of the input-output based national carbon footprint in 2014–15 (Malik *et al.* 2018), which provides an indication of energy use within the industry. For comparison, similar methods resulted in an estimate of 4% in the UK and 10% in the United States.

The three areas of health expenditure that generate the most emissions are public hospitals with 34%, pharmaceuticals at 19% and private hospitals at 10%, therefore accounted for almost two thirds of all health emissions under this estimation, which excludes transport to and from health services. Hospitals also accounted for 40% of health spending in 2018–19 (AIHW 2019).

The method used in this calculation is based on national accounts input-output analysis, which provides a translation of expenditure in the health sector to other sectors of the economy and is widely used to estimate value added in value chains and contributions to gross domestic product (GDP). For emissions calculations, the value of input into the health sector from other industries is converted to emissions using CO_2 per expenditure factors. Therefore, this emissions estimate includes a wider range of intermediate inputs of production to health care services than the direct value calculated as part of the Commercial and Services sector by DISER (2020).

To reiterate, this methodology provides insights into the relative scale of carbon emissions within Australian health care by converting costs attributed through apportioning costs across other value chains. If emissions are assumed to reflect energy use, then it also provides insights into elements of the health care sector that are responsible for significant energy use. Therefore, hospitals are the primary focus for analysis for energy productivity benefits, followed by pharmaceuticals.

Energy use in hospitals

Data on energy use in hospitals indicates that it is predominantly standard building systems that are the source of most consumption, as indicated in Figure 13. Chillers, boilers, fans, lifts and internal lighting account for 85 % of hospital energy use in Melbourne and 84 % in Brisbane, with variations particularly in the use of chillers and boilers likely due to the different climate in the two cities. High rates of ventilation also increase energy use in healthcare facilities. Equipment and medical gasses account for only 14 % of energy use in the sector, indicating a lower potential to increase energy productivity through changes to medical processes and procedures, particularly as this would include a range of equipment requiring different innovations.

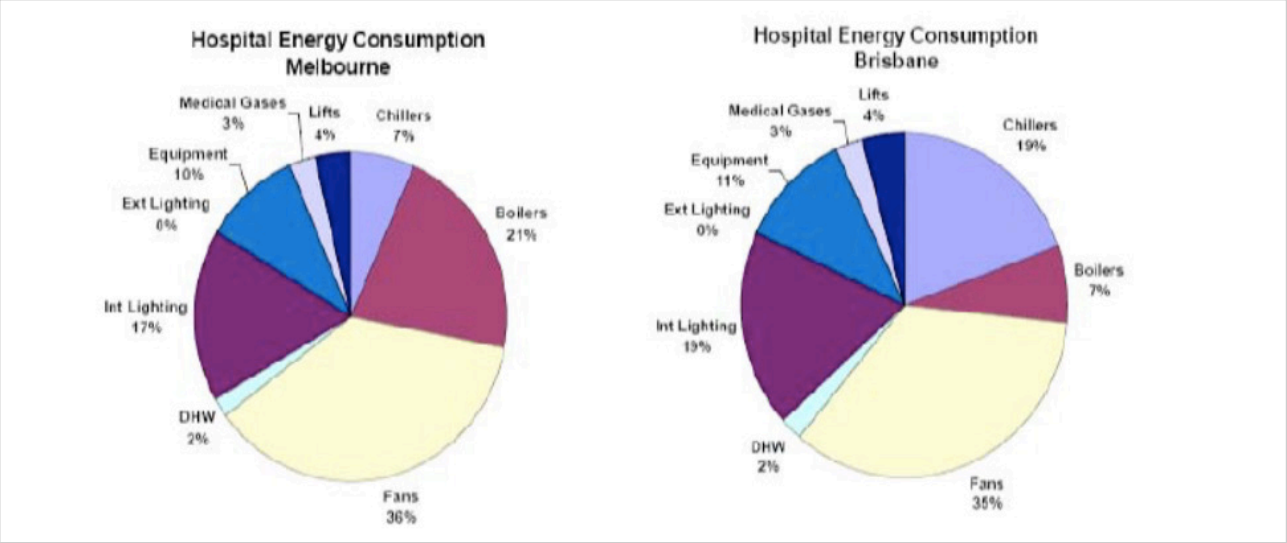


Figure 13. Hospital energy data. Source: Harris, B. 2009, cited in Burger & Newman (2010, p. 8).

Therefore, to improve energy productivity in the health sector, the primary opportunities are in making hospital building systems more efficient or through reducing demand for hospitalisations.

Health expenditure

As noted above health care is a major component of Australian government expenditure. It has been increasing, doubling in real terms between 2000–01 and 2017–18 and increasing by 57% per person over the same time, as shown Figure 14. Over this period health expenditure has also risen from 8.3% of GDP to 10%.

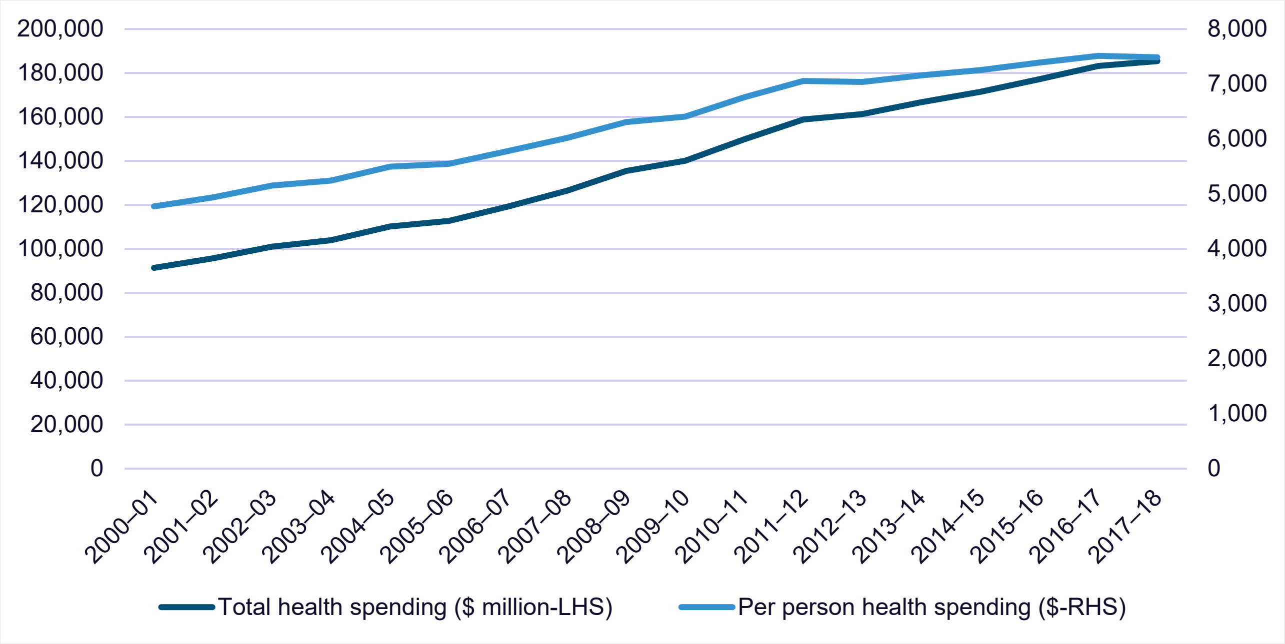


Figure 14. Total health spending and health spending per person, 2017–18 prices, 2000–01 to 2017–18. Source: AIHW Health Expenditure Snapshot (AIHW 2019).

The Health Care and Social Assistance sector employed 1.75 million people in Australia in 2020, approximately 465,000 more people than Retail Trade, the next largest employer (ABS 2020). It is the fastest growing employment sector in the country, increasing by 221,100 positions between 2015 and 2020, and has been a particularly important provider of employment in regional areas (Fairbrother & Denham 2019).

Measuring productivity

The measurement of productivity in health care, as well as other non-market provided services, is problematic as a value is not placed on the outputs of production and it is difficult to identify the measure of output. Given the issues in measuring value added and productivity in health care, the emphasis is placed on energy efficiency or the reduction of energy used in the provision of health care services. This does not preclude productivity gains, as all else being equal a reduction in energy use results in increased energy productivity. Where appropriate qualitative assessments of productivity gains will be included in the discussion, which has been used in other economic evaluations where quantitative measures are unavailable (Denham, Dodson & Lawson 2019). A further productivity benefit, also difficult to measure, may result from decreased worker absenteeism as a result of health interventions.

Reconsidering the end use service

The end use service provided by the health sector is for people to be well, free from physical or mental conditions that impact their lives. By considering this as the end point of health services, rather than the supply of hospital capacity, general practitioners (GPs) or specialists, a wider range of opportunities for energy productivity gains can be considered. In particular, the end use service of 'people to be well' includes keeping people out of medical service centres through telehealth and the prevention of illness and public health initiatives within its scope, as well as reduces absenteeism.

Opportunity 1: Telehealth

There were more than 400,000 GP visits per day in Australia in 2018 (AIHW 2018), indicating that the health sector generates transport demand in Australia's cities and towns, adding to congestion and travel times. It also decreases the requirement for additional floorspace and equipment, and associated energy use. Aspects of Australia's health system rapidly transferred to online platforms in 2020, providing a range of services via telephone and internet conferencing systems. Improvements to the telehealth system can help to sustain increased energy productivity in Australia.

Opportunity 2: Public health

At 2% of the health budget, Australia's spending on public health measures is low in comparison to other OECD countries, yet public health initiatives present high return on investment (PHAA 2019). For energy productivity in the health sector, their importance lies in their capacity to keep people out of hospital, which is the most energy intensive part of the health care system. Therefore, increasing public health spend presents an opportunity to provide long-term improvements to energy productivity in the health sector.

Other opportunities

Paperless hospital and health systems

The replacement of paper-based records with digitised records is seen as an opportunity for implementing blockchain technologies as a productivity and energy saving initiative in hospital systems, as well as other aspects of the health sector (Soltanisehat *et al.* 2020). While the replacement of paper-based systems with blockchain distributed ledger systems may improve health care systems, given the energy use within the sector is predominantly in hospitals and their building systems, the energy productivity prospects of this opportunity were considered to be lower than for tele- and public health opportunities.

Building management systems

Approximately 85% of energy use in hospitals is in standard building systems such as chillers, boilers, lighting and fans. Therefore, improvements in the energy efficiency of building systems will impact on the energy efficiency of the health care sector, and all else being equal the energy productivity. Existing facilities are often very energy intensive, therefore energy productivity improvements may be realised through improved commercial and public building system efficiencies.

Pharmaceuticals

Pharmaceuticals manufacturers have reacted to increasing energy costs and environmental concerns in Switzerland, where chemical and pharmaceutical production is the major energy use sector in the country, at 22% (Müller *et al.* 2014; Zuberi & Patel 2019). However, Australia imports 90% of medicines and "is at the end of a very long global supply chain making the nation vulnerable to supply chain disruptions" (IIER 2020, p. 8). Vaccines are manufactured in Australia, and Commonwealth and Victorian governments are investing in a new facility (DJPR 2020), but there is limited production of essential medicines and supply is maintained through a national stockpile.

The importation of medicines means that Australia has exchanged the energy-intensive processes of pharmaceutical production for storage and international transport logistics. As the value added in the manufacturing process is also located offshore, whether there has been a net gain in energy productivity as a result of importing most pharmaceuticals cannot be easily determined. Structural shifts in the Australian economy have resulted in improvements to national energy productivity (Atalla & Bean 2017), but that does not necessarily mean for small but high-value items such as pharmaceuticals that is the case.

Regardless of these questions about pharmaceutical supply, energy productivity outcomes are likely to be a result of innovation in storing and distribution, such as in the cold chain.

4.5 Infrastructure

4.5.1 Introduction

Infrastructure provides the underlying support for economic, social and productive activities: it is fundamental to the way the country operates. The main sectors within Australian infrastructure are transport, water, communications and energy, which are listed as 'nationally significant' within the Infrastructure Australia Act of 2008. There is some overlap between infrastructure and other RACE for 2030 initiatives, as aspects of transport, electricity, water and data, a central aspect of contemporary communications, are included elsewhere. Given these more detailed investigations of specific types of infrastructure undertaken elsewhere, this analysis of energy productivity opportunities takes a strategic view of infrastructure energy productivity, considering how to improve energy efficiency in infrastructure as a class of public asset and its contribution to energy productivity in other sectors. The embodied emissions and energy used in annual infrastructure construction are significant. Tehhe *et al.* (2019) estimate 5.2 Mt CO_2-e for road and bridge construction alone.

4.5.2 Sector context

Infrastructure makes a significant contribution to GDP in Australia, directly through construction activity and the associated expenditure and indirectly through its facilitation of other activity.

The projected expenditure on infrastructure in Australia in the four years to 2023–24 is $225 billion (IPA, 2020). Transport is the main form of infrastructure projects in Australia, dominating Infrastructure Australia's 2021 Infrastructure Priority list. Of the 40 Stage 1 High Priority Projects 26 on the list are related to road or rail transport, while there are three each for water, communications and data and five others (Infrastructure Australia 2021). Expenditure on transport infrastructure has also rapidly increased over the past two decades, as indicated by the analysis of road and rail projects (Terrill *et al.* 2020, p.5).

Additional large infrastructure projects in Australia include the National Broadband Network, at more than $50 billion. There are also major projects in early stages of development, including $5 billion for the Western Sydney Airport (Infrastructure Australia 2016) and the estimated $3.8–4.5 billion for Snowy Hydro 2.0 (Snowy Hydro Limited 2020).

Primary concerns regarding infrastructure and energy productivity should therefore consider whether greater productivity can be arrived at by better use of existing infrastructure and making better choices for the infrastructure that is constructed. As ACCC Chair Rod Sims (2013) noted, for infrastructure to be most effective in driving productivity growth then better infrastructure decisions need to be made, regulation that promotes efficient use of infrastructure put in place, and price signals and incentives are needed to make sure that new and existing infrastructure is used at its best. Similarly, the Productivity Commission found:

> *There are many examples in Australia of poor project selection leading to highly inefficient outcomes. In such cases, investment in public infrastructure is a drain on the economy and tends to lower productivity and crowd out more efficient projects (Productivity Commission 2014, p. 75).*

While not explicitly stated, the poor selection of projects also has implications for energy productivity in Australia, through the embodied energy in construction materials, and also through the energy use that is facilitated by infrastructure decisions, particularly in the transport sector.

Energy use in infrastructure

There are two aspects to the use of energy in infrastructure, the embodied energy in the materials used in the construction of infrastructure, and the energy demand created by use.

Embodied energy

Concrete and steel are major inputs to the production of infrastructure and are also energy intensive. Australian concrete production results in 0.82 tonnes of carbon dioxide per tonne of concrete, and on global average a tonne of steel produced 1.85 tonnes of carbon dioxide (Beyond Zero Emissions 2018; Kikken 2021). Australia has the 13th highest level of embodied carbon in infrastructure per head of population, at more than 50 tonnes of carbon dioxide and equivalents per head of population based on 2008 carbon replacement value (CRV) (Müller *et al.* 2013). This may be a result of the large distances between our major cities, as well as the low density and sprawling nature of those cities requiring longer roads and rail infrastructure than more compact cities. In addition to the structure of our cites, the prevalence of roads also increases the energy use associated with infrastructure.

While this indicates Australia has comparatively large stocks of carbon-intensive infrastructure, for roads on a lifecycle basis the majority of the energy is a result of the vehicles that use it. Estimates from Europe indicate that vehicle traffic accounts for 18 times more energy for roads than the energy embodied in the infrastructure (Pavement Interactive 2012). Further energy is in the embodied energy within the vehicle stock, which is much greater for cars than the equivalent transport capacity in rail.

Energy in use

Stationary energy infrastructure will have direct impact on energy productivity; however, it is dealt with in detail in other streams of RACE for 2030, particularly the RACE for Networks project. Of the remaining three, transport has the most significant impact on energy usage through its use by individuals and industry, and the embodied energy in transport infrastructure. To elucidate, transport infrastructure is part of stationary energy due to its embodied energy in materials and minor contributions of construction, maintenance and operational energy.

In 2018–19, the transport sector, including postal and warehousing, was only behind households and manufacturing in terms of energy usage by sector (ABS 2020). The transport sector does not include household travel, and petroleum accounted for 48% of household energy costs in that year, indicating significant energy use. Cars accounted for 68% of all journeys to work in 2016 (ABS 2016) and in 2018 there were 19 million motor vehicles in Australia that each travelled 13,400 km on average (ABS 2019). Automotive transport also has embodied energy, and any road project indirectly contributes to the value chain of the automotive sector, but with limited local economic benefit due to the closure of local production in 2018.

Measuring infrastructure productivity

Given the costs of infrastructure construction, there are well-developed processes for infrastructure appraisal and decision-making, predominantly using the economic approach of cost-benefit analysis. The Commonwealth and States have established arms-length infrastructure bodies to assess and prioritise investment priorities across the core transport, water, communications and electricity sectors. Theoretically, these processes provide a rational assessment that results in estimates on benefit-cost ratios and net present values by considering economic impacts of the project proposal over its effective lifespan. However, the processes have been criticised for being overly politicised and undertaken after government commitments as a support for already made decisions (Denham & Dodson 2018), and Infrastructure Australia (2018a) has produced recommendations to improve the process.

Cost benefit analyses provide the basis for assessing the energy productivity of infrastructure in a broad sense, within the limitations of how the established methods for monetising the full range of social, economic and environmental costs in the appraisal process (De Rus 2021). To elucidate, the rational project appraisal method implies that the energy costs associated with the project are included within the purchase prices of the materials used. These costs are also weighed against the marginal productivity gains of the infrastructure users, for example in reduced travel time for transport projects. Energy costs are often a relatively small proportion of the cost of materials which, in turn are only part of the total project cost, therefore standard appraisal methods may involve limited focus on energy costs. Further, standard practices to use concrete and steel for much infrastructure means other options may not be considered, or they may not have mature supply chains or be able to capture economies of scale.

From a pragmatic viewpoint, the use of cost benefit analysis as a standard process in infrastructure provision provides the basis for measuring its productivity, regardless of the form and purpose of the infrastructure.

End use services

The end use services provided by infrastructure vary and can be seen as dependent on the use-case rather than consistent across all users, between as well as within the different types of infrastructure. For example, the end use service of water infrastructure may be to make people and their possessions clean, to provide essential drinking water, to support hydro energy systems or as an intermediate input into production.

While this suggests that reconsideration of end use services for infrastructure has limited usefulness, it also is related to infrastructure having a cross-cutting effect on industry sector productivity. That is, increasing energy productivity in infrastructure choices will impact on a wide range of industries.

4.5.3 Energy productivity opportunities

There are two opportunities for improving the energy productivity of infrastructure proposed. The first is focused on reducing demand for transport infrastructure and travel through improvements to teleconferencing. The second has a broader scope, focusing on improving infrastructure decision-making, to result in efficiency benefits across all forms of infrastructure.

Opportunity 1: Improve telecommunications productivity

Improving the productivity of telecommunications would reduce low-productivity work travel, and as a result improve the energy productivity of existing infrastructure and reduce the demand for new infrastructure. The experiences of remote working and the cessation of work-related travel in 2020 provides the basis for identifying ways to improve the information transfers from telecommunications, and therefore replace more travel to work (commuting) and for work.

Opportunity 2: Make better infrastructure decisions

Infrastructure decisions are generally supported by cost benefit analysis, which is administered by the Commonwealth and State infrastructure agencies. Cost benefit analysis also includes a measure of productivity in the estimation of the net present value of the infrastructure. A greater focus on non-capital expenditure options to solve issues associated with infrastructure, as well as improvements to the cost benefit analysis process, would lead to improved energy productivity in both new and existing infrastructure in Australia.

4.6 Shelter

4.6.1 Introduction

The residential construction sector (i.e. shelter sector) in Australia employs one million people and in 2019 generated $76 billion of work and contributed about 6% to Australia’s GDP. Approximately 200,000–220,000 new dwellings are started each year, of which 55% are classified as detached houses and 45% are units (including apartments). In addition, in 2016 there are almost 10 million existing dwellings in Australia (Australian Bureau of Statistics 2017). About 42% of the residential stock in 2050 is predicted to have been built before 2019. Household energy use accounted for 5% of the Australian total in 2019 (DISER 2020). Housing built before the early 2000s is estimated to perform between about 1–3 stars on the 10-star NatHERS scale, well below the current 6-star minimum requirements. The majority of new dwellings are built to only meet the 6-star standard, with less than 1.5% achieving the performance and economic optimum of 7.5 stars and above. These 6-star requirements are about 40% below international good practice. Just over 66% of dwellings are owner-occupied (with and without mortgage) and 27% are private rental housing with a further 3% social rental housing.

4.6.2 Shelter context

The manufacturing of construction material for buildings and the operation of buildings, including housing, are two of the highest users of energy across all building types (A2EP 2017). For the operational costs across Australian housing, energy is predominantly used for heating and cooling (32%), followed by appliances (20%) and water heating (18%). This breakdown differs for each state and also by building type, size, quality, age and occupant use. For example, space conditioning (heating and cooling) is responsible for most of the residential energy consumption in Victoria, Australian Capital Territory and Tasmania, while appliances and water heating energy are the larger contributors in locations like Queensland (Ryan & Pears 2019). Also, modern buildings that comply with building codes are much more efficient than older ones, though they face a number of emerging issues such as summer discomfort and condensation/mould problems. The need to create innovative design for buildings to adapt to changing climate that leads to higher temperatures and humidity, more frequent and intense hot spells, storms, bushfires, rain and flooding. These factors increase the risk that key infrastructure may fail or be damaged. Recovery from natural extremes can take months or more, so issues relating to protection, rapid rebuilding, etc are also of increasing significance.

End use service of the shelter industry

The main end use service of the residential shelter industry is the provision of shelter that at the same time provides the feeling of safety, security, comfort and well-being. The residential shelter industry also provides a means to carry out lifestyle and living functions (sleep, cook, work, study, etc.) and provides financial means for investment. Australian Council of Social Service (ACOSS, 2019) proposed that improving housing energy performance will provide a ‘safe, healthy and affordable life’. All of the energy productivity opportunities aim to either provide these services at reduced costs or enhance the provision of these services using the same or similar costs.

Measuring energy productivity

Energy productivity in the shelter sector can be measured via the output: how well a building performs (de Wilde 2018) and how well it provides end use services based on its input, the presence of material and appliances, the use of energy, and the cost to operate the building (Arts 2008). Analysing building performance is crucial to achieve optimal energy productivity and productivity can be improved through improvement of design, construction, and operation of buildings. Measures can include predicted, actual, and future energy use for optimal building performance. Methods used to measure energy productivity within the shelter sector include, for buildings, building performance system analysis, use of life cycle assessments (LCA) (Fouche & Crawford 2017) or by tracking real time data on energy and appliance end use (Department of Environment, Water, Heritage and the Arts, 2008). The COAG Energy Council (2018) initiatives have made recommendation to achieve low energy existing homes, however the implementation of Trajectory agreements have been found to make slow progress.

4.6.3 Energy productivity opportunities

The three opportunities presented here from part of Priority Research Cluster 2: Housing Monitoring and Performance and are discussed in more detail in Section 5.2.

Opportunity 1: Building performance transparency

This opportunity combines proposals for improved systems to monitor building energy performance during use and occupation, rather than the current focus on the star rating system during the construction process. Better information on energy use can inform better housing choices through digital systems, blockchain and digital twins.

The underlying opportunities are:

- Onsite assessments to verify energy performance, in conjunction with housing transactions and occupation, and real-time data on energy use for households.
- Energy performance transparency to inform buyers' and renters' housing decisions.
- Enhanced monitoring and data analytics to provide information for occupants, energy retailers and governments to target improvement programs.
- An electronic building passport. A user manual that provides a standardised information on energy use and operations.

Opportunity 2: Water for community

Part of households' energy use is associated with water consumption, predominantly through shower use, hot water system efficiency losses and clothes washing (Binks *et al.*, 2016). As an adjunct to the systems discussed in Opportunity 1, smart metering and water end-use data could assist to identify consumption patterns to reduce water supply and demand. Leakage within the household and water distribution systems can also be detected using smart meters or clip-on adapters to convert 'dumb' meters into cloud-connected smart meters.

Opportunity 3: Innovative building materials and design

By incentivising innovative building materials and design, energy productivity in the shelter sector could be improved. This includes manufacturing of construction materials and their transport to sites, and the construction and installation phases. Additional benefits arise through changing building design as well as planning for the end-of-life disassembly and reuse. In addition to energy productivity outcomes, the use of innovative materials and designs increases energy can inform and be informed by the improvement in building performance monitoring systems.

4.7 Water

4.7.1 Introduction

Water sources in Australia comprise surface water, groundwater, desalination water and recycled water. Surface water is the major source, at 81%. The water industry accounts for approximately 1% of GDP in Australia (ABS, 2018). The Australian economy used 15,100 gigalitres of water to fulfil society's demand in 2018–2019. The water and wastewater sector consumed 16.5 PJ energy in 2018-19 with a 2.8% average annual growth of energy consumption in the last ten years (DISER, 2020). The standard electricity from grids is the primary source of energy used in the water value chain, which is the predominant source of greenhouse gas emissions (GHG) (Cook *et al.*, 2012). Reliance on energy-intensive water sources including desalination and recycling, pumping of water from rainwater tanks, etc means marginal energy consumption of water supply is increasing.

End-use services of the water value chain are diverse, including potable water, washing and cleaning, as a coolant, and as an input into production systems. End users of the water value chain are agriculture, mining, manufacturing, electricity and gas supply, water supply, other industries, and households. Agriculture and households are the two largest water users and account for 62% and 21.4% respectively of the total water consumption in Australia (ABS, 2019). While the agricultural sector has much higher water usage, the overall expenditure by households on water and water-related services is close to $5.9 billion in 2018–19 (ABS, 2019). Therefore, this review has agriculture and households selected as the focuses of the water and energy opportunity analysis and discusses options on how to transform the energy productivity within these water value chains.

4.7.2 Sector context

Energy is consumed at every stage of the water cycle from supply to sewage services, including pump stations, water treatment, water supply, wastewater treatment, and water reuse. In 2012, the energy demand for water distribution was estimated between 0.38 to 1.1 (kWh/kilolitre) dependent on water source and location in Australia (Beca Consultants 2015). The total energy use for water and wastewater services in Australian cities was estimated at 7.1 PJ/annum in 2006–2007 (Kenway *et al.*, 2008).

Water pumping accounts for the most energy consumption in water production and supply, and along which the treatment process accounts for 45% of the total energy required for water supply (McNabola *et al.* 2011). The energy consumption of conventional water treatment in Australia is within 0.01–0.2 KW h/m^3 (Plappally and Lienhard, 2012). Wastewater treatment consumes additional energy over water treatment in general and, depending on the treatment process, the energy consumption varies. Desalination is the most energy intensity water treatment process; the energy consumption of seawater reverse osmosis process is between 2–6.8 KW h/m^3, significantly higher than conventional supply (Plappally and Lienhard, 2012).

There are two main users of water in Australia: agriculture and households. These sectors are considered in more detail below.

Agriculture

Agriculture plays a crucial role in Australia's water consumption, which has a 70% share of the Australian water withdrawals, as shown in Figure 15. There are 9,400 agricultural businesses in Australia, which cover 348 million hectares of agricultural land. The Australian agriculture sector contributed to only 2% of GDP in 2019, while using 8 million megalitres (ML) of water in 2018–2019 (ABS 2020). The Australian Bureau of Statistics estimated that in 2018, 5.0 million ML were applied to crops and 2.2 million ML applied to pastures (ABS 2020).

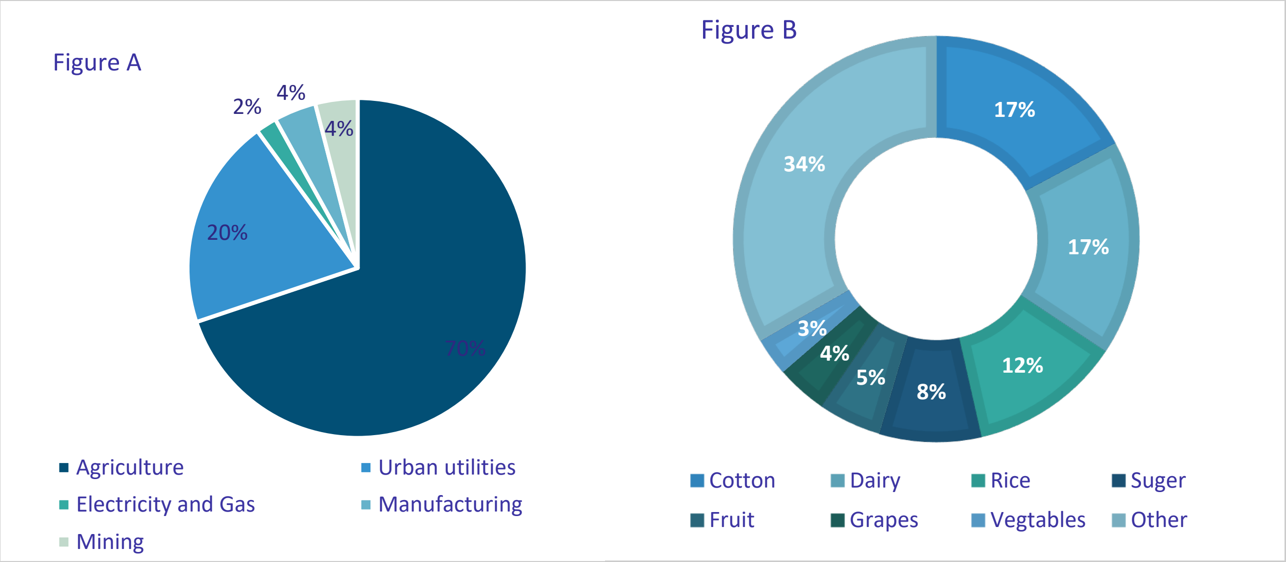


Figure 15. Australian water consumption sector (A) and Water used by agriculture sector (B). Source: ABS (2020).

The demand for irrigation and water usage highly depends on climate conditions. During dry weather periods, the demand for irrigation increases as a result of the lower availability of water. If the primary water source for irrigation is surface water, then the demand for groundwater, accessed through bores, increases during the drought period. In Australia, the source of agricultural water mainly included irrigation channels or pipelines (34%), groundwater (29%), surface water (25%), and on-farm dams or tanks (10%) (ABS 2020). Grid supplied electricity and diesel fuel are the primary types of energy used in agriculture. Water pumping is the primary user of energy, consuming 175,418 megawatts (MWh) of power per annum (Welsh & Powell 2017). Audits of irrigation farms have demonstrated that the water used for pumping can account for between 50–80% of a farm's total energy bill and the cost of pumping water is between $35 and $80/ML (Beca Consultants 2015).

Households

Households account for approximately 30% of water-related energy consumption in Australian cities (Kenway *et al.*, 2008), mostly related to the water use within the household rather than the supply of water to the premises (Kenway *et al.*, 2015). Studies indicate that shower use, hot water system efficiency losses and clothes washing are the major contributors to the water-related energy across households (Binks *et al.*, 2016). Residential hot water heating in Australian cities represents a significant portion of the total energy consumption related to water end-use and consumed approximately 35.5PJ/annum energy in 2006–07 (Kenway *et al.*, 2008).

Measuring energy productivity

Energy productivity aims to capture multiple gains from improved energy efficiency, increased or improved quality of goods/service outputs, as well as enhanced social, health and safety benefits. Therefore, a total factor energy productivity (TFEP) method should be adopted to measure the energy productivity for water value chains, especially for the water value chain for households as the end-use customers.

TFEP combines all the factors related to energy use as inputs (Honma and Hu, 2009). For water value chains, the inputs of TFEP would be direct energy consumption related to water use within the sector (agriculture or household) and energy embodied in water and wastewater services. Primary energy should be used to represent energy consumption in measuring energy productivity, as it correlates well with the operating energy and GHG emissions in Australia. Primary energy inputs could consist of various sources, including conventional, renewable, and recovered energy such as bioenergy generated from biogas. The outputs would be the total value-added including economic, health, social and environmental values. Organisations such as United Nations and CSIRO value water beyond its monetary value. Although it is challenging to quantify health, social and environmental values, there are different methods from the literature that quantify these additional values of water. The TFEP method also considers the reuse and potential increasingly reuse of recycled water and energy production from the wastewater treatment. The value-added of water is influenced by many factors and it is important to identify the key factors when measuring the energy productivity of the water value chain. However, currently the value-added usually only refers to the economic value-added for the water value chain, as it can be challenging to quantify the social and environmental benefits and combine all the added values as outputs of energy productivity.

For the water value chain for agriculture, two main methods are currently used: an energy-consumption-efficacy indicator (ECEI) and energy-economic-efficiency-estimate (EEEE). ECEI considers the ratio of total output value to the energy input consumption. The disadvantage is that even though the indicator shows the average energy efficiency, it lacks clear and independent criteria for distinguishing high and low performance. The indicator relies on its record or other targets and thus does not provide a guideline for independent judgment (Chen *et al.* 2020). EEEE is another method for measurement which does not rely on historical data or other targets but focuses on itself and the current condition.

Table 4. Energy productivity measure of the water value chain in the household sector. Source: (Honma and Hu, 2009).

Output	Input
Total value-added (True water value) Economic value Social value, e.g. perceptions and satisfaction of the water quality and services Environmental value, e.g. resource recovery	Total factor related to energy use: Direct energy: water-related energy use within the households Embodied energy: energy use of water and wastewater services

4.7.3 Energy productivity opportunities

The two energy productivity opportunities identified in the water stream focus on the household and agricultural sectors, and are detailed below. These projects are included in priority research clusters and are therefore discussed in more detail in Chapter 5.

Opportunity 1: Smart household water metering

Part of households' energy use is associated with water consumption, predominantly through shower use, hot water system efficiency losses and clothes washing (Binks *et al.*, 2016). In addition to the Shelter opportunities discussed in Section 4.6, smart metering and water end-use data could assist to identify consumption patterns to reduce water supply and demand. Leakage within the household and water distribution systems can also be detected using smart meters.

Opportunity 2: Agriculture, water and energy

Agriculture accounts for 62% of water consumption in Australia (ABS 2019), indicating the impact of water use on energy productivity in the food as well as water sector. A shift to energy-smart farming would include adopting a circular economy approach, as noted above, smart irrigation systems, greenhouse management through sensors and improved pumping efficiency.

Key barriers of transformation

The major barriers to transforming energy productivity within the water value chain are limited budget for adopting and implementing innovations, lack of innovation and skills, organisational structure, and employee pushback. There is a lack of direct financial benefit to utilities to consider and support managing the water-related energy use and GHG emissions at water end-use (Lam *et al.*, 2017). System integration and interoperability are also challenging to the adoption of digital solutions. This is where blockchain and other digital options can help to fairly share revenue and costs and ensure provenance/accountability. Human resources concerns and silo mentality related to skill gaps, workforce transition, and management changes impact the transformation process (Sarni *et al.*, 2019). A comprehensive understanding of digital technologies must be understood by water utilities, households, and agriculture sectors. The specific barriers of each sector need to be recognised. Strategies need to be established to address the challenges with digital technologies and practices. Barriers to digital agriculture are the development, widespread and maturation of the technologies. In Australia, the development and adoption of digital agriculture technology are less mature than in the USA (Nolet 2018). The barriers can be overcome by bridging the different expectations between farmers and the technology community and understanding the complexities faced by farmers. A major barrier to energy productivity improvement in agriculture is the lack of comparative information on energy use and performance of vehicle and irrigation pumping for farms. It is crucial to have the relevant data to analyse and identify the specific areas that need improvements (A2EP 2016).

4.8 Summary

The review of value chains included in this chapter underscores the discussion in Section 2.3, that in this context value chains are a mode of production system analysis. It highlights the assumptions made about what is the end use service provided and the boundaries of production and consumption, as well as what is included within an industry, and how they impact on the outcomes of the analysis. As a result, the energy productivity opportunities from the sector research can be recategorised into thematic or methodological clusters, as detailed in the following chapter.

The summary of the data relating to energy productivity sectors is set out in Table 5. The data identified varies and is not available for all opportunities, and is therefore not directly comparable across sectors, an outcome of the issues with energy productivity discussed in Section 2.1. Also, transport energy use to is excluded from the data, which according to the analysis in this chapter is a consideration for services sectors such as education and health. Therefore, rather than providing a ranking of sector opportunities, it gives an indication of the key sectors of energy productivity opportunity. The two sectors that are clearly both large contributors to national productivity and also consume significant shares of energy are Food and Shelter, particularly when the aspects of these sectors not included within the data are considered. That is:

- For Food, energy use post-primary production is not included but is likely to be large due to transport, processing and storage costs.
- For Shelter, the ongoing value provided by existing dwellings is excluded.

The opportunities afforded by these sectors have informed the organisation of two of the four research clusters in Chapter 5 around these opportunities: Food Systems, and Digital Housing Monitoring and Performance Systems.

Table 5. Summary of value chain production and energy data.

	Value of production		Energy use	
Value chain	**Estimate**	**Notes**	**Estimate**	**Notes**
Data	$315 million	Only data-driven innovations (Alphabeta advisors 2018)	4% national primary energy consumption	Data generation and transmission, data centres (IT Brief, 2020)
Education	1.8% of GDP	Government expenditure only (Budget 2019)	Less than 5.4% of total energy use	As part of Commercial and Services grouping of 11 sectors (DISER 2020)
	$140 billion	Australian university education in 2014 (Universities Australia, 2021).		
Food	$138 billion	Food and agribusiness industry, including all wholesaling, retailing and services (Wynn & Sebastian 2019)	118 PJ in 2017–18 (0.5% of net total)	Agriculture, forestry and fishing sector only (DISER 2020)
Health	$81.8 billion	Commonwealth expenditure (2019–20)	Less than 5.4% of total energy use	As part of Commercial and Services grouping of 11 sectors (DISER 2020)
Infrastructure	$225 billion for the four years to FY2023–24	Includes new construction only (IPA, 2020)	Approx. 52 t CRV (2008)	Estimate of carbon embodied in Australian infrastructure, based on energy required to replace in 2008 (Müller *et al.* 2013). Use energy data not available.
			136 PJ in 2017–18 (0.5% of net total)	Energy use for total construction sector.
Shelter	$76 billion in 2016	Value of residential construction work	460.9 PJ in 2018–19 (5% of net total)	Residential energy use 2018–19 (DISER 2020).
			136 PJ in 2017–18 (0.5% of net total)	Energy use for total construction sector.

5 Research priorities

This chapter provides a summary and recategorisation of the 15 energy productivity opportunities included in more detail than in the previous chapter. As noted previously, there were considerable overlaps and synergies among the opportunities identified in the research, regarding the nature of the opportunities rather than the sector that they applied to. In addition, two clusters were organised around the Food and Shelter value chains, due to their contribution to the Australian economy and their energy use, as discussed in Section 4.8. The four research clusters and the logic in the groupings, which emanate from the research in Chapter 4, are described below.

Cluster 1: Food systems

The four project proposals in this cluster include the three identified in the food value chain research, plus the agriculture proposal from the water value chain. There is a shared focus on agricultural and food production and distribution systems improvement for energy productivity.

Cluster 2: Digital housing monitoring and performance systems

This cluster includes the opportunities identified in the shelter analysis and the household water use opportunity. The three opportunities address the gaps in general understanding and awareness of how housing performs in terms of energy use and efficiency, in design, construction and operation. An important aspect of this is to use this information to influence housing decisions and transactions.

Cluster 3: Improving digital information exchanges

The shared idea for the three opportunities in this cluster is that travel demand can be reduced by increasing the effectiveness of digital information exchanges. This includes the need to travel for work, either for daily commutes or business travel purposes, travel related to health services such as GP visits, and travel for face-to-face teaching. These opportunities are informed by the transfer to teleconferencing and other forms of remote communications during the COVID-19 pandemic and associated lock-downs.

Cluster 4: Policy for energy efficiency

Three of the opportunities identified as a result of the value chain research involved changes to policy to affect energy productivity outcomes. The opportunities identified indicate that it is important to consider more than the technical opportunities in meeting energy productivity goals. The opportunities included reducing the need for international student travel to Australia by increasing university's offshore teaching engagements, a greater focus on public health to prevent hospitalisations and a greater focus on the implications for energy use arising from infrastructure decisions.

The connections between the research clusters and the value chains and energy productivity opportunities are detailed in the Table 6 below.

Table 6. Summary of research clusters and energy productivity opportunities.

	Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**
Value chain	**Food systems**	**Housing monitoring and performance**	**Improving digital information exchanges**	**Policy for energy productivity**
Education			Digitisation of education delivery	Travel minimised Transnational education
Food	Reducing food loss Cold chain for food Food transparency			
Health			Telehealth	Public health
Infrastructure			Improve telecommunications productivity	Make better infrastructure decisions
Shelter		Building performance transparency Innovative building materials and design		
Water	Agriculture, water and energy	Smart household water metering		
Data	Blockchain for data provenance, supporting			

In addition to introducing the clusters, the following section provides insights to the clusters from the IRG and the resulting prioritisation for subsequent RACE for 2030 projects. As a result of this process, the two priority clusters identified in Section 4.8 based on their value add and energy use were confirmed:

- Cluster 1: Food Systems (Transparency and Distribution)
- Cluster 2: Housing Systems (Monitoring and Performance).

Following the description of the assessment process, these two priority clusters are discussed in more detail, followed by an overview of Clusters 3 and 4 in Section 5.3.

Assessment process

Two assessment processes were undertaken to rank and prioritise the outcomes of the sectoral research detailed in Chapter 4. First, the researchers who contributed to developing the sector analyses and resulting energy productivity opportunities were invited to participate in a multicriteria assessment of the proposals across six criteria:

- goal alignment
- scale of benefit—direct and indirect
- application/implementation limits
- RACE for 2030 role in opportunity
- state of research and development
- other/overall.

Nine responses were received and are summarised in Table 7 below: lower rankings indicate a preferred project proposal.

Table 7. Research team energy productivity opportunity ranking.

Energy productivity opportunity	Sector	1 Ranks	Ave rank	Ave score
Public health	Health	3	3.4	40.5
Reducing food loss	Food	3	3.7	39.7
Telehealth	Health	1	4.8	37.9
Improve telecommunications productivity	Infrastructure	1	4.9	34.9
Make better infrastructure decisions	Infrastructure	2	5.3	37.4
Cold chain for food	Food	0	5.4	38.7
Building performance transparency	Shelter	0	5.7	36.9
Agriculture, water and energy	Water	1	5.8	37.0
Food transparency	Food	1	5.9	37.4
Innovative building materials and design	Shelter	2	6.2	35.6
Smart household water metering	Water	0	7.2	33.5
Digitisation of education delivery	Education	0	9.2	27.2
Blockchain for data provenance	Data	0	9.3	26.9
Data monetisation	Data	0	10.0	26.3
Travel minimised transnational education	Education	0	11.0	23.0

Following the multicriteria analysis of energy productivity opportunities by the researchers, the clusters were presented to the IRG for feedback and prioritisation. The presentation included the rationale for establishing each of the research clusters, and a brief introduction to their constituent projects as listed in Table 6 above. At the end of the presentation, attendees ranked the clusters in order of priority from first to fourth, with the results shown in Table 8 below.

Table 8. IRG cluster prioritisation.

Research clusters	1st	2nd	3rd	4th	Average
Cluster 1: Food transparency and distribution systems	2	3	1	2	2.37
Cluster 2: Housing monitoring and performance systems	4	4	0	2	2.00
Cluster 3: Improving digital information exchanges	1	0	5	2	3.00
Cluster 4: Policy for energy productivity	3	2	2	2	2.33

Cluster 2 was clearly the foremost priority in the opinion of the IRG, with little difference between the second and third ranked Cluster 1 and Cluster 4. Given the closeness of the results between Clusters 1 and 4, it was decided in consultation with the project steering group to proceed with Cluster 1 as the second priority due to the evidence in Section 4.8, the underlying projects having clearer paths to energy productivity benefits in the short term, and greater alignment with industry partners.

Within each cluster, the top two projects from the research team analysis in Table 7 were selected as the primary opportunities.

The IRG also provided comments on the clusters, including other research opportunities, similar projects underway and potential industry partners. These insights are included at the end of the discussion of each research cluster.

5.1 Priority cluster 1: Food systems (transparency and distribution)

This cluster of research projects will investigate opportunities for energy productivity in the production, labelling and distribution of food, including digitalisation. Previous projects have identified the opportunity to use emerging digital technologies such as the Internet of Things and Blockchains for monitoring food systems and providing information on provenance to the consumer (A2EP, 2017). There is also a drive to improve productivity in the sector, with a production target of $100 billion by 2030: if this is to be achieved energy efficient and productive methods, infrastructure, management systems, and regulations need to be in place (Australian Government, 2021b).

Opportunities 1,2 and 3 arose from the food value chain investigations, and Opportunity 4 from water.

5.1.1 Opportunity 1: Food transparency

Improving the transparency of how food is produced can result in less food lost to problems in production systems, as well as increase value through provenance and providing information to consumers on product quality. This may be done through QR codes, chemical identifiers, blockchains and packaging systems.

Information systems in the food value chain is central to this opportunity. A transparent, traceable, and well-connected information system can reduce the potential of food fraud, and reduced food waste from unsold food and/or mislabelling of food. Food traceability and transparency may also aid in detecting parts of the food chain that may be faulty, violate regulations or other potential food security issues, therefore reducing loss and waste. From a value perspective, product quality, trust, and security are important for Australia's competitive advantage and would likely facilitate industries to invest in technologies to reduce risks.

Food transparency to increase energy productivity includes the provision of digital provenance systems, as consumers will pay more as a result of the information transferred at the point of purchase. It provides consumers with more robust information regarding food sources and food products including nutritional value, energy use and environmental footprint. Information added through digital systems may assist consumers to include energy and carbon emissions factors in their decision making to further support energy productive options provided in the market. The technology may also assist in connecting consumers with small scale businesses and protect small scale value chain actors from exclusion.

Technologies that may support this sector include sensor technologies, internet of things, digital codes such as QR codes, chemical identifiers, and ledger technologies such as block chain use (World Economic Forum & McKinsey & Company 2019). In addition, package labels providing information on energy productivity, such as star ratings, may also be alternatives for customers not willing to scan or use digital information systems.

In other countries, blockchain and IoT are embedded in apps for supermarkets such as Walmart and Carrefour. Walmart has successfully completed blockchain for food traceability and transparency for two pilots, pork in China and Mangos in the Americas (Kamath, 2018). In Australia, the use of blockchain and information systems has been implemented through the Beefledger (2021) system, and there is interest to invest in the implementation of blockchain for other produce such as grains, citrus and wine (Citrus Australia, 2020; Dowling, 2020; Gunasekera & Valezuela, 2020).

Opportunity summary

Scope and scale of the transformation

Demand for transparency from consumers is increasing Industry actors claim transparency is the most important factor in building consumer trust in food systems. Up to 94% of consumers find food transparency from manufacturers important (Astill *et al.*, 2019). If applied globally blockchain can support food traceability and transparency, reduce food fraud and food loss from local, national to international scope. This includes food imported into Australia (tracing it's true origins) and exported outside of Australia (verify its authenticity of origin and increase credibility). The scale of transformation is dependent on the level of industry adaptation. Walmart blockchains in the US has traceability reaching international scales. In Australia, Beefledger aims to support global supply chains.

Australia has developed a blockchain roadmap for 2020 to 2030 to allow optimal implementation in several sectors. The roadmap up to 2025 focuses mainly on developing infrastructure, management, regulations and testing case studies required for national blockchain implementation. The anticipated uptake of blockchain nationally might potentially be feasible from 2030 (Australian Government, 2020).

However, as with all innovations and opportunities, there are barriers that need to be resolved for optimal implementation. Overcoming these barriers would require support from industry and the Australian government. More details on this are elaborated in the business model transformation section.

Business model transformations

Implementation providing food transparency using blockchain and other technology is still in its infancy. At the moment the system is still with pilot study implementations to present a proof of concept allowing investment for larger scale implementation (Sylvester, 2019; Gunasekera and Valenzuela, 2020). Documented success tracing produce from farm to fork at national, even international levels has resulted in million dollars of investment into the technology for associated businesses (Kamath, 2018; Kamilaris *et al.*, 2019; Citrus Australia, 2020). Regardless there remains barriers to be overcome and the need for business model transformation if this opportunity were to be implemented on a scale that would result in long term benefits. Business model transformations are crucial to overcome these barriers.

The main barriers in implementation of these technologies include storage capacity, scalability, high cost, high energy use, privacy leakage, and regulation problem, and lack of skills (Zhao *et al.*, 2019; Gunasekera and Valezuela, 2020). Adoption of the blockchain technology would require high-quality data and data management infrastructure, which are concerned to be energy intensive and high in cost (Blandin *et al.*, 2020; Kramer and Hanf, 2021).

For food transparency to increase energy productivity in the food sector, consumer and industry trust, support and uptake of the opportunity is essential. Concerns of privacy leakage and lack of regulations should be addressed in business transformations. A simple approach is increased communication to industry and community stakeholder in simple information transfer. Communicating information of transparency from the food production system, including environment footprint, is complex. The currently existing food supply chain business model has not developed a standardised method for calculating and communicating carbon emissions and energy use as a result of production, along with other aspects of the food system that support food transparency (Shakhbulatov *et al.*, 2019). For supporting efficacy in transactions and information distribution, development needs to continue in the process of designing, verifying, implementing and enforcing systems used to support blockchain in value chains.

Adoption of the blockchain technology would require high human resource skills and capacity development, alongside with these regulations. Adaptation of business models and existing systems need to focus on investment from the public sector and the government in research and innovation and education and training to highlight potential benefits of implementing blockchain. From policy, presence of regulation and standards is essential to encourage development of blockchain ecosystem and support the technology as a means for competitiveness and sustainability. Research and economic analysis to assess efficacy of this tool create improvement and communicate findings are also essential (Kamilaris *et al.*, 2019; Gunasekera and Velezuela, 2020).

Finally, national and international collaboration and investment needs to be considered to allow this system to be effective in Australia (Hallwright and Carnaby, 2019; Australian Government, 2020). Currently, the investment of digital technology in the agriculture sector in Australia is relatively low compared to other sectors (Gunasekera and Velezuela, 2020). Investment is essential if blockchain were to also support economic growth (example of benefits in the following sectors)

Expected benefits of transformation

The benefits expected from food transparency through blockchain is a change in the management of the industry and a change in purchasing behaviour to support energy productivity and efficient. About 20–30% savings can be achieved through behavioural changes and up to 10–20% savings are achieved through change in management of the industry (Wang, 2014).

For behaviour change, there is an emerging number of consumers who prefer to purchase food that is transparent in its energy use. Up to 39% of consumers in a US survey preferred food with greater transparency and up to 73% would choose food that is sustainable (Nielsen, 2017), which is also associated with lower energy use. A survey conducted in Belgium indicates carbon transparency through easy to interpret food labelling increased the participants' purchase decisions environmental friendliness by 5%: environmental friendliness was a combined measure of factors including carbon and energy use (Vlaeminck *et al.*, 2014).

For industry, blockchain logistics management systems can save businesses through better organisation and utilisation of trucking, in both costs and energy consumption (Rogers, 2019). Trucks in the US may drive up to 29 billion miles with partial or empty truckloads due to complicated and inefficient information systems (Salama, 2018). Interviews with truck drivers in Australia show that 30% of trucks run with empty loads, truckers spend up to 40% of their work week without work, and one third of costs contributes to overhead and other costs not related to trucks (Green, 2021). These results from research in the US and Australia indicate that creating a more organised system that matches the supply with the demand more accurately can increase efficiency. One approach that can be realised is through blockchain implementations in the supply chain. Reducing transport cost is an aspect of Australian industry identified as having potential to realise energy productivity improvements (COAG Energy Council, 2015).

Blockchain may also support food savings by preventing food fraud and food security issues through integrated information systems that track food from the source (farm) to the market. By tracking product through its processes, blockchain can reduce time required to trace food that requires recall by 99.9% (Wass, 2017; Crawford, 2018; Kamilaris *et al.*, 2019). In the case of mangoes, blockchain reduced time to trace the origin of mangoes from 6.5 days to just a few seconds (Wass, 2017). By providing a transparent record of food provenance, it has been estimated that blockchain may reduce losses due to food fraud of $31 billion by 2024 (Frangoul, 2019).

Some case studies have shown that blockchain benefits may span beyond increasing transparency, traceability and productivity of food. Transparency supported by blockchain may support waste reduction and environmental awareness along with better supervision and management of supply chain. Details of this transformation would be listed under the food loss opportunity (opportunity 2) as it is more closely aligned with that transformation.

Blockchain has been used in produce markets. In 2016, the company AgriDigital in NSW executed the world's first sale of grain on blockchain, of 24 tons. Since then, 1,300 users and more than 1.6 million tons of grain have been involved in blockchain transactions and has created over $360 million in grower payments (AgriDigital, 2017; Kamilaris *et al.*, 2019).

Application and implementation

Application of blockchain requires key elements: a distributed database, peer-to-peer transactions, and users and participants that can set up the algorithms and rules to trigger transactions between the chain's nodes (Iansiti and Lakhani, 2017; Gunasekera and Velezuela, 2020). At the moment, Australia has developed a blockchain roadmap to provide these elements, the infrastructure, and create strategies, management, regulations, communication, and facilitate increased adoption for implementation by 2030 (Australian Government, 2020). As discussed above, there are elements of the food sector that are using blockchain for tracking, transparency and provenance but as a new technology, there needs to be refinement of the business models to promote uptake, and an understanding of how its use interacts with current policy on transport, logistics and food safety regulations.

5.1.2 Opportunity 2: Reducing food loss

There are two types of waste from the food supply chain that causes large financial loss, food loss which are food that cannot enter the supply chain due to inability of harvesting, and food waste, which are food that cannot be sold into the market or deteriorates in consumers' homes, and is required to be disposed. The financial loss from waste resulted from food loss or food waste from the food supply chain has been estimated at up to $20 billion annually (Australian Government, 2017). COVID-19 that may result in larger impacts, as food loss resulting from unpicked harvest estimated to result in a loss $38 million on farmgate prices.

Innovations to prevent or reduce food loss and waste include automated produce picking, and productive use of waste. However, these innovations need to be supported and scaled up to facilitate adoption to realise energy productivity gains. These innovations are described below.

Automated produce picking

Energy productivity for fruit and vegetables is best optimised by decreasing food loss from unharvested yield and maintaining food quality from time of harvesting to processing. Australia's fruit and vegetable harvest are highly dependent on casual food pickers working on farms. Absence of these workers creates large volume of loss resulting in high cost and carbon by-products. This is most prominent during the COVID-19 pandemic. To prevent situations such as this and increase efficiency, potential innovations in the form of machine powered AI technology for harvest picking could be implemented. Currently this implementation is in its early stages and more research and development is required for large scale implementation (Onishi *et al.* 2019).

Productive food waste

Food produced that does not enter the supply chain can be composted, used for energy generation or thrown into landfill. Reusing the waste would move the sector towards a circular economy, making waste an input material for other uses. One such opportunity is to use the food waste as material for bio-packaging, an alternative to plastics. Bio-packaging uses less energy to make, resulting in energy efficiency and depending on the marginal change to value-add, may also increase energy productivity. The CSIRO (2019) estimate that the transition to more environmentally friendly reusable, recyclable, or compostable packaging may result in up to $900 million in wholesale revenue and the equivalent of $1.7 billion in carbon emissions, water, and energy savings by 2030 (CSIRO, 2019).

Businesses that support gathering of food loss and waste can support provision of raw materials to create liquid biofuel or biopolymers for production or for innovations include plastic made from bio-sourced sugars and protein (Cutter 2006; Weber *et al.* 2002), compostable plastic (Song *et al.* 2009), edible packaging (Mohamed, El-Sakhawy & El-Sakhawy 2020) among other products. This opportunity also supports Australia's plan to phase out plastic by 2030.

Work done by these food gathering businesses, waste management companies, or even Australian government may also be supported through blockchain and robotics and AI innovation. Blockchain can provide rewards and incentives for the public to gather waste at a collection point. Similar to the container for change system, users collect and deposit waste and then can be rewarded by digital tokens that can be stored in blockchains and used in several places. The sorting of waste can be supported by robots and AI systems, further separating those that can be used as an input for food waste reduction circular economy (Wilts, 2021). Blockchain and IoT can also monitor the waste to ensure it would eventually end up in circular economy.

Example of the use of blockchain to support circular economy and reduce waste has been used by an initiative named the Plastic Bank (2019). This initiative originated from Canada yet is implemented in Haiti, Peru and Colombia. It plans to extend to Indonesia and the Philippines. The initiative incentivises people to collect, sort, and bank plastic waste in recycling centres, then reward the action with digital tokens that are provided and secured via blockchain. The tokens that are received can be used for various needs from food to phone charging tokens (Kamilaris *et al.*, 2019). Despite use here is for plastic, it can potentially be used for food waste as well.

Use of blockchain use to monitor food waste approach has been used in France. Here waste is monitored on the quantity and types by waste managers to understand how waste is moved around. Blockchain stored information related to actions taken and has assisted food waste management in France (SNCF, 2017; Kamilaris *et al.*, 2019).

Short food supply chains

Shortening the food supply chain will result in a decrease in transport and storage energy use. It can increase productivity within the farm and increase value for customers through increasing quality and freshness of food. Connecting consumers directly to farmers provides additional value through assured provenance, and a positive for consumers through supporting local farmers, as farmers themselves have guaranteed customers. There are businesses that provide means to connect farmers directly to consumers, however they are currently at a small scale. Upscaling these businesses may support further productivity in energy and value.

Food standards

Another issue of food waste may be that some vegetables deemed not suitable for sale due to their cosmetic appearance. In 2012, it was estimated that 44 million tonnes of food is wasted annually (Edwards and Mercer, 2012) Marketing for these products should be increased, movements such as 'the ugly produce' campaigns support purchase of produce that does not fall into cosmetic standards. This has been attributed to the concentration of market power in Australia's supermarket sector, indicating the need for government intervention to reduce waste (Devin & Richards, 2018).

Opportunity summary

As discussed in Section 4.3 of this report, food loss and waste accounts for 8% of global GHG emissions. In Australia, management of waste counts for 5% of energy use and may cost up to A$20 million annually. Energy used for transportation counts for 14% of energy use in the supply chain (A2EP, 2017). Australia has also committed to a goal of reducing organic waste by 50% by 2030 (Australian Government, 2021a), to eliminate unnecessary plastics by 2025 and have all packaging recyclable, reusable or compostable by 2030 (Australian Government, 2021b). The use of recycled and compostable resources can make a significant contribution to meeting these goals. This indicates both the alignment of the opportunity to national objectives and the overall possibility of the scale of transformations from initiatives addressing food waste.

Scope and scale of the transformation

In 2018–19, the Australian Agriculture and Food industry consumed 103.1 PJ and the beverages and textiles sectors 153.5 PJ of energy (DISER, 2020), totalling 256.6 PJ. The scope and scale of the benefits for each of the elements of this energy productivity opportunity are set out below.

The use of technology in the form of AI, robotics, machine learning and IoT contributes to RACE for 2030 goals by creating opportunities that reduce costs and increase efficiency and productivity. The harvesting stage of production results in food loss of up to 20% (Chen *et al.*, 2020), while effective production systems can lower energy emissions by up to 28% (Crippa *et al.*, 2021). In addition, weed management costs more than $ 4 billion per year in Australia, including costs in its removal and lost production (Sinden *et al.*, 2004; QUT, 2021). The following are existing opportunities and examples of the associated benefits:

- Fruit picker and weed removal robots have already been developed, tested and launched into the market.
- A robot developed by QUT, Agbot II, could save the farm sector up to AU $1.2 billion per year by automating weed removal and improving agricultural productivity (a 30% savings in cost) (McCool *et al.*, 2017; Perez *et al.*, 2017).
- Fruit picker robots can lift productivity. Robots designed for automated raspberry picking can pick up to 25,000 berries a day, compared to human pickers with 15,000 berries a day. Robots also can operate up to 20 hours a day and are not dependent on labour supply (Kollewe and Davies, 2019).
- Apple picking robots under development have reached up to 95% accuracy and may take 7 seconds to pick a single fruit. Humans are currently faster, at 4 to 5 seconds per fruit, however humans cannot operate up to 20 hours a day as robots can. Additionally, the speed and accuracy of the robots will increase as development continues, along with demand for picking robots (Kang *et al.*, 2020).
- Automated sensors are also being deployed and tested using Internet of Things, machine learning algorithms and AI to predict soil, plant and weather conditions and determine the best location, soil and time for planting. This supports efficient production and management of farms.

The use of productive food waste contributes to RACE 2030 by creating opportunities that reduce cost, increase efficiency and productivity, save energy and reduce carbon emissions. The example focused here is the use of food waste to create plant-based materials such as bioplastics.

For produce, food loss stems from production (20% loss), transport (3%) packaging (4%), retail (12%) and the consumer (28%) (Chen *et al.*, 2020). Plant based materials help not only reduce waste, but also recycle and reuse waste as a source of raw material to create other products, mainly packaging. Mainly used are materials such as bioplastics.

Plant based materials can be sued to save energy and carbon emissions. Bioplastics for example, uses at most 92 MJ/kg non-renewable energy compared to conventional plastic that uses at most 156 MJ/kg energy. Manufacturing bioplastics also uses 41% less energy than conventional plastics. At the same time, bioplastics can save between 241 and 316 million tons of CO_2 per year (Spierling *et al.* 2018). To elucidate, if bioplastics capture 12% of the market by 2050, one gigaton of carbon emissions would be avoided. If bioplastic captures 46% of the market 3.8 gigatons would be avoided. The cost to implement bioplastics globally has been estimated to cost between US$33 billion and US$114 billion (IDTechEx, 2020). In comparison, the global value of the industry of bioplastics was US$7.8 billion in 2018 and is predicted to reach US$26 billion in 2026 (Fortune, 2020).

Razza and Innocenti (2012) list benefits of bioplastics:

- The use of bioplastics to replace plastic mulch film can reduce waste, saving up to 40 kg per mulched hectare.
- The use of bioplastics for catering increases recycling by up to 50%, and can increase landfill diversion by 36%.
- Using biodegradable carrier bags can result in a five-fold increase of bio-waste quality, that is the reduced content of non-compostable materials. Research has shown that the amount of non-compostable materials in Italy has even dropped from 10% to less than 2% in its waste management.

There are concerns regarding bioplastics, as studies have shown that the end cycle of the plastics may become more detrimental than beneficial for energy saving, however these studies have not considered bioplastic production using circular economy approaches. The example of a blockchain incentivised circular economy initiated by Plastic Bank described previously shows promise. By creating incentives, users gain interest, waste can be reduced and enter back into the economy. The Plastic Bank to date has over 1 million participants, more than 2000 collector units and collected more than 300 million kilograms in plastic (Kamilaris *et al.*, 2019).

As discussed above, shorter supply chains decrease energy use and carbon emissions used for the transportation of food from farmers to consumers. Some businesses provide food box delivery services, which may further increase productivity by delivering directly to the customers, giving extra value in knowing food sources, supporting local produce, and reducing energy and cost from storage.

- A shortened supply chain can save carbon emissions by reducing the need for individual customer trips from home to markets/ shops to purchase groceries. Rather, delivering vegetables to home directly from farmers reduces the need for storage, energy, and carbon emission as deliveries are done in bulk.
- Deliveries are thought to save up to 70% of travel per shopping load and carbon emissions could reduce by 17–87% (Coley *et al.*, 2009)
- Food delivery systems were found to be more the most energy and carbon efficient option from all means of sale of produce (Majewski *et al.*, 2020).

- Food loss in transport and packaging accounts for 1% and 4% respectively, while food loss in retail display can reach up to 12%. Presence of food boxes also reduce cost from food loss, and allows farmers to have more control over what are sold, increasing efficiency.

Business model transformations

Robotics and blockchain are still under development, although the technologies included in these opportunities are generally available in Australia. Their uptake has been limited to date, indicating they are still within the niche innovations categorisation in socio-technical transitions theory.

As robots are expensive it may be that farm consolidation is required to increase scale to make the return on investment in advanced technologies economical, as has been the case with previous technological develops in agriculture. The impact is on one aspect of the system of production, the removal of product from trees, replacing often temporary, itinerant and low-paid workers with machines. This can be seen as a continuation of the Australian agricultural sector's transition from labour to capital intensiveness over recent decades, in response to global competition in commodity markets (Productivity Commission, 2005).

Blockchain systems for agriculture have tended to be provided as a service to producers and other participants in the sector, either through industry groups or commercial providers (e.g. Beefledger, 2021; DISER, 2018). It is likely that the business models will continue to undergo change and innovation to meet the needs of producers and consumers, given the nascent state of blockchains in agriculture. For more detail on blockchain, refer to the previous opportunity 1.

The energy productivity opportunity in shortening food supply chains is a business model transformation, proposing a greater distribution of smaller food processing, wholesale and retailing facilities, including on-farm, to reduce the costs and energy use associated with prevailing systems of transporting food from production to consumer. The circular economy is similar as an opportunity that requires business model transformation more than technical development, as it is in essence a realignment of priorities in the structuring of production systems.

Application and implementation

The benefits of the energy productivity proposals included in this discussion of the food sector are likely to be slow and accumulate over time.

For robotics and AI in picking, research and development is required to refine the systems and facilitate mass production and increase the speed of uptake. This is the same for blockchain in the food waste system, although blockchain may involve further complex issues.

For bioplastics, currently the cost is higher than for the production of conventional plastic. However, increased uptake of bioplastics would allow economies of scale, initially in waste collection but may extend to other elements of the production system, which would make the transition reduce the costs of bioplastics. Further research is also required to address the concerns regarding their sustainability discussed above, as well as improvements to the production process and its use as food packaging (Kakadellis & Harris, 2020).

5.1.3 Opportunity 3: Cold chain as a service

Cold chain service has the potential to improve energy productivity by reducing primary energy use and increasing value gains through improved food quality and reduced product loss. To realise these benefits, two project opportunities are proposed: high performance and low-cost refrigeration system, and clean and reliable refrigerated transportation.

High-performance and low-cost refrigeration requires the following:

- High efficiency equipment
- Optimisation of system layouts and reduction of heat gains,
- Integration of renewable energy generation and energy storage,
- Recovery of waste heat for heating to enhance system efficiency
- Transformation of business models through deployment of IoT and modern control technologies, and
- Continuous energy use monitoring.

An immediate and considerable amount of energy saving can be achieved within businesses by upgrading to more modern and efficient equipment. For the same cooling load, adopting best practice could save up to 30% in energy consumption (A2EP, 2017a; Commonwealth of Australia, 2021). From 2021, refrigerated cabinets and household refrigerators and freezers sold in Australia have to meet more stringent Greenhouse and Energy Minimum Standards (GEMS) (Energy rating 2020a, b), which over time will result in the phase-out of low efficiency equipment.

Intelligent digital technologies enable the energy optimisation of the whole value chain and facilitate business model transformation. IoT, modern control and cloud computing technologies have enabled the real-time temperature tracking at pallet level, and integration with refrigeration systems for reduced food waste, better food quality and reduced energy consumption and cost.

Poor temperature control is estimated to account for 35% of chilled food spoilage in the supply chain (Wu *et al.*, 2021). As an example of innovations to reduce temperature-related waste, Walmart has installed over 7 million unique IoT data points across over 4,600 U.S. stores, indicating the scale of benefits (Berthiaume, 2021). In Australia, a cold chain study indicated that improving food condition monitoring could result in 5% and 10% reduction in energy use in stationery and trucking refrigeration, equivalent to annual cost savings of approximately $120 million and $15 million respectively (A2EP, 2017b).

Clean and reliable refrigerated transportation improves energy productivity and reduces environmental impact. The cost of transportation accounts for 60% in cold chain logistics (Food Logistics, 2008). There have been increases in the frequency and length of cold chain transportation, for example as a result of consolidation in milk processors (Productivity Commission, 2014). Diesel engine driven vapor compression is dominant in transport refrigeration systems, which has a very low coefficient of performance (0.5–1.75) and consumes up to 40% of diesel during transportation (Tassou *et al.* 2009) and has negative environmental impact due to burning diesel and refrigerant leakage. Alternative refrigeration technologies, including thermally driven refrigeration, thermoelectric cooling and power generation, and air cycle refrigeration should be considered to reduce energy use in food transport refrigeration systems (Tassou *et al.*, 2009).

Thermal energy storage technologies should be overviewed and assessed for their potential to be integrated into the primary refrigeration system. The benefits of using thermal energy storage were highlighted in (Selvnes *et al.* 2021), including peak refrigeration load shift, peak/average load reduction (up to 29 and 25%, respectively), fuel cost reduction and improving reliability.

Replacing diesel with alternative fuels from renewable energy sources has the potential to be an effective measure to achieve energy improvements. Options include liquid biofuels (ethanol and biodiesel), biogas (converted to CNC and LNG) and green hydrogen to power either conventional or adapted internal combustion engines (A2EP, 2017c). Electrically driven vehicle can be powered by using renewable electricity and a 3-month trial over 5,000 km demonstrated an energy saving of 73% compared to diesel driven trucks (Green Truck Partnership, 2015). Improved driving technique through training and driver assistance software can also reduce fuel consumption by up to 20% (A2EP, 2017c).

Transport of food occurs at multiple locations throughout the system of production. Long distances and frequent transit increase the risk of perishable food experiencing temperature variability. Therefore, real-time temperature monitoring in transport is essential to maintain food quality. As a result of real-time monitoring, 10% of energy reduction in cold chain transport is expected, which is equivalent to $15 million per annum in Australia (A2EP, 2017b). Energy productivity benefits in cold chain transport can also be realised through system optimisation approaches to the freight network and associated infrastructure network, the latter of which will influence the energy use in the other parts in the value chain (A2EP, 2017c). Decentralizing warehouse and grocery retailers, even though which maybe more expensive to build and operate than the centralised facility, shortens the time that chilled/frozen food spends in the refrigerated vehicle and allows for fuel saving and more efficient delivery (Food Logistics, 2021). IoT-based technologies can use real-time road conditions and the driving speeds to help optimise vehicle routing and minimise the cold chain and vehicle energy use (Sarrab *et al.*, 2020).

For the stationary cold chain, energy savings can be realised by energy efficient equipment, minimizing heat gain, as well as indirectly through reducing food waste. Another opportunity is the cooling of product immediately after harvest, as a lot of quality is lost soon after picking if the product is not cooled, but there may be a trade-off between energy use and additional produce value. Also, advanced packaging represents another opportunity to preserve food freshness and quality, extending shelf life, reducing food and associated energy waste, as well as reducing need to freeze or allowing less refrigeration.

Energy productivity can be improved using real time food condition monitoring in cold chains, realising value gains and energy savings. This is achieved through temperature management for maintaining food quality and safety while eliminating the temperature abuse and reducing food waste. Digital technologies such as real time temperature monitoring and user-friendly software for shelf-life modelling can be used to optimise cold chains for low-temperature food products. Sensors can be fitted to perishable food to ensure it remains at an appropriate temperature with the appropriate period, and for accurate temperature monitoring to improve food quality, manage shelf life and reduce energy and carbon emissions. Real-time tracking of temperature and food conditions and communication of the cold chain will ensure that emerging problems can be detected before food quality or safety is adversely affected. For large commercial and industrial refrigeration systems and transport, implementing smart monitoring systems can help to detect refrigerant leaks early, minimizing impacts on energy efficiency as well as GHG emissions. The optimisation of the cold chain may also support and be supported by the other energy productivity opportunities, through shorter supply chains and enabling lower food loss.

Also, improvement is driven by energy efficiency and electrification (reducing primary energy use and moving toward clean/renewable energy sources). Carbon dioxide refrigeration cycles, integrating with renewable energy and thermal energy storage, can be used to recover waste heat for refrigeration in food cold chains, improving both efficiency and economics of food cold chains (Barta *et al.*, 2021; Glaciem Cooling, n.d.).

Opportunity summary

Scope and scale of the transformation

Two aspects of the cold chain provide the potential to improve energy productivity: high performance and low-cost refrigeration systems, and clean and reliable refrigerated transport. The use of efficient refrigeration in cold chains can save up to 30% in energy consumption (A2EP, 2017a; Australian Government 2021c). As noted previously, improvement of food condition monitoring has been estimated to result in 5% and 10% energy reduction in stationary and trucking refrigeration costs, a total of $135 million per annum (A2EP, 2017b).

Businesses using food cold chain services are shifting toward energy optimisation across the supply chain with the support of digital technologies. The optimisation of cold chain through digital technologies includes:

- Optimising refrigeration energy use and transit
- high efficiency and low carbon refrigeration
- Optimising freight energy performance and logistics (Ndraha *et al.*, 2018).

The annual primary energy use in Australian cold chain is estimated to be 255 PJ and the related GHG emission is approximately 30.3 Mt (A2EP, 2017a). By addressing the identified opportunities, approximately 40% of the energy consumption can be potentially reduced, comprising:

- 30% by using high-performance refrigeration equipment (A2EP, 2017a; Australian Government, 2021);
- 5% by real-time food condition monitoring (A2EP, 2017b); and,
- 5% by reducing the cooling load and minimizing energy loss during operation throughout the chain (approximation due to lack of information).

The value added due to improved food quality and reduced food loss is not considered. As the government has suggested to replace the refrigeration system more than 10 years old (Australian Government, 2021). Assuming a linear replacement rate of 10% per annum and the average growth rate for food consumption is 2.4% per annum (Department of Agriculture, water and Environment, 2020), the projected energy consumption with and without adoption of those opportunities were projected up to year 2035 and presented in the figure below. The 40% energy saving in year 2035 is equivalent to 146.1 PJ.

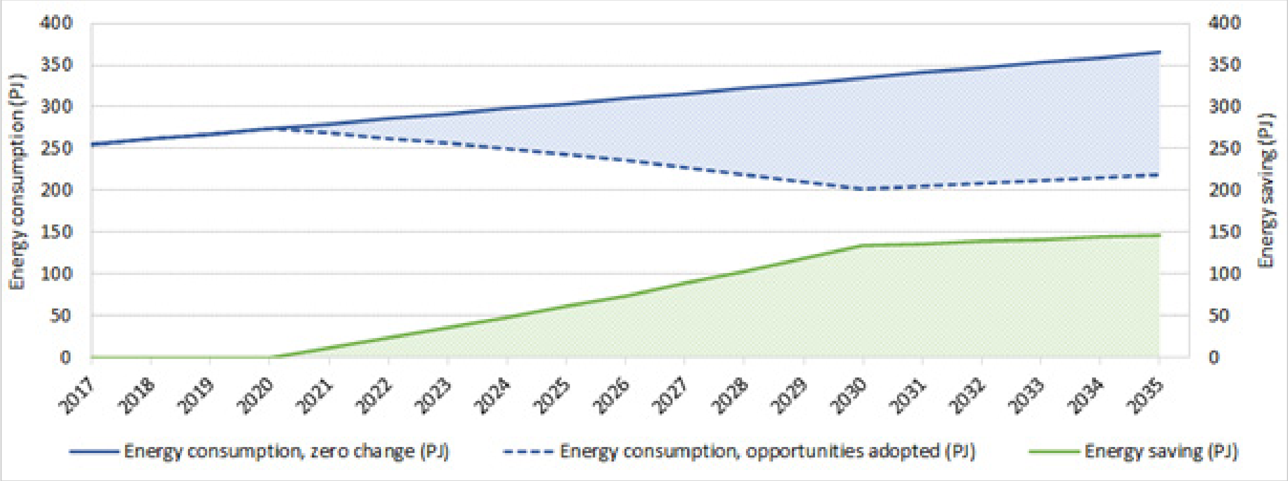


Figure 16. Projection of energy consumption and potential reduction in food cold chain. Source: Authors, A2EP (2017a), Australian Government (2021).

As an example, Oxford Cold Storage, the 21st largest public refrigerated warehouse worldwide, has improved the energy efficiency by 29.7% from 53.5 kWh/m^3 to 37.6 kWh/m^3 over three years through: applying high energy-efficiency standards to construct new facility, energy-efficiency benchmarking of existing facility, improved monitoring and control of chamber temperature and plant controls, improvements in door design to reduce infiltration, retrofitting energy saving LED lights, retrofitting variable frequency drives to existing screw compressors and fans, and over-sizing evaporative condensers (Oxford Cold Storage, 2013).

Business model transformations

Energy productivity benefits in cold chain transport can also be realised through system optimisation approaches to the freight network and associated infrastructure network, the latter of which will influence the energy use in the other parts in the value chain (A2EP, 2017c). Decentralizing warehouse and grocery retailers, even though which maybe more expensive to build and operate than the centralised facility, shortens the time that chilled/frozen food spends in the refrigerated vehicle and allows for fuel saving and more efficient delivery (Food Logistics, 2021). IoT-based technologies can use real-time road conditions and the driving speeds to help optimise vehicle routing and minimise the cold chain and vehicle energy use (Sarrab *et al.*, 2020).

Businesses using food cold chain services are shifting toward energy optimisation across the supply chain with the support of digital technologies. The optimisation of cold chain through digital technologies includes:

- Optimising refrigeration energy use and transit
- high efficiency and low carbon refrigeration
- Optimising freight energy performance and logistics (Ndraha *et al.*, 2018).

The application of digital technologies in the cold chain is still at an early stage of development and it has the potential to be integrated into every process of the chain to enhance the visibility and control. IoT technology has been used for high value, highly temperature sensitive products (A2EP, 2017b). Adopting IoT technology in cold food chain requires additional investment, which remains one of the biggest challenges for small producers and manufacturers. Low-cost monitoring of cold chain in Australia is mainly constrained by the extent of low power wide area networks (LPWAN), which should be resolved within 1–2 years (A2EP, 2017b). Thermal energy storage as an energy efficient technology for cold chain need to be tested and validated during operation in both laboratory and field.

Application and implementation

A significant amount of energy saving of up to 30% could be realised by applying the most efficient refrigeration system available in the market. This is an effective and immediate solution for energy productivity improvement in both retrofits and new installations. To promote the market uptake of efficient systems, further work needs to be done to (1) extend the existing government regulations and energy performance standards to cover all the refrigeration equipment and (2) reduce the cost of the advanced system. Internet of Things, being an emerging technology, is getting recognised and progressively implemented in the food cold chain, such as the aforementioned applications in Walmart and Oxford Cold Storage. However, complete adoption of this technology is still facing the challenges in technical, financial, social, operational, educational and governmental issues (Aamer *et al.*, 2021). Additional research is still needed to overcome those challenges.

Worldwide, the refrigeration industry is facing changes in phasing out HCFCs and phasing down HFCs. Refrigeration systems using alternative refrigerants, such as carbon dioxide, ammonia and air, are available and needs to be addressed in future demonstration, particularly with the integration with renewable energy and energy storage.

5.1.4 Opportunity 4: Agriculture, water and energy

Agriculture accounts for 62% of water consumption in Australia (ABS 2019), indicating the impact of water use on energy productivity in the food sector, as well as food production on energy use in the water sector. A shift to energy-smart farming would include adopting a circular economy approach, as noted above, smart irrigation systems, greenhouse management through sensors and improved pumping efficiency.

For agriculture, business model innovation can be key in effectively capturing the value from energy efficiency improvements to irrigation systems and productivity gains from novel farming and land management practices. Due to the seasonal nature of irrigation, the water and energy demand for irrigation varies month to month. There is an opportunity for water and energy storage while there is no irrigation actively running.

The energy productivity of the agriculture sector has declined in recent years, mainly due to an increase in diesel and LPG consumption, and 80% of the energy consumed in agriculture is diesel (A2EP 2016). Therefore, energy efficiency and diesel alternatives for heavy farm vehicles and bulk water are potential areas of interest in the agricultural sector. For example, biodiesel can be produced from carbon farming and potentially increase the incomes of farms, reduce the costs of energy and assist in reducing GHG emissions. Behind-the-meter energy systems such as solar panels and wind turbines can also be used as renewable energy for the agriculture sector, which will decrease grid-supplied energy demand (Briggs *et al.*, 2018).

In general, the agriculture sector is an example of the rational business logic discussed in Section 2.1.1 of this report, driven by efficiency gains in using existing resources (Geissdoerfer *et al.* 2018). As an alternative, sustainability-based business models consider “not only how organisations produce and deliver goods and services, but, at the same time, how they contribute to the betterment of society—environmentally and socially” (Ulvenblad *et al.* 2019, p. 15). In agriculture, business can adopt this business model by creating value from waste, maximising efficiency in resource and energy use, and substitutions with renewables, agritourism amongst others (Broccardo *et al.*, 2017; Ulvenblad, *et al.* 2015). What is important to recognise is that adopting such an approach requires a fundamental rethink of agricultural production. This may include changing the structure of value chains so that agriculture can capture a larger share of the value-added (Fairbrother *et al.*, 2018; Marsden *et al.*, 2020). On this basis, two projects are recommended to describe the opportunities that exist and can be used to increase energy productivity within agriculture industries.

Opportunity 4a: Mapping and benchmarking energy use in the Australian irrigation

Australian agriculture energy use is affected by the local climate and the irrigation and farming methods used. Irrigation accounts for only 5% of arable land in Australia but produces 30% of all agricultural production (NPSI, 2012). Water pumping is the primary user of energy in irrigation, consuming 175,418 megawatts (MW) of power per annum (Welsh & Powell, 2017). Audits of irrigation farms have demonstrated that the water used for pumping can account for between 50–80% of a farm’s total energy bill, and the cost of pumping water is between $35 and $80/ML (Beca Consultants, 2015). Irrigation also increases the yield per hectare by up to 3 times that of rainfed agriculture (Chen *et al.*, 2015). Grid-supplied electricity and diesel fuel are the primary types of energy used in irrigation systems. Electricity for irrigation is problematic in managing the energy load related to weather conditions; Irrigation demand is typically highest during peak household load periods, such as freezing in winter and hot afternoons (Jackson, 2009).

Further, Irrigation practices vary considerably from farm to farm. This largely depends on the volume of water pumped, the lift involved, the friction and minor head loss through pipelines and pump, and drive-train and motor efficiencies. These factors are influenced by specific irrigation requirements such as climate and ground conditions and farmers' irrigation management skills. The current standard pumps used in irrigation systems are cheap and responsible for 30%-40% of all direct energy use in this sector. Generally, these pumps are only capable of running at between 50% and 65% efficiency due to poorly maintained equipment, poorly designed pumping stations and poorly designed pumping layouts (Foley *et al.*, 2015).

Therefore, energy resources and related environmental impacts are some of the main challenges facing agriculture and irrigation systems. These issues can be managed through research and the adoption of industry best management practices. By understanding the amount of fuel and electricity required, farmers have the right to adjust and choose the most efficient growing method for them.

Even though irrigation is one of the major energy-intensive systems, currently, there is little energy data available in the public literature concerning key irrigation processes of different crops. This lack of data is particularly significant because a considerable proportion of overseas research results may not be relevant to Australia due to our different climate and irrigation requirements.

Opportunity 4b: Agriculture 4.0 for improved energy and water productivity

This second opportunity provides a long-term outlook on the potential for Agriculture 4.0 to improve energy productivity through smart irrigation systems. Here, an exploratory investigation on the impact of key smart irrigation tools, technologies and management practices on energy productivity present significant opportunities, as well as challenges. This opportunity would draw on and extend the outcomes from Opportunity 4a.

A recent report by Austrade highlights the immense potential for agri-businesses to leverage digital technologies for organisational growth (Australian Trade and Investment Commission, 2019). Here, it is interesting to note that innovation within this sector appears to be more producer-led: farmers are coming up with solutions for problems the market is yet to cater for. This has led to a surge in ag-tech enterprises in Australia that competing for a projected $20.3 billion in estimated value that can be realised through the adoption of digital technologies in agricultural production (KPMG, 2018). However, effectively making use of such technologies has its challenges, particularly within the agricultural industry.

5.1.5 Opportunity summary

Scope and scale of the transformation

Opportunity 4a would quantify the energy use in Australia's irrigation systems, providing a baseline for future initiatives. For this purpose, in the first step, we assess the appropriateness of current strategies in irrigation systems in terms of energy uses to identify the challenges relating to existing strategies. In the second step, the amount of energy use will be quantified for the current irrigation systems adopted in Australia. Also, this research will benchmark the best industrial practices across various climate zones in Australia. This background will enable us to develop a framework for assessing the impact of alternative scenarios for improving the energy uses in irrigation systems.

The significant impacts from this project could be 50% energy savings (per ML of water pumped) in irrigation systems through improvements in irrigation equipment selection and adoption and water management practices by 2034. The estimate is calculated based on the available data for energy consumption for irrigated land in the major products (wheat, barley, sorghum, vegetables, sugar can, cotton, rice and dairy) and the land area covered by these products. The estimates draw upon ABC, World Bank, IEA, FAO, Department of Agriculture and Water Resources and other peer-reviewed national and international data sets and research

(ABARES, 2016; ABS, 2020; Chen, Maraseni, Banhazi, & Bundschuh, 2015; DAWE, 2021; IEA, 2021; PWC, 2019; Statista, 2021; Welsh & Powell, 2017).

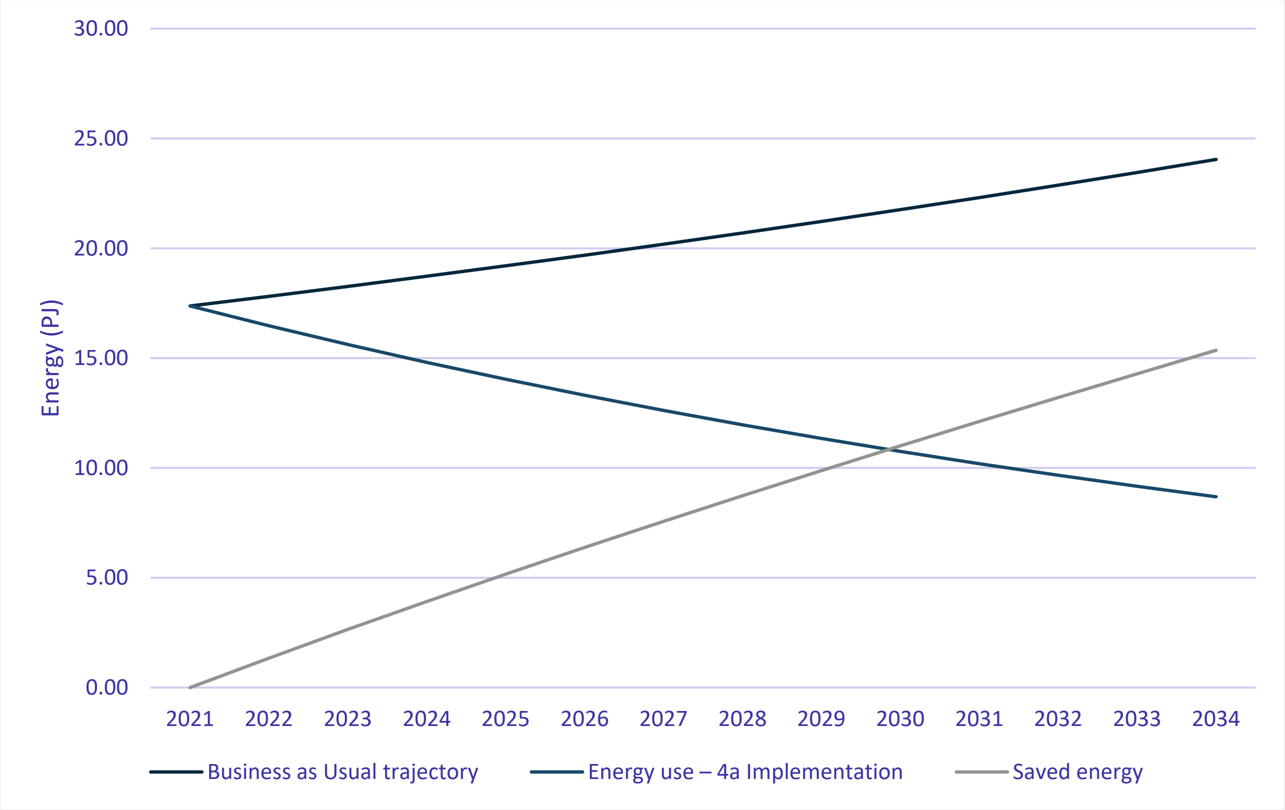


Figure 17. Projected energy use and savings in irrigation systems.

The main assumptions considered for this calculation are as below:

- There were 1.5 million hectares of irrigated land in Australian in 2019–20, using 17.3 PJ of energy (ABS, 2021).
- According to DISER (2019), energy consumption in agriculture grew by 2.5% per annum over the previous decade: this is used to project business as usual energy use.
- The savings are based on improved pump efficiency. The estimate is of 70% energy savings over time, based on average electric motor efficiency of 90% and the average large diesel motor efficiency is estimated at 35% (Foley *et al.*, 2015)
- Energy consumption GJ/ha is the average energy use in various irrigated land uses.
- The scope of potential savings is limited to the total land used under irrigated farming
- In some crops which energy consumption was not available, the hypothetical farm developed for analytical purposes by Chen and others (2015) was used.

The outcome of this opportunity could provide the calculation of energy use of different processes in irrigation systems, which are largely unknown. Further, assessing existing strategies in terms of energy uses will shed light on the main challenges. This would identify the effectiveness and limitations of existing approaches. The developed framework will demonstrate the linkages between energy and irrigation systems, enabling us to assess the impact of the ‘business as usual’ scenario for existing situations in the short term and assess the impact of alternative scenarios in the irrigation system for short and long term.

For Opportunity 4b, work being conducted as part of the Smarter Irrigation for Profit project and the Queensland Farmers Federation's Energy Savers initiative indicate s that considerable energy savings may result from the implementation of smarter irrigation technologies. For example, energy savings from between approximately 10k-18k kWh were recorded using soil and pressure monitoring devices coupled with variable speed drives on electric motors in intervention case studies (QFF 2021). In addition, behavioural changes associated with greater transparency of pumping station energy efficiency metrics have also been observed as a secondary impact from the adoption of smarter irrigation systems (QFF 2019).

Whilst Opportunity 4b provides potential energy productivity impacts and follow-on effects at the market and wider societal level, these also seem to draw parallels with the notion of industry 4.0 when it concerns industrial organisations. A roadmap to implementation that helps organisations to implement and leverage the use of such technologies to a practical effect is required (Ghobakhloo *et al.*, 2021). Indeed, the impact of such technologies on the operations of industrial firms remains contested (Szász *et al.*, 2020). As such, some possible outcomes of this project could also include decision support tools for the design and management of smart irrigation systems—identifying the barriers and enablers associated with their adoption and the respective impact on energy productivity.

Business model transformations

Opportunity 4a will recommend an approach that maximises the energy efficiency in the irrigation systems in Australia while decreasing associated greenhouse gas emissions. In addition, due to the various climates of Australia, for each climate, the best solution is different from others. However, the presented framework for irrigation systems could meet the demand for each type of climate in terms of energy and water. This will provide the basis for shifting agricultural business models to increased energy productivity.

Greenhouse horticulture could use solar energy to power the greenhouse and treat seawater for irrigation. It largely reduces the usage of conventional energy and mains water supply. This business model is the ideal growing environment to produce high-quality crops. As an example, Sundrop Farm in South Australia is an $200 million horticultural producer, using solar energy and desalination technology to irrigate and grow 20 hectares of tomato crops, enough to meet 10–15% of Australia's demand. Most of Sundrop Farm's solar energy comes from 23,000 mirrors, which are directed at a 115-meter-high receiving tower. Saltwater is drawn from Spencer Bay and then thermal desalination technology is used to produce fresh water. It is estimated that 18,000 tons of tomatoes can be irrigated and planted per year (Ramos, 2016).

It is also expected that fossil fuels as the primary energy sources replaced by renewables in irrigation systems which could reduce the negative environmental impact of the system in Australia in the short term—possibly leading to energy savings beyond 100%. This estimate is based on the case studies provided information by QLD Farmers' Federation (QFF). The case studies present various farms based on irrigation type, pump type, applied technology and location. The results show that energy-saving could go beyond 100% if renewable energy replaced by fossil fuels (QFF, 2021).

Application and implementation

The application of digital technology to optimise irrigation energy is still in an early stage. Most of the previous applications were limited to specific crops (e.g. VARIwise), which aims to developed, simulate and compare site-specific irrigation control strategies (McCarthy, Smith, & Hancock, 2013). On the other hand, existing applications such as Low Energy Precision Application (LEPA) maximise their total water resource use and significantly increase irrigation efficiencies. Therefore, the full picture of the Internet of Things technology needs to be addressed to enable the collection, storage, processing, and sharing of digital data from various sources for different crops.

Industry Reference Group responses

The IRG provided the following responses to the Food Transparency and Distribution Systems research cluster.

5.1.6 Other research opportunities

In addition to general comments regarding energy and water efficiencies, the additional prospects for energy productivity savings in the Food sector included:

- Drying or dewatering of produce to reduce transport costs
- Transport energy in the food system
- Reducing refrigeration requirements through new preservation methods as well as changing diets

Existing projects

The existing projects with a similar focus to the energy productivity opportunities in this cluster that were listed by the IRG were:

- To draw on the approaches developed in the pharmaceuticals industry.
- Build on previous work in supermarkets on energy reduction.
- Projects looking at food waste and recovery: food banks, work by the Department of Agriculture and EPA NSW.
- The RACE for 2030 project investigating energy production from agricultural waste streams.
- Studies of direct farm to consumer systems, with lower energy use through reduced processing.
- Restaurant chain Guzman and Gomez are proposing full provenance for customers via QR codes.
- Dairy Australia has done work in assessing technologies to reduce waste in dairy manufacturing.

The connection to other research projects was also noted, including the Food Agility CRC and the Fight Food Waste CRC.

Industry partners

Potential industry partners nominated for projects in this cluster were:

- Stop Food Waste Australia
- Nutritionists and dieticians
- Australian Institute of Refrigeration, Air conditioning and Heating
- Food and Grocery Council
- Dairy Australia
- Major food distribution companies
- Sustainability Victoria
- NSW Environment Protection Agency and Department of Planning, Industry and Environment
- Meat and Livestock Corporation
- AgriFutures Australia
- Tetra Pak or GEA—food and beverage packaging suppliers
- Food Innovation Australia (FIAL)
- Australian Institute of Packaging

- Refrigerated Warehouse & Transport Association of Australia

The connection between this opportunity and the Fight Food Waste CRC was also noted by an IRG representative.

5.1.7 Path to implementation

The path to implementation for this project would include engaging with actors across three main sectors:

- Participants in the food production system, including major companies and the range of industry bodies and transport and logistics firms
- IT and database firms and research organisations.
- The waste and food reuse sector

One industry representative noted that an issue with adopting blockchains for transparency and logistics in the food sector is that it requires all participants to use the system, which is an issue for food product manufacturers as some have more than 100 suppliers of inputs. The inter-operability of data, or a coordinated approach to provide benefits to all participants, is therefore important if blockchains are to meet their potential in the food sector. This alludes to an additional barrier to implementation raised, that the benefits in terms of sale revenue through provenance are realised at the retail end of the chain, while the costs fall on producers and suppliers.

An additional question raised in an interview with a representative from the food sector was the extent of the food waste problem in Australia. There is a profit-based motivation for producers to find uses for product that does not meet standards for household consumption, including for use in food product manufacturing, animal feed and in the emerging bio-fuels sector.

There is research underway to promote the opportunities within this research cluster. Australia is developing a blockchain roadmap which in partnership with CSIRO, to establish the foundations required to use blockchain in many sectors. There continues to be research looking into algorithms to make blockchain more efficient in its energy use, a major issue with the technology. Food transparency through blockchains is the focus of continued research from the Victoria government, for grains, citrus and wine. The development of Beefledger as a commercial enterprise is also of note, as an example of the development of business models for agriculture and blockchains. Globally there is much work on using blockchain for food transparency, indicating ongoing development of technology, use and business models (e.g. Kamilaris *et al.*, 2019). Research into robotics for picking is continuing, with algorithms to improve the accuracy of fruit picking, weed picking and waste sorting.

Research is also continuing to improve energy productivity in Cold Chain as a Service, including IoT technology to monitor the food condition in real time to achieve energy saving and reduce food waste. Also, under development are alternative refrigeration systems and refrigerant with the potential to reduce energy consumption and refrigerant leakage. A third research direction is in the use of renewable energy sources to power refrigeration system.

RACE could help provide pathways for implementation of these opportunities, particularly through ongoing research into the market transformation potential across aspects of the food supply system. In general, technologies to realise the benefits identified in this research cluster are available, but the salient questions relate to the socio-technical regime and how to facilitate the adoption of innovations in the food sector. A key issue in this regard raised by an IRG member was education, that many enter the food sector with an understanding of their product, but not how to consider issues such as energy efficiency in their systems.

5.1.8 Cluster summary

This cluster is an example of the issues raised in the discussion of socio-technical transitions in Chapter 2. The barriers to implementation relate to industry co-ordination and changing prevailing understandings of how industry can improve energy productivity, through initiatives such as reducing waste. There is a need for continuing technological development, particularly in order to enhance the returns to industry in pursuing these opportunities, particularly in robotics and remote sensors, as well as the most effective method to store and communicate produce information through blockchains. The impact of regulations, such as food safety, on industry uptake of these opportunities also needs to be considered.

A major issue for the assessment and measurement of outcomes in this sector is the lack of detailed data. It is possible that high-level statistics could be collected on the uptake of blockchain in the food sector, but connecting this to energy productivity outcomes would most likely depend on surveys or other bespoke data collection initiatives. Government initiatives in tackling food waste indicate a broad focus on measurement for this opportunity (Australian Government, 2019).

5.2 Priority cluster 2: Housing systems (monitoring and performance)

Households account for approximately 10% of energy use in Australia and a total of 460.9 PJ of energy in 2018–19 (DISER, 2020). Australia's housing stock is mostly comprised of older homes, constructed prior to minimum energy efficiency standards. The development of systems to monitor and analyse household energy consumption. This cluster combines improving information on energy use in existing, new and rental housing, including water provision, as well as opportunities to reduce the energy associated with housing construction. The central argument is that energy productivity gains in the shelter sector can be realised by including better information on housing energy characteristics in housing markets. Improving housing energy efficiency has been a target of government policy for more than a decade (e.g. Australian Government 2010), and there are numerous initiatives underway (Murray 2021), however there is still a need for more industry-focused research that investigates household energy use. The pursuit of energy efficiency however is not equivalent to transformation of value chain energy productivity. The former focuses on seeking energy use reductions within existing value chains, whereas the latter seeks to transform value chains so that they may no longer operate on the same basis, potentially removing entire sequences of energy consumption.

Opportunities 1 and 2a-c are from the shelter sector, and 2d is from the water sector.

5.2.1 Opportunity 1: Innovative building materials and design

Over recent decades there have been a range of innovative building materials and design developments which have improved energy productivity within the shelter sector. There are opportunities to use digital solutions and increase incentives to use efficient and low-carbon materials. Examples included in this opportunity are building Information management and modelling systems, the use of digital systems monitoring, and virtual reality for training in using these systems.

Materials and design innovations may provide rapid performance improvements, for example through:

- The use of residential solar panels;
- Energy efficient heating and cooling systems;

- Internet of Things sensor and data analysis to increase the efficiency of heating and cooling systems; and,
- Development of advanced construction materials to improve thermal performance, among others.

Innovative materials and systems include engineered timber or tensile structures, optimising operations (such as use of high strength alloys, composite materials), even requiring expert assessment for optimal material design, construction and installation, to increase productivity (A2EP 2017).

More detailed evaluation of building performance, such as analysis of rea- world thermal bridging, air leakage and water vapour would support the development of improved materials, systems and installation practices. To further increase energy productivity, materials, and labour for design and installation should ideally be from local manufacturers and sources to decrease cost and energy used in transport. Investment in strategies to increase adoption, enhance certainty of financial returns for innovators and train practitioners could support development of local production, which resonates with socio-technical transitions theory.

Increased use of innovative materials and the revision of design could also enhance productivity. It is important to consider the planning of a building design, that includes operational efficiency as well as energy productivity measures for the end of the building's life (e.g.: disassembly and reuse for further long-term energy productivity benefits in the shelter sector).

Government should also support the adoption of these practices, by providing incentives and fast track planning approval for buildings that reach high-performance standards, as currently proposed in Victoria (VPA, 2020). These incentives will facilitate opportunities for the increase in energy productivity. However, research is needed to build a case for government action.

Opportunity summary

Scope and scale of the transformation

The use of high energy performance building materials will help to increase energy productivity and potentially deliver outcomes in a more cost-effective way. The scope includes wide-spread application of innovative building materials, such as Structural Insulated Panels (SIPs). There can be energy consumption savings by using SIPS compared to the construction of walls with fiberglass batt insulation, all else being equal. Walvaren (2018) reported that SIPs have 58% more R-value (a measure of resistance to heat flow), and 88% less air leakage, reducing heating and cooling costs. The pre-fabricated SIP panels also reduce the onsite waste by 98%, save labour cost by 55% and decrease onsite construction time by 50%.

New materials require government support to reach wider implementation and to ensure they are within regulatory and rating frameworks. Informing designers and builders of the benefits of new materials is also needed in order to achieve their full potential in energy savings. In terms of thermal energy performance, a minimum of 8 stars on the NatHERS scale should be mandatory; a level of performance which is cost efficient and technically possible in many climate zones around Australia. The current minimum is 6 starts, although the draft National Construction Code includes a revision to 6.5 or 7.0 stars (Australian Building Codes Board, 2022).

With the right support and incentives, the building industry can produce new houses with 8-star ratings. Based on the assumptions that:

- By 2023 minimum new housing efficiency will be an 8-star rating, which aligns with expected changes to minimum standard;

- Between 2023 and 2030 50% of new housing will achieve an 8-star rating, to allow for a phasing in of the requirement.

The savings in 2030 would equate to 16% energy reduction across new housing built during that period of time, or 1% of total residential energy consumption in 2035. This equates to more than 8 million MWh of avoided energy consumption across that period of time.

The estimates of energy savings are conservative, and could be significantly higher with a more coordinated governance and support program for the building industry and consumers.

Business model transformations

The first business model transformation is to work with the existing building materials companies that deliver innovative, higher performing and more sustainable material options. Educating the building industry about material innovation will be required to drive uptake. The government will need to facilitate capacity building of the designers and builders in the use of innovative building materials, as well as ensure that regulations and ratings tools are updated continuously: delays in approvals impact on industry margins and reduce the appetite for innovations. Government support for the research and development of new materials that improves the building performance, and compares material performance would also facilitate change.

The uptake of innovative materials can potentially be increased by also incentivising consumers. Currently, many sustainability related financial innovations relate only to technologies, but there is an opportunity for this to be expanded to cover sustainable materials.

A crucial aspect of innovation in housing for energy efficiency is that energy related costs are not adequately accounted for in mortgage assessments and property valuations, reducing the demand for better materials with greater upfront costs. The impact on investment decisions of the differences in capital and operational costs is likely to be a substantial barrier to improving energy efficiency in the shelter sector, and is also an issue in the other proposals in this research cluster.

Benefits

The estimated savings above do not factor in:

- Other innovations or technology developments which may come to market over the next 10–15 years.
- The continued uptake of solar panels and batteries or the role that electric cars may have, not only at the household level but also as part of a two-way energy storage system and impact on the broader energy network.

The benefits do not just relate to the potential energy reduction as described above, but also include reducing the impacts of housing on the broader energy network and the need to build new energy generation plants.

The improvement to the thermal quality of housing will also result in wider health, wellbeing and other social benefits for households in addition to reducing living costs. Improving the sustainability of housing has been shown in Australian and International research to reduce the number of trips to doctors and hospitals which helps reduce impacts on the wider health care system. The above opportunities would also better prepare Australian housing and households for a changing climate where more extreme weather events are expected.

Application and Implementation

There are already a number of innovative building materials and construction practices that have emerged in recent years, such as SIPS and 3D printed buildings. However, such innovations have at times struggled to demonstrate compliance with outdated building codes. Therefore, governments need a greater focus on updating building codes and planning scheme requirements, to ensure that energy efficient and productive innovations are widely accepted and their use does not delay construction programs. Increases to minimum NatHERS ratings, as are likely, will also create a greater demand for high-performance building materials, and increased production should lead to economies of scale and reduced material costs over time.

5.2.2 Opportunity 2: Building performance monitoring and transparency

In Australia, the energy performance, and therefore productivity, within the shelter sector has been determined through the setting of minimum performance requirements under the NatHERS system. The minimum standards have increased over time, but there remain several ongoing challenges hindering improvement to energy productivity in the shelter sector.

A key challenge is that many of the policies and innovations are relevant only to new dwellings or those undergoing significant renovation. As a minimum requirement, the impact is on improving the standards at the bottom end of the market rather than fostering innovation in building performance. There is also an issue in that while minimum performance requirements have seen an improvement in the thermal energy performance of newer housing in Australia, the majority of new housing is only built to meet minimum standards, with less than 1.5% being designed to meet environmental and economic optimum outcomes (Moore *et al.*, 2019). For example, a new dwelling must, subject to appropriate enforcement, demonstrate compliance with minimum building code regulations based on design intent. An issue of relying on design intent is there is no requirement to update this information, or the dwelling, based upon actual performance data. Given international best practice is for new housing to be built to a zero energy or carbon performance outcome, housing energy performance for new housing is significantly behind what is possible, and in fact required, for a low carbon future.

A further implication is that the majority of housing, existing dwellings, are not required to meet even minimum efficiency standards. Implementation of energy productivity innovations (e.g. energy retrofits) to older buildings are not governed by the same requirements as new housing in Australia. Furthermore, retrofit of existing housing has been perceived to be high in cost and difficult to undertake. The only state or territory in Australia which does require mandatory disclosure at point of sale/lease after an initial building code compliance check, is the Australian Capital Territory in 2010 Queensland implemented a mandatory sustainability declaration requirement for the selling of houses. This declaration was intended to encourage higher energy productivity by increasing energy efficiency and raising awareness of the issue to the community (Christensen 2012). The requirement was repealed in 2012 as part of the efforts to reduce red tape in Queensland, a priority of the then-incoming state government (Building Codes Queensland, 2012).

The lack of energy performance validation and tracking over time in the shelter sector impacts on the energy productivity of the shelter sector, as consumers are not provided with adequate information to include costs in their estimate of housing value.

Secondly, means to implement energy productivity measures are limited for those that rent. Rental homes in Australia are known to be of poorer overall quality and less energy efficient (Dignam 2019; Pommeranz & Steininger 2021). In addition, renters historically have had limited opportunity to install or request energy productivity measures, due to rights over what renters can do to their rental property, and concerns over spilt-incentives with landlords (Aliento 2018). Properties that are energy efficient may have higher rental premiums (Pommeranz & Steininger 2021; Khazal & Sønstebø 2020). In some regions in Europe it is compulsory to provide energy performance certificates for buildings, including rentals (Daly *et al.* 2019), however for the use of such certificates is still uncommon in Australia. There is also a lack of ratings and information based on real world performance—most is based on modelling during design or visual inspections.

The final issue is the lack of awareness around energy productivity as a feature for home buyers and for sellers (Bryant & Eves 2011; Wong *et al.* 2020). However, to date, statements on sustainability measures of a house are often not a selling point as indicated by the mandatory disclosure discussion above. Many real estate advertisements focus on features that increase comfort, aesthetics, and liveability rather than energy productivity and cost efficiency. The lack of awareness regarding this issue for both sellers and buyers remains (Moore & Hurst 2018), although may be starting to slowly shift (Dellow, 2021). Interestingly, this is being driven by a shift away from a focus of energy usages environmental impact to affordability and liveability outcomes. This is demonstrated via CSIRO's s training on liveability features for real estate agents to be their 'clients' trusted advisers' when they explore options to transform their homes (CSIRO, 2020). It is also recognised through the Victorian Residential Energy Scorecard, which provides information on things such as liveability of the dwelling being assessed during a peak weather event such as a heatwave.

These limitations in information on housing performance provide the underlying rationale for the following opportunities to increase energy productivity.

Opportunity 2a: Assessment of building performance systems

Building performance assessments provide identification of performance issues throughout the building's life cycle. Assessment systems that may be beneficial for building performance include factor screening or characterisation (identify which factors have most effect on performance), optimisation (find parameters that assist in optimising performance), confirmation (to verify that systems perform as expected), discovery (finding new performance alternatives that may increase performance to existing systems), and robustness (study how a system change in adverse conditions). As each dwelling operates differently according to the build, materials, and the systems (appliances) that operate inside the building, an assessment such as this is crucial, otherwise potential upgrades may not improve energy productivity and could even result in increased energy use.

Therefore, there needs to be an active assessment of building performance systems, for new buildings, retrofits and rentals. The performance test should be undertaken pre-occupation and pre-transaction. In addition, real time data and energy use for building occupants or for cluster/ development/ network scale in terms of sharing energy regulating peaks and more. This should also be linked to a shift in building approvals based upon design intent to as built ratings to close the gap between design and real-world performance.

Opportunity 2b: Energy performance transparency and incentives

Energy efficient measures are not factored into housing decisions by sellers, buyers and real estate agents due to lack of awareness may limit energy productivity in the housing sector (Wong *et al.* 2020). Environment Victoria (2020) highlighted this issue when they conducted a 'secret shopper' survey of real estate agents and potential purchasers at open-for-inspections. They found the majority of real estate agents did not know the energy star rating of the dwelling they were selling and often failed to identify energy or sustainability features.

Long term, investment in energy performance and efficiency may provide a return, however housing and financial systems do not adequately account for the benefits of improved housing performance. As a result, financing for improved sustainability and energy outcomes remains a challenge with many financial institutions hesitant to fund housing performance improvements if they believe the market is not going to value it. Previous research from Australia and around the world has found that there can be significant financial improvements to households of sustainable and low energy housing including reducing (or eliminating) energy bills, paying off home loans more quickly and achieving higher resale value (Hoen *et al.* 2021; Moore 2012).

A housing finance model and system that considers operational cost savings, as well as the various comfort and liveability aspects of houses that result from better systems, is a crucial step in increasing energy productivity in the housing sector. For home buyers, increased mortgage payments can be serviced as a result of lower energy bills. Similarly for investors, lower household costs should enable higher rents to be charged. Financial incentives have also been found to be important for driving improvement of performance and rewarding early adopters of higher performing buildings.

While there are benefits for investors, such system changes should also benefit renters. Renters are often limited in options for housing and those rental properties that do have energy efficient measures are limited and may be more expensive to rent, particularly as newer houses are generally both more efficient and attract higher rent for non-energy related reasons. It is also difficult for renters to implement their own energy productivity measures (at their own cost) due to the potential complicated process in negotiating with landlords, and as a result of 'make good' clauses in rental agreements. In addition, many rental properties go through real estate agencies that do not directly connect renters with owners, further complicating negotiations.

In these situations, it is possible that negotiations between landlords and tenants can provide positive outcomes for both, as the capital cost of efficiency upgrades is offset by higher rents, which are in turn subsidised in effect by lower tenant energy bills. Landlords would also benefit through higher property values as a result of better appliances and energy-inclusive property valuations. However, outcomes such as these would require energy efficiency to be properly accounted for in housing markets and appropriate channels for negotiations of mutual benefit.

These measures should also be encouraged and protected under the RTA in the case of any legal liability caused from these actions. Recent changes for rental laws in different states in Australia (e.g. Victoria) have taken steps towards making it easier and more equitable for occupants in rental housing to have a minimum quality of performance, as well as undertake certain changes to improve performance themselves. There is also an increasing range of programs and financial incentives specifically targeting landlords and tenants to overcome the split-incentive gap, for example in purchasing solar. While a step in the right direction, there is still more that must be done.

Opportunity 2c: Building performance tracking and information systems.

From the time of design to use and end of the building life, there is often limited information on building history, such as design, building materials, construction, improvements, experience of equipment performance, building comfort and more. As discussed above, regulated mandatory disclosure of building performance, or similar approaches such as the voluntary Residential Efficiency Scorecard developed by the Victorian government, demonstrate an approach to provide further information about the actual performance of a dwelling. The Residential Efficiency Scorecard takes this further by providing recommendations for improvements, which can make decisions about how to improve energy productivity easier. Setting a pathway to require mandatory disclosure at point of sale or lease would increase the benefits of the Residential Efficiency Scorecard, and similar market interventions, and help consumers make more informed decisions and provide opportunities for proactive owners to differentiate their product. A key challenge is to provide potential buyers or renters with an indication of operating costs and comfort: improving data analytics makes this more feasible.

With the development of blockchain technology and innovation, storage of such information can be digitalised and recorded in systems such as an electronic building passport. This may improve productivity in buildings, and in developing an understanding of the future that may be possible. The electronic building passport could also increase access to real time energy use data, which enables data analytics, and remote energy assessments. Techniques such as digital twin approaches could also allow variations in occupancy and user behaviour to be accounted for in energy analysis.

Other techniques and innovations that may be able to store this information use artificial intelligence technology in the form of automated sensors, which could potentially monitor real time use of energy and convert it to estimated costs (Gagan 2018). AI technology can inform users if energy is being wasted, overused and can take direct action or provide options for actions to conserve energy and reduce cost (Mehmood *et al.* 2019; Sanders *et al.* 2018). This may be presented to the household and even identify sources of high energy consumption. It can also be used to deliver a more connected and 'smarter' home and draw upon a range of different information to improve performance outcomes (Pears & Moore, 2019). For example, heaters might turn on when an occupant is within 10 minutes of home rather than having set times the heater might turn on regardless of if anyone is home, or the battery in an electric car may act as a bi-directional storage depending on the energy consumption of the house. The expectation is that the presence of this information system gives weight to encouraging behaviour that is conscious about energy use and cost creating increased energy productivity.

Opportunity 2d: Smart household water metering

Households water consumption also has energy implications, predominantly through shower use, hot water system efficiency losses and clothes washing (Binks *et al.*, 2016). As an addition to the systems discussed in Opportunity 1, smart metering combined with advanced data analytics allow identifying water consumption patterns and provide feedbacks to end users to enhanced water conservation and management and reduce associated energy use. Leakage within the households and water distribution systems can also be detected using smart meters and allow fixing these issues sooner.

There is potential for energy savings as less water than before is needed to be produced and pumped to distribution networks as a result of household water measures. Potential prevention of water loss was reported within the of the total water usage range of 1.56% to 46.73% (Randall and Koech 2019). Water conservation with smart water meters could lead to an average of 26.5% household water use reduction in Australia (Randall and Koech 2019, Sonderlund *et al.* 2014). Currently, smart water metering in Australia is mainly implemented on a pilot basis by water utilities. However, there is an increasing trend in the adoption of smart water meters. Water-related energy consumption can also be reduced through energy management of efficient water heating systems. For example, using solar boosted heat pumps can dramatically improve energy efficiency and reduce carbon emissions (Harrison and Eng 2017). In Australia, household solar water heating systems and heat pump water systems are increasing. With the application of high energy efficient water heating systems, Australian households could save 65% of the energy costs of water heating by 2030 (DISER 2021). Water and energy monitoring and management could optimise the use of both, while providing insights to guide future development of more energy and water-efficient solutions. Evaluation of users' experiences and attitudes could also link technology development to consumer preferences.

The implementation of smart sensors for household water management could have a significant impact on energy productivity, but it requires collaborations between water utilities and household water end users. The reduction of water consumption of households drives the decrease of water production. The implement of efficient hot water systems will have an impact mainly on the household part of the water supply chain as it is closely related to the household sector. These two opportunities demonstrate the potential water savings and related energy savings and cost-savings benefits. Additional benefits could also be achieved including customer satisfaction and enhanced community engagement for the end users (Randall and Koech 2019). However, various challenges could be encountered for the implements of smart technologies. It is always a challenge to commit the expenditures for water utilities and the water end users. Cost is a significant barrier to the implement of smart water meters in full scale (Cheong *et al.* 2016) such as the installation and annual costs of the smarter meters for customers. Other challenges associated with the implementation of water and energy management have been recognised such as data management, interpretation, and analysis and privacy (Boyle *et al.* 2013). Public anxiety about third parties' access to and misuse person information, which may lead to the reluctance to use smart meters (Boyle *et al.* 2013). The challenges of efficient water heat systems such as solar-thermal and air-source heat pumps are mainly the limitations in colder climatic regions because cold temperatures reduce the performance of these systems.

Opportunity summary

Scope and scale of the transformation

The scope and scale of the transformation outlined in Opportunity 2a-d above covers the entire residential sector in Australia. This includes new housing constructed up to the year 2035 as well as existing housing. It covers owner-occupied housing as well as the rental housing stock. The options include opportunities which could be focused on across short to longer time scales and are all opportunities in which could be applied based upon currently available technologies, materials and industry skills.

These estimates drew upon ABS, NatHERS, YourHome, AHURI, HIA, RMIT and other peer reviewed national and international data sets and research (ABS, 2020a, b; Australian Government 2021a, 2021b; HIA 2016; IPEEC 2019; NatHERS 2021; Sustainability Victoria 2021). Key assumptions include a current housing stock of 9.9 million, a knockdown-rebuild rate of 7500/year, new dwelling completions of 200,000 per year (with majority of new construction in Victoria, New South Wales and Queensland). It was also assumed that implementation of any policy, industry or household changes would not start until 2024.

The total estimated energy savings of the four constituent opportunities is a reduction of 34–37% in residential energy consumption by 2035. This includes the following savings for each sub opportunity:

2a: Assessment of building performance systems—19–20%

- Estimate based on the design-performance gap—10%, appliance improvements for key appliances (fridge, TV, dishwasher, washing machine) would improve by 2 stars upon replacement, heating and cooling and other appliance maintenance—5% per year, retrofit of select number of pre-1990 houses from 2 to 6 stars

2b: Energy performance transparency and incentives—5–7%

- Estimate based on improved star rating in ACT, which has mandatory disclosure over other states in 2019 was 0.7 star. Assuming 0.5-star improvement from disclosure and market value, this is assumed to apply to all new housing around Australia and all existing housing built prior to 2005 (introduction of national standards) but excluding any existing housing retrofits from 1a.

2c: Building performance tracking and information systems—5%

- International research finds mixed results from improvements of AI, optimisation and other innovations from rebound to 20%+ improvements—conservative assumption of 5% improvement as a result.

2d: Smart household water metering—5%

- This estimate based on two aspects of water-related energy savings within the households: 1) from water conservation within the households with the utilisation of smart water meters and 2) from the reduction of water-related energy use through the implementation of solar hot water heating system or heat pump systems. A 50% improvement of energy performance was assumed for households. This is a conservative estimate of energy savings from this opportunity, as it excludes the reduced energy used in the water supply system as a result of reduced water use.

In 2018–19, Australian household energy use of 460.9 PJ in 2019 (DISER, 2020). Using this as a baseline, along with estimated population growth, the estimated savings in peta joules can be estimated as set out in the following chart, indicating 98 PJ of energy savings in 2030. The following assumptions have been made:

1. Population growth at 1.1% per year, as estimated by the Centre for Population (2020), which includes the impact of the pandemic.
2. Household energy use grows in line with population, at 1% per year.
3. The benefits of the shelter energy opportunities are cumulative, increasing by 3.3% per year from 2024, to reach the estimated benefits of between 34 and 37% in 2035. For the estimate in the chart, 35% was used for the estimated savings.

In addition to the standard uncertainties associated with these types of projections, such as technological change and changing population and demographic trajectories, further uncertainty is a result of using population projections made during the closure of international migration as a result of the COVID-19 pandemic. A key aspect of the energy savings that may result from these projects is that they are dependent on continuing construction of new housing and housing transactions, which provide the basis for energy outcomes through transforming the housing market. The reliance on transactions, and to a lesser extent major renovations, also means that the benefits accumulate over time, as indicated in Figure 18.

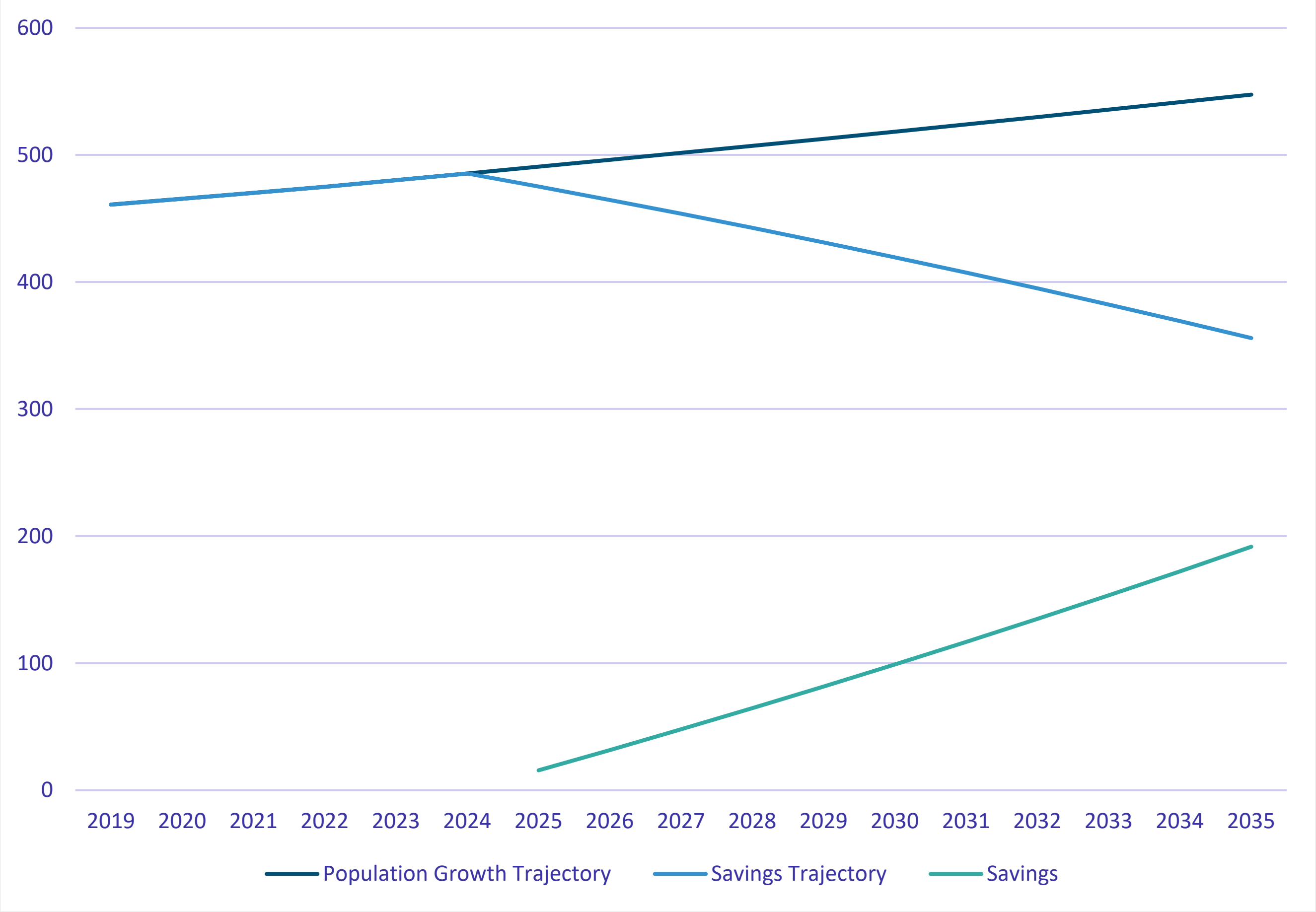


Figure 18. Shelter cluster Estimated energy savings, 2021 to 2035. Source: Household energy use (DISER, 2020), population projections (Centre for Population, 2020).

Business model transformations

There are a number of elements within current business models or governance approaches which would need to change to deliver the above benefits. The removal of the design-performance gap is partially related to updating design models and assumptions but also about requiring improved quality and construction by construction workers. The lack of checks and balances of work undertaken means there is little fear of having poor quality work identified, and there is the need for independent auditing and clear penalties or recourse if performance outcomes are not met.

Government intervention, through regulation, to remove poor preforming appliances from the market would also assist. This would by default shift consumers to better performing appliances, and through increased market shares help to reduce purchase costs of these appliances. In the retrofit space there is the need for a coordinated effort to develop a retrofit industry with a greater focus on holistic energy efficiency. Currently, the retrofit industry operates as a range of silo retrofits which is often shaped by ad-hoc government programs or the skills and supply chains of those involved. There is also a need to ensure training and quality of work in the retrofit industry, as the EEC has recently called for in relation to insulation installations. This is not just about providing improved structure for the industry but also for consumers to know what to expect, how to ensure that outcomes are delivered and what recourse is available should outcomes not be met.

To identify the value of sustainability in housing there is a need for clearer market information such as is demonstrated with the ACT mandatory disclosure program, as well as in other locations such as the EU. There should also be a push to have real estate agents, who are critical intermediaries, communicate key sustainability features of housing in a clear and systematic way. Another possible market mechanism is to allow for landlords to only claim tax offsets for maintenance or work on their investment property for things which improve energy and thermal outcomes: e.g. replacing a dishwasher with one which is at least 1 star higher than the one it is replacing, or replacing the gas hot water system with a heat pump hot water system. Policies and planning requirements also need to evolve to ensure that energy efficient technologies are not excluded or penalised within approval processes. Heat pump hot water systems are an example of where current regulations and requirements have not caught up to the improved technology and are sometimes not able to be installed due to a failure to recognise their performance within the regulations.

There is also an opportunity for energy (and water) retailers to use their data sets to identify high energy (and water) residential consumers to work with them to improve efficiency and performance outcomes. This will not only help the consumer to save money and reduce their energy consumption, but it will have broader benefits for the energy network through reducing peak energy demands.

Expected benefits of transformation

The benefits of high-quality houses for new building or renovation will be similar to those outlined for opportunity 1. It will also allow companies in Australia who innovate to position themselves as world leading and be able to explore international opportunities for expanding their market reach. Changes in some locations such as across the UK and Europe now require certain sustainability credentials to be met by material supply chains. If such companies in Australia do not innovate quickly, they will be locked out of future international opportunities.

Application and implementation

The residential sector is a critical sector to help deliver a low carbon future. If the above opportunities are not addressed, then Australia will not be able to deliver that sustainable future. It will also lock in households to poor quality and performing houses for decades to come if action is not taken soon. However, any of the above opportunities could be delivered in part with reduced benefits then resulting for households and the broader residential sector. The replacement of appliances and hot water systems with higher performing options is one element above which is likely to be a slower roll out if replacement waits to the end of life of current appliances and hot water systems. Other activities should be implemented sooner rather than later, especially given the international demonstration which shows many of the above opportunities are already in place in more advanced jurisdictions.

It is clear though that there is a lack of data about a number of these elements and future Race for 2030 research should look to address these data gaps to provide a more comprehensive understanding of not only the current situation but opportunities for improvement. For example, there is very little information about what the performance of appliances are that people have in their homes, or even how they are being used, especially with the rapid uptake of solar systems across the residential sector, and what the impact of the trend towards all electric means for appliances in practice. Therefore, the ability to target programs or uptake of improved performance is limited due to the quality of data. While there are some larger data sets collecting some of this information such as the Victorian Residential Energy Scorecard, more needs to be done to both analyse that data but also to scale up this information across the broader housing stock.

It must also be a focus on any transition to improving energy productivity outcomes in the residential sector does not just focus on those who can afford to engage with these changes. For example, there are increasing instances of households in fuel poverty in Australia which is only likely to be exacerbated if the above opportunities are delivered without ensuring that vulnerable households are included and focused on. Such a focus would likely result in significant wider social benefits, in addition to any energy productivity benefits.

5.2.3 Industry Reference Group responses

The IRG provided the following responses to the Housing Monitoring and Performance research cluster.

Other opportunities

The additional prospects for energy productivity savings for the Housing Monitoring and Performance cluster included:

- Real time feedback for consumers and smart meters, including add-on modules that convert existing gas, water and electricity meters to cloud-connected real time data sources, without replacement or technical installation. At present, limited access to utility quality smart meters is a bottleneck that limits innovation. Adapting existing meters can bypass this barrier by avoiding cost and delays of meter replacement.
- A range of building performance recommendations:
  - post occupancy building performance should be include in the building performance transparency
  - energy performance certificates
  - comparative energy and water use for suburbs and housing types
  - education on energy type usage
  - compulsory sub-metering (or digital analytics that provide equivalent information) for energy and water
  - leveraging data from energy retailers to give more detailed breakdowns of consumption by dwelling type and number of people
  - national disclosure framework, based on housing attributes. Linking to this may reduce the change of duplicating efforts.
- Cross-laminated timber as substitute for concrete to improve thermal efficiency while serving as a carbon sink.
- The role played by councils in assessments and signing off on sustainability requirements, as well as virtual building assessments and the levers available through local planning to drive sustainability.
- Investigate the role of sustainable finance options, and incentives to take up sustainable options in housing provision.
- Investigate the water and energy nexus: household shower times and their energy implications for example.

One IRG member suggested that commercial buildings should also be a focus, as they are not all covered by NABERS and few are ISO 50001 compliant.

Existing projects

The existing projects with a similar focus to the energy productivity opportunities in this cluster that were listed by the IRG were:

- The SimbleHome housing energy analytics system.
- Smart meter trials, including Sydney Water. This could fit with development of adapters to allow existing dumb water meters to be ‘smart’ and connected.

- The Fairwater Living Lab research study on sustainability, resilience, well-being and commerciality. Maybe scope for partnerships to leverage off what they are already doing.
- Wollongong University's Digital Living Lab, which provides an IoT network to create smarter living in buildings. Maybe scope for partnerships to leverage off what they are already doing.
- The EpiC database for material embodied energy, but needs help to build quality and detail. MECLA (WWF led) may also help here. UK has a comprehensive scheme that could be a model for estimation and reporting of embodied emissions.
- Mirvac's Affordability Experiment—surveys and monitoring to explore outcomes and learn from experience.
- The Green Building Council of Australia (GBCA) and thinkstep-ANZ are working for DISER on a project titled Embodied Carbon & Embodied Energy in Australia's Buildings. See MECLA and EpiC above.
- The Materials Embodied Carbon Leadership Alliance (MECLA), which involved the NSW Department of Planning, Industry and Environment, Lendlease and the World Wildlife Foundation.
- Partner with NatHERS and Sustainability Vic to integrate area data into modelling and rating tools. This could potentially link to energy retailers and network operators, who have a lot of data, though there are confidentiality issues regarding its use.
- Education on to use energy data to inform design processes.
- The Shergold Weir report on building surveying in NSW. This highlights issues of compliance and enforcement, as well as the broader issue of quality control. It could link to blockchain, Building Information Management Systems etc.
- Energiesprong housing, including net zero housing refit packages—these relate to 'deep' renovations that achieve substantial performance improvements but also involve substantial capital investment. Choosing which buildings to target and developing mechanisms for finance are significant challenges.

The Low Carbon Living CRC and Building 4.0 CRC were also listed as a similar project to this research cluster. LCLCRC is now completed, but there is a substantial research base on which future projects could be built. Building 4.0 could logically partner with RACE projects, as digitalisation etc are core elements of RACE.

An IRG member also raised a concern that there were already initiatives underway to address similar issues to those included within the Building performance opportunity, including representatives from DISER and the Property Council. While there is much work being done on building performance in Australia, such as the Trajectories program (e.g. COAG 2018), there are gaps within the research initiatives and the regulatory advances are generally voluntary rather than mandatory (Murray 2021). Therefore, pursuing building performance monitoring and transparency will require engagement and coordination with existing programs in this field, to ensure complementarity.

Industry partners

Potential industry partners nominated for projects in this cluster were:

- Innovative building material companies, such as Bondor InsulLiving
- GBCA
- Energy utilities for demand management opportunities (e.g. Ausgrid, Planet Ark Power, AGL, Powerpal)
- NatHERS
- MECLA—low carbon building materials
- ACOSS
- Housing industry associations and state building and construction authorities
- Local government AAEP

- Sydney Water
- Energy Efficiency Council
- Energy OS
- Solar analytics
- Energy Consumers Australia
- Brotherhood of St Laurence
- Master Builders Association/Housing Industry Association.

5.2.4 Path to implementation

There are a range of participants in the shelter sector that engagement would provide further insights into the opportunities presented in this section:

- The peak industry bodies: PCA, HIA, MBA, as well as trades
- Materials companies
- Sustainability-focussed housing developers (e.g. Nightingale, Lochiel Park, Cape Paterson)
- Industry regulators and government agencies
- Green Building Council of Australia
- Energy retailers
- NatHERS
- ACOSS
- Australian Energy Foundation
- Energy Consumers Australia.

The example of the mandatory disclosure laws in Queensland, as well as the concurrent step back from mandating 6-star energy efficient housing (Building Codes Queensland, 2012) provides some indication of the resistance to increased regulation to foster improved energy usage in the shelter sector. Developing a wider understanding of how major industry participants, such as industry bodies and the large-scale developers who operate in the major cities, respond to recommendations for materials, design and greater disclosure is a crucial aspect of pursuing this proposal. The SimbleHome housing energy analytics system is being installed into a new development in Sydney by Mirvac, indicating a willingness to innovate in this area (Simble, 2020).

Support from the finance industry to realise this opportunity is also required, because a crucial aspect of innovation in housing for energy efficiency is that energy related costs are not adequately accounted for in mortgage assessments and property valuations. Therefore, needed are collaborations to support the reduction of greater upfront costs to implement better materials and to eliminate the difficulties in deciding between differences in capital and operational costs.

Also, there has historically been slow uptake of sustainability or energy efficiency outcomes in the residential space in Australia. There are groups of early adopters out there as demonstrated by the less than 1% of new housing built to above an 8-star standard, or being retrofitted to a similarly high standard, and also demonstrated through the early uptake of solar panels, batteries and electric cars. However, as the examples of solar panels and other residential sustainability programs have shown, when the right combination of regulation, incentives and industry capabilities are provided the uptake of these technologies has seen a wider adoption showing that there is a willingness of the wider community to engage when the incentives support them to do so. The above opportunities should continue to target the typical early adopters of sustainable homes to help them deliver improved outcomes, but must find a way to engage in the next group of people who would engage if it was slightly more economically feasible for them. There are also other key issues in that the housing industry and supply chains are not set up to scale up and there is a high reliance on materials, technologies and skills which still come from overseas. Australia must be doing more to develop these capabilities closer to home; e.g. double-glazed windows where a high percentage are still imported.

There is currently an ARC Linkage project (Housing Energy Efficiency Transitions) exploring the lived experience of households engaging in deeper retrofit and their experience of various support programs. The project is also exploring the industry capacity to scaling up and will develop a policy pathway with project partners (including state government of Victoria) about how to scale up retrofit in Australia. There is also an AHURI Inquiry project looking at the circular economy and the residential sector in Australia. This includes sub projects looking at materials and supply chains, neighbourhood scale sustainability, retrofit and apartments. These all build upon the previous research mentioned such as the CRC for Low Carbon Living.

In addition to the SimbleHome example mentioned above, there are some smart water metering pilot studies have been done by water utilities and local councils, including Sydney Water. The following are examples of the smart water metring and hot water projects:

- Mid-Western Regional Council NSW had a smart water project (2019–2020), which utilised open system water smart meters to identify water leaks and water usage patterns. The open system allowed end users accessing their water usages, saving energy costs as less water than before was pumped to distribution tanks, reducing the water extraction from the river.
- After a successful smart water meter pilot project with the Wujal Wujal Aboriginal Shire Council, the Remote and Isolated Communities Essential Services (RICES) project was rolled out to four other communities in far north Queensland and the Northern Territory in 2019. Water use was reduced by 25–50% using culturally appropriate
- A smart hot water system project is currently undertaken by the Advancing Renewables (ARENA) Program in Victoria. The hot water system uses home energy usage and weather data to optimally use excess solar photovoltaics (PV) to heat hot water and maximise homeowner economic benefits.
- Rheem Active Hot Water Control project is another one currently conducting by the ARENA Program. This project aims to demonstrate active control for residential hot water systems in South Australia by improving renewable energy hosting capacity of networks and optimising the energy efficiency of households and the distribution network.

RACE for 2030 can ensure that improved quality of data is developed to inform the decision making moving forward for policy makers and the industry. For example, earlier it was mentioned that there was a lack of data about the actual appliance performance in people's dwellings. Addressing this data gap would help to improve the potential pathway forward to improving outcomes from appliances. RACE for 2030 could also bring together many of the incumbent regime across the building industry who have traditionally been resistant to change around housing performance or the introduction/improvement of verification of outcomes. E.g. peak industry bodies. It may only take a couple of the larger actors in the residential building and retrofit space to take some significant steps towards the opportunities outlined above before the rest of the industry could follow.

Digital transformation technologies that can help to optimise energy efficiency, energy production and reduce carbon emission for the housing monitoring and performance are smart construction and simulation technologies, big data and predictive analytics, real-time monitoring systems. Smart construction and simulation technologies are building information modelling, virtual twin experience for construction monitoring, modular construction with 5D. Digital technologies such as bid data analytics can provide decision support information by identifying the most effective and efficient ways to reduce the use of energy for housing. The utilisation of smart water and energy meters allow real-time analysis of water and energy consumption within the buildings. Water and energy can be saved by providing the end users accessing the consumption data and advice on how to reduce the consumption. For instant, smart buildings employ digital technologies to connect all the equipment and systems, and even the smart power gird, which optimise the energy performance at the lowest cost and environmental impact over the building lifecycle.

5.2.5 Conclusion

For both opportunities, the materials and innovation approaches already exist, however the feasibility of the implementation of this opportunity relies on change in business models and the support from the government to deliver the benefits. For new materials, an industry representative saw the development of viable supply chains as crucial for the adaptive use of biproducts from other industrial processes in reducing the energy use. The industry needs to support uptake and provide co-design for optimal implementation, while government needs to facilitate change through actions such as updating building codes, planning scheme requirements, educating and incentivising the industry and consumers in the importance of material uptake, and how the benefits outweigh the cost in the long term. As indicated above, communication with the stakeholders to engender support from the transformations included in this research cluster is crucial.

A key aspect of Opportunity 2 is that the value of sustainability in housing requires clearer market information. Examples can be taken from the ACT mandatory disclosure program, as well as in other locations such as the EU. Real estate agents are critical intermediaries, and need to communicate key sustainability features of housing in a clear and systematic way: this may require education. For retrofits, there is the need for a coordinated effort to develop the industry with a greater focus on energy efficiency, also supported by appropriate education and training in how to achieve higher energy efficiency in housing. Smart metering as a part of the housing monitoring and performance is a business transformation project. The near real-time water and energy data presents opportunities for improvement in energy savings and energy productivity in water and building value chains. The key transformation steps involved are the collaboration between utilities and end users, reliable user-friendly platforms autonomously produce useful reports and feedbacks. The latter is the critical component of a successful smart metering system. As stated in the discussion, there are a range of projects and initiatives related to energy efficiencies and transparency in the shelter value chain. Therefore, an important first step in pursuing this opportunity is to map and coordinate with the other actors in this area.

5.3 Additional research clusters

Details of the other research clusters included in the evaluation process are included in this section, for reference.

5.3.1 Cluster 3: Improving digital information exchanges

Three projects from different clusters draw on the use of telecommunications in service delivery to reduce the need for travel. As research initiatives, the experience of the rapid transfer to online provides lived experience of remote systems in workplaces. The research identified associated opportunities in the health and education sectors, but the prospects for energy productivity improvements extend to much of the knowledge-intensive and services-based economic activity that it more amenable to remote work and digitised information exchanges (Autor & Reynolds, 2020). This cluster has the potential to extend to a wider range of opportunities for information transfer than the sectors listed here. For example, the use of drones for the remote collection of systems performance data in agriculture, mining and manufacturing.

Opportunity 1 is from infrastructure, Opportunity 2 from health, and Opportunity 3 from education.

Opportunity 1: Improve telecommunications productivity

Improving the productivity of telecommunications would reduce low-productivity work travel, and as a result improve the energy productivity of existing infrastructure and reduce the demand for new infrastructure. The experiences of remote working and the cessation of work-related travel in 2020 provides the basis for identifying ways to improve the information transfers from telecommunications, and therefore replace more travel to work (commuting) and for work. It also offers potential to explore a range of options for working arrangements, such as adapting buildings in suburbs for micro-offices and sub-offices so workers could enjoy social and business relationships, avoid costs and other issues of working from home, and improve potential for management to supervise and support staff in future workplace models. We can learn from recent experience so future developments are more likely to be successful.

Opportunity 2: Telehealth

There were more than 400,000 GP visits per day in Australia in 2018 (AIHW 2018), indicating that the health sector generates transport demand in Australia's cities and towns. Aspects of Australia's health system rapidly transferred to online platforms in 2020, providing a range of services via telephone and internet conferencing systems. Improvements to the telehealth system can help to sustain increased energy productivity in Australia.

Opportunity 3: Digitalisation of education delivery

Similar to the health sector, education in Australia underwent a rapid transfer to online teaching delivery systems in 2020, which if continued would reduce transport energy usage for school commuting. There are also prospects of reduced energy use, and thus productivity gains all else being equal, through the reduced demand for university facilities. Improvements to digital methods of education delivery may also reduce the demand for international students to travel to Australia to study. A better understanding of what students value in their educational experiences could help to maintain or improve educational and other value outcomes.

Industry Reference Group responses

Other opportunities

The additional prospects for energy productivity savings for the Improving Digital Information Exchanges cluster included:

- Virtual site inspections and documentation for quality control and compliance
- Virtual and augmented reality for training and guidance on-site for installation, repair and servicing
- Local shared offices may offer an alternative to working from home
- Digital metering could greatly assist with determining energy saving opportunities. This could include performance tracking to improve preventive maintenance and optimal timing of appliance replacement
- In the property sector, digital information in residential, commercial, industrial and retail sector.
- Automated data collection and monitoring, including drones.
- Sociological research on the professional status value of travel, how it is valued as part of working life.
- Platforms and practices that can provide better virtual experiences.

Existing projects

The existing projects with a similar focus to the energy productivity opportunities in this cluster that were listed by the IRG were:

- The solar PV industry uses apps and phone cameras for quality control and reporting of installations, documentation for future repairs, safety checks
- The NSW Government is consolidating its data centres.
- Research into telehealth during the pandemic provided mixed results, it wasn't appropriate in all circumstances.
- SimbleSense solar performance and power purchasing agreement reporting for business.
- Sydney Water are monitoring pipes using Internet of Things technologies.
- Beefledger blockchain ledger for the Australian beef industry
- Provision of precinct access to IoT comms such as LoRaWAN, a low power wireless data system.

Industry partners

Potential industry partners nominated for projects in this cluster were:

- Data Centre providers in Australia
- Federal and state government departments in the related sector: telecommunication, health, education and social housing.
- Telecommunications industry and broadband/mobile providers, plus virtual platform providers.
- Regulators and trade training organisations.
- Software and encryption innovators and digitalisation businesses.
- Regional health service providers.
- Remote operations companies, such as the mining sector.

5.3.2 Policy for energy productivity

In addition to the systems and technological approaches listed above, there were considerations of how policy changes could lead to energy productivity improvements in health, education and infrastructure. There are also other sectors where policy approaches could prove beneficial, such as shifting from stamp duties to land taxes to encourage shifting to housing of appropriate size as families change. Also, existing policies such as first home buyer schemes and business accelerated equipment write-off could be adapted to achieve EP outcomes beyond existing policy focus.

Opportunity 1 is from health, Opportunity 2 from infrastructure, and Opportunity 3 from education.

Opportunity 1: Public health

At 2% of the health budget, Australia's spending on public health measures is low in comparison to other OECD countries, yet public health initiatives present high return on investment (PHAA, 2019). For energy productivity in the health sector, their importance lies in their capacity to keep people out of hospital, which is the most energy intensive part of the health care system. There is a need to document the benefits of preventive health, and incorporate them into government and private sector decision-making, as well as making it possible for businesses to capture returns where public benefit is achieved. Therefore, increasing public health spend presents an opportunity to provide long-term improvements to energy productivity in the health sector.

Opportunity 2: Making better infrastructure decisions

Infrastructure decisions are generally supported by cost benefit analysis, which is administered by the Commonwealth and State infrastructure agencies. Cost benefit analysis also includes a measure of productivity in the estimation of the net present value of the infrastructure. A greater focus on non-capital expenditure options to solve issues associated with infrastructure, as well as improvements to the cost benefit analysis process, would lead to improved energy productivity in both new and existing infrastructure in Australia.

Opportunity 3: Travel minimised transnational education

Other than the energy use by education buildings, international student travel is a major contributor to the energy usage in the tertiary education sector in particular. Australian universities have offered TNE study programs to international students in countries in Asia for some time, with more than 100,000 students engaged with Australian education providers in other countries in 2018 (HESC 2018). Extensions of and additions to these programs may lead to energy productivity benefits for the Australian tertiary education sector. There is also a need to understand the motivators of students to come to Australia for education, so that alternatives can offer a comprehensive mix of outcomes that will be attractive, not just education. For example, it may be that enhanced rights to settle in Australia, cultural acclimatisation or other features must be packaged with virtual education to attract international students.

Industry Reference Group responses

Other opportunities

The additional prospects for energy productivity savings for the Housing Monitoring and Performance cluster included:

- Energy education and training
- Gamification of self-monitoring of health
- For infrastructure decision-making, reduce the perceived risk of adopting innovations, through testing and case studies. Also, reviewing why unsuccessful policies have failed.
- The role of targets, regulatory and pricing instruments in providing signals to markets and sectors as to energy productivity expectations.
- Increased durability and reliability testing of materials and equipment
- Flexible demand management of infrastructure systems
- Embodied energy (carbon) information for products and services
- Expand energy saving schemes into other areas.
- The impact of the focus on short-term outcomes, as well as discounting rates for alternatives to construction.
- Understanding the connections between energy and other aspects of organisations, including data and cultural barriers to achieving better energy productivity.

One IRG member noted that public health and is not always possible, genetic illness for example. Also, reducing hospitalisations can also happen in hospital through repeated admissions from poor discharge systems. An associated proposal was to investigate aged care and the energy requirements of the aging population.

An associated recommendation was to consider the role of major financiers, particularly those adopting climate risk, adaptation and mitigation frameworks, in facilitating energy productivity outcomes.

Existing projects

The existing projects with a similar focus to the energy productivity opportunities in this cluster that were listed by the IRG were:

- hospital in the home programs and transition care
- the NEPP, however it was not well supported.

Industry partners

Potential industry partners nominated for projects in this cluster were:

- The Health Promotion Association of Australia
- Public health agencies and major hospitals.
- Health and environment organisations—The Climate and Health Alliance, Doctors for Environment, etc.
- NABERS and GBCA hospital energy programs
- Infrastructure Australia, and state equivalents.
- Infrastructure financiers
- State treasuries and transport agencies on infrastructure decision making.
- Energy Consumers Australia
- Facilities Management Association

5.4 Enabling and cross-cutting opportunities

Energy productivity opportunities identified as a result of this research should be considered due to their role in enabling energy productivity outcomes across Australian industry: they are not just confined to one sector.

Opportunity 1 is directly from the Data sector analysis in Section 4.1. The second and third are adaptations of other opportunities from Shelter and Infrastructure.

5.4.1 Opportunity 1: Blockchain for data provenance

The main data energy productivity opportunity identified is Blockchain for Data Provenance, which is included in detail within Section 4.1.4. The discussion of the Blockchain for Data Provenance opportunity notes the application to the food and agricultural sector, as well as health and education.

Data Provenance is one of the key components of data value chain (Data Economy). Data Provenance refers to a process of cloud data auditing by enabling data tracking from the source of data (Simmhan *et al.* 2005). Today consumers are more digital savvy and are more demanding regarding the information about the food stuff they buy. The recent studies on data provenance revealed that one of the challenges is to establish a trust between data users and cloud services preserving privacy of sensitive data. Blockchain has the capability to offer transparency, traceability, and trust (Liang *et al.* 2017). Blockchain as a technology has been known for quite some time but its use for data provenance be transformative for business processes changes and thus improving overall energy productivity in the data value chain.

There are other possibilities with Data, including digital twins for improving energy productivity in health and shelter value chain. Digital Twin is an innovative data-driven real-time modelling tool. One can leverage digital twins for business process automation and predictive analytics which influences energy productivity.

5.4.2 Opportunity 2: Commercial building performance

The issues identified within the Shelter sector discussion in Section 4.6 also apply to the commercial sector, including public buildings as noted in the Education and Health sector reviews. Energy use and emissions from buildings is seen as an unrecognised challenge in Australia (Saddler & Jotzo, 2021), and it has been estimated that 10% of Australia's greenhouse gas emissions are a result of buildings such as shops, hotels, restaurants, and offices, industrial buildings, schools and hospitals, and much of the use is in HVAC systems (DISER n.d.). This indicates that commercial building performance is a potential future focus for RACE for 2030, providing the basis for energy productivity across large sections of the economy.

5.4.3 Opportunity 3: Work-related travel

Along with commercial buildings, work-related travel is the major source of energy consumption for knowledge and information-intensive sectors, such as finance, IT, education and professional services. Energy use on travel is not necessarily allocated to these value chains, indicating their industry-wide energy use is underestimated (Fourcroy *et al.*, 2012). The halt in business travel during 2020 provides the basis for reconsidering the need to travel, with further work in establishing policy and market settings, for air travel in particular, likely to provide energy productivity outcomes.

5.5 Summary

This chapter has set out the research priorities that has resulted from the investigations into energy productivity. The priorities have been identified as a result of three aspects of the methods set out in Chapter 3:

- The desktop review of industry sector productivity and energy use, detailed in Chapter 4.
- The ranking of energy productivity opportunities by the research team.
- The ranking of research clusters by the IRG.

As a result of these processes, the recommendations for priority projects as a result of the research are:

Priority Cluster 1: Food Systems:

1. Food Transparency
2. Reducing Food Waste

Priority Cluster 2: Housing Systems (Monitoring and Performance):

1. Innovative Materials and Design
2. Building Performance Transparency

In addition to these priorities, valuable opportunities have been identified within the Food Systems cluster, as well as those listed within Section 5.3 on longer term options and particularly in 5.4 Enabling and Cross-cutting Opportunities, which would underpin energy productivity opportunities across Australian value chains. These alternative perspectives on opportunities for energy productivity inform the arguments presented in Chapter 6.

6 Discussion

This chapter reviews the methodologies used in this project to identify energy productivity opportunities that align with RACE for 2030 objectives. The discussion draws on the foundations for the research set out in Chapter 2 to provide recommendations for the design and methods of future projects in this field. This includes the role of policy and market transformation, the pros and cons of productivity and efficiency as the basis for analysis and the approaches to opportunity identification.

6.1 Policy for energy productivity

Socio-technical transitions theory includes the role of institutions and policy in determining the adoptions of niche innovations and changes to the socio-technical regime. As discussed in Section 2.2.3, institutions and policy form part of the socio-technical landscape, the factors that shape the direction of change in the socio-technical regime, with the analogy to directing the 'flow' of change. Geels (2007, 2011) is alluding to that in order to achieve the preferred outcomes, in this case improvements in energy productivity, the landscape needs to be structured in a way that influences changes in that direction.

This underscores the need to consider policy settings that influence the uptake of technologies and business and organisational models that promote energy productivity adaptations. This includes industry-specific policies, as well as the economy-wide policies relating to innovation, energy use and generation, and carbon emissions. The following two sections extend this argument for a focus on policy to facilitate energy productivity outcomes alongside direct, industry-focussed research.

6.1.1 Policy for market transformations and innovation

A central aspect of the innovations and socio-technical landscapes literature is that shifts in the ways goods and services are produced and consumed require combinations of technical and policy changes. As argued in Section 2.4, it is likely that the more transformative changes are, the greater the role of the non-technical aspects: business models, organisational changes, policy and shifting consumer preferences. In the multi-level perspective, this generally aligns to the socio-technical landscape that guides the social adoption of niche innovations (Geels & Schot 2007). However, the wider changes to societal norms can be more difficult to realise, as one IRG member pointed out:

> *Some of these sectors are institutionally large and not prone to innovation or transformation. While the technological change is relatively feasible, the institutional changes to transform energy productivity are likely to be very challenging.*

As implied in the quote above, there is a greater risk that projects directed at policy and shifting the socio-technical landscape fail to achieve their aims. The interviews with industry representatives undertaken to support and validate the project recommendations reiterated this point.

The role of policy, social considerations and standards in facilitating market transformations and energy productivity outcomes was also evident in the IRG responses to the research clusters, including:

- lack of sticks and carrots
- split incentives between those who have to act and the beneficiaries
- energy considered a cost of business or living, not as part of cost of goods sold that can be managed or reduced
- breaking the existing mindset, for example new houses still connected to gas

- setting a new bar for the construction industry that is not giving me the biggest house for my dollars
- short-termism.

The use of policy to change the way markets operate is central to the proposals for Priority Cluster 2: Housing Systems (Monitoring and Performance) in addressing the lack of information on energy use in housing transactions.

The outcomes of such projects are also more difficult to quantify than process efficiencies, due to their indirect effects and also the likelihood that the impacts will take longer to realise and also be accumulative as the economy and society adjusts.

Shifting the socio-technical landscape to incentivise energy productivity outcomes may make a significant contribution energy productivity gains, including through increasing the development and uptake of process efficiencies. Such initiatives are also more difficult to quantify, are likely to take longer to have an effect and are associated with risks due to political changes and priorities. Even with these concerns considered, policy interventions that address incentives and innovation for energy productivity are a crucial aspect of achieving Australia's energy productivity goals, and in general technological innovation depends on these broader policy interventions and cultural shifts. Recent research into mission-based innovation policy and public sector innovation and policy entrepreneurship may provide the basis for considering how policy and institutions can contribute to the long-term aims of RACE for 2030 (e.g. Karo & Kattel, 2016; Mazzacuto *et al.*, 2019).

6.1.2 Efficiency and disruption

The purpose of this research has been to reconsider consumption and systems of production to realise energy productivity benefits in Australian value chains. To recap, energy productivity is a measure of unit of output per unit of energy use, therefore energy productivity benefits can result from changes to both or either of these factors. The depiction of energy savings prospects from the NEPP, depicted in Figure 2.2, suggest that the two factors can be seen as separate responses to energy productivity: energy cost savings on one hand, and market benefits on the other. The emerging focus on energy productivity, multiple benefits, circular economy and other such formulations reflect a widely-held view that both factors are intertwined, and that factors other than direct energy savings can be major influences on behaviour. The projects identified in the sector analysis are a mix of approaches to energy productivity, for example:

- **Cold Chain as a Service** can be seen as an energy cost savings approach.
- **Building performance transparency** helps consumer value energy efficiency in their consumption choices.
- **Public health** argues for the redirection of demand in the health sector away from energy-intensive hospitalisations,

However, none of the opportunities identified could be considered truly transformative in their impact on incumbent industry participants. This can be seen as a result of critiques of disruption theory. The first is that a criticism of disruption theory is that it is not predictive: technologies, business models and organisation structures can only be described as disruptive once they have dislodged incumbent industry players and production systems (Kostoff *et al.* 2004). Therefore, identifying and forecasting the combination of technical and business model innovations that will lead to disruption is unlikely to result from the inductive methods used to undertake this research, which started by analysing data and progressing to theories of energy productivity savings.

It is important to consider how to create and shape markets and systems that guide innovation towards socially-desirable outcomes, in addition to directly identifying best or better practice within systems of production and consumption. Therefore, a role for government and policy is to direct innovation and change by 'tilting the field' to prioritise decision-making that aligns with long-term social goals.

6.1.3 Project recommendations

The foregoing discussion forms the basis for recommending that the RACE for 2030 program of work continues to engage with the policy questions arising from energy productivity and socio-technical transitions. There are two parts to this recommendation:

1. First, industry-specific research projects need to include policy and market analysis within their scope. This responds both to the IRG views on 'carrots and sticks' as well as socio-technical transitions theory. Priority cluster 1: Housing systems (building performance transparency) is an example, where the focus on collecting data on building systems and energy use requires policy to facilitate the translation into market effects. It may also involve other concerns, such as the development of suitable training resources, certification schemes, and where policy already exists but is ineffective because of flawed or under-resourced implementation. These elements are evident in the housing proposals in Priority Cluster 2.
2. Second, wider policy settings that impact on and direct market transformation, innovation and transitions towards improved energy productivity need to be part of the RACE for 2030 research agenda. The IEA (2015) made the observation that industry is heterogenous, even within sectors, and therefore pursuing energy savings within value chains from a technical or process perspective may miss opportunities to engender far reaching change through innovation policy, incentives and other market mechanisms and other interventions that can cut across industry and consumers. Accordingly, we suggest that RACE should consider establishing an ongoing program stream that considers the market transformations required for an energy productivity and value-chain transformation agenda to be successful. This stream would not be technically applied, in terms of working directly with industry on specific value-chain transformations. Rather it would address the whole context of policy, regulatory and industry engagement with the notion of energy productivity for value chain transformation and the market transformations necessary to enable this conceptual shift. Such considerations are reflected in the latter two components of the 2015 COAG NEPP (see p. 17 above), namely 'More Efficient Energy Markets' and 'New and Innovative Products and Services'. Such a program would also need to account for the multifarious and divergent policy, regulatory and industry perspectives and interests, including factors that retard transformative thinking. This program would also need to grapple with questions of innovation ecosystems including the need to have multiple sectors and stakeholders, both industry, policy, and external, involved in the innovation process. In addition, this program would require further engagement with the theoretical and conceptual aspects of value-chain transformation for energy productivity, given the limited literature on which this project has been able to draw. To this end we have included in the roadmap a proposed RACE for 2030 program stream addressing these Agenda issues.

6.2 Foundations and methods

This section reflects on the foundations and methods of the research addressing the need for quantitative data for impact metrics and a formal measurement and evaluation process for assessing the impact of research projects.

6.2.1 Challenges in industry energy productivity

While conceptually simple, calculating energy productivity for an industry or a specific output of production is complicated. This is also true of other subsets of the economy, either spatial or industrial, where allocating value added within the units under investigation relies more greatly on assumptions due to the data requirements (Eurostat 2013; Gretton, 2013). Energy productivity is also a derived statistic or measure, calculated by dividing value add or output by the energy required for production. As it is calculated from combining observed data, energy productivity improvements can result from any combined or individual change to value add and energy use that results in greater output per unit of energy, which can impact on the approach taken by researchers in identifying opportunities.

The limited availability of disaggregated data on energy use and value added for fine-grained analysis of energy productivity constrains the calculation of energy productivity at more than an industry scale, which is compounded if the measure is of primary rather than energy use. A range of factors unrelated to energy, such as variability in prices or short-term weather impacts on energy use can distort estimates of energy productivity in the short term, as well as within specific parts of the economy. The energy associated with intermediate inputs to production (Scope 3 emissions) is also difficult to quantify (WEF & BCG 2021).

The value of outputs and value added within an industry sector also adds complexity. For industries in the service and non-market traded sectors, which contribute 79% of value added in the Australian economy, measuring productivity is complicated by the lack of a standard unit of output, and the consumer affects the production of the service. Inputs to service production are also more difficult to measure than for goods, as it is dependent on measures of worker skills and can be affected by outsourcing and industry categorisations (Productivity Commission 2021). In the Australian system of national accounts, the provision of health care and education are considered “transfers in kind, which occurs when one party provides a good, service or asset to the other without receiving anything in return” (ABS 2015, p. 47). Due to this issue government services such as health care and education are included at cost in production methods of calculating gross domestic product.

The outcomes of this research provide support for these arguments. The two value chains that are the most linear and physical product orientated in their systems were selected as priorities: water and shelter. While there is obviously a range of factors in this result, it is also notable that these are the two that most clearly align with Porter’s value chain concept. The potential outcomes of the energy productivity opportunities within these two sectors can also be seen to have a more direct impact on energy use within the associated systems of production, particularly in comparison to proposals such as increasing transnational education provision, data monetisation and public health.

These issues are compounded when making estimates of the benefits of sub-sectors of the economy, as well as projects that impact on aspects of an industry sector, as data on current energy use and the number of businesses using that specific process would be required to make an estimate. While estimates and projections of energy savings have been made in this research, consideration should be given to aligning with other measures of and approaches to energy use and benefits in industry. The paucity of detailed data to assess the potential impacts of the opportunities identified in this report also informs the research agenda for RACE for 2030 set out in Chapter 7, which recommends focused feasibility studies to address this issue in a targeted way.

6.2.2 Approaches to impact measurement and appraisal

A major challenge in this research has been to development estimates of the current energy productivity and the impact of the proposals, as indicated by the summary of productivity and energy data in Table 5. As mentioned in Section 2.1.1, other approaches to energy use than energy productivity in industry are currently being developed. The primary distinction of these approaches to energy productivity is they begin with energy efficiency and then argue that there are other beneficial outcomes that arise from energy productivity, whereas energy productivity as used in this research begins from the end use service. Measurement is also related to methods, as indicated by the above comparisons of energy productivity and multiple benefits indicates.

Assessments of the benefits of energy saving and management actions tend to focus on the value of energy saved, a likely result of the complexity of undertaking a full and detailed appraisal (Ürge-Vorsatz *et al.*, 2016). In most cases this is a small component of input costs, while the processes that rely on energy are seen as essential for production (Instinct and Reason, 2015). The measures involved are often technically complex, and raise concerns regarding risk to production or successful implementation. Consideration of the value related to services or, the 'multiple benefits' (IEA, 2015), can dramatically improve the attraction of energy saving action to industry but these benefits are rarely costed and factored into decisions on energy management. This is often because they are difficult to cost, or they accrue to beneficiaries beyond those immediately involved in the project and, indeed, often beyond the boundaries of the organisation.

Further, assessing the value of a measure must also explore the potential risks and disbenefits perceived by each decision-maker and participant. These create barriers to action, and may reduce the proportion of industry moving to new methods of production. A risk perceived by one participant can undermine adoption of a measure that offers a net benefit to an organisation or to the system of production. It is interesting that many studies of energy efficiency focus on barriers to action, and ways of overcoming them. This is the flip-side to consideration of the multiple benefits. The energy productivity and value chain approach supports consideration of multiple benefits, risks and barriers, as well as recognising the perceptions of participants of factors such as risks and costs.

Various attempts have been made to estimate the broader benefits of demand-side energy improvement action and the International Energy Agency (IEA 2015, 2019) has also conducted extensive work on identification and valuation of multiple benefits from energy efficiency. As Ürge-Vorsatz and others (2016, p.29; see also Chaterjee *et al.* 2018) caution in measuring the benefits of projects such as those included in this report:

> *... this task is very complex and so far lacks appropriately elaborated methodologies that, among others, (a) systematically account for all impacts and (b) systematically and consistently examine the interactions among them and integrate them in a manner that avoids over- and undercounting issues.*

This discussion of the difficulty of measurement presents an issue for energy efficient and productivity project appraisal. Limiting the inputs to the decision-making and prioritising processes to available data and singular metrics such as energy savings omits or in the least de-emphasises both costs and additional benefits. However, undertaking cost benefit analysis to support decision making is also resource and data intensive, and is prone to biases (Department of Resources, Energy and Tourism 2010; Denham & Dodson, 2018).

There are approaches to estimating energy productivity and benefits currently being developed, reflecting the importance of ex-ante estimations in policy and project decision-making. Two of these methods are, COMBI and the aforementioned Mbenefits. The purpose of including these two examples is aligning with existing research into measurement and appraisal should be considered as a way to address the issues raised in this discussion. While these methods will provide indicative estimates of project benefits, there is still a need to undertake detailed outcomes assessments through trials to underpin the development of business cases and models, advocacy and facilitate industry adoption of energy productivity innovations.

COMBI

The COMBI modelling tool has been applied across many European Union countries. It considers air pollution, resource consumption, social welfare, economy (employment, GDP and public budget and long-term factors including structural effects and prices of energy and energy upgrades), energy systems and energy security (COMBI, 2015; Therma 2018).

The Mbenefits Project

The European Union *Mbenefits* project has developed a practical approach to organisation-level strategic analysis and proposes a process. On the website several examples are shown where consideration of multiple benefits significantly reduces the simple payback period relative to consideration of only energy savings (Mbenefits, 2019). Factors that contribute to these additional savings and reduction of risks include:

- Reduced hazardous waste costs
- Decreased O&M and technical control costs
- Reduced absenteeism
- Reduced emergency responses
- Improved employee safety, reduced accident risk
- Reduced legal risks (health/compliance) and insurance costs (e.g. accidents)
- Reduced risk of hardware damage
- Improved thermal and visual comfort, reduced occupant complaints
- Improved worker productivity and production rates, staff loyalty (recruitment costs, training)
- Increased financial turnover due to employees not diverted to non-manufacturing activity (e.g. maintaining boiler)
- Improved image/reputation and customer satisfaction
- Improved equipment reliability, reduced disruption, reduced reject and re-work rates
- Reduced noise level and improved compliance with noise standards
- Improved air quality in workspaces
- Reduced down-time due to repairs, reduced emergency callouts for outages
- More consistent product quality
- Optimised process performance and coordination
- Reduced climate impacts and carbon costs
- Deferred capital investment
- Achievement of improved ventilation required for pandemic
- More space/improved space utilisation
- Access to government incentives
- Example to others within organisation

While not all of these benefits can be easily quantified, they add to the strength of the business case presented to management.

Other examples of benefits beyond energy savings from other sources include:

- Reduced food waste and, where food lost has been processed, transported and handled, associated reductions in staff time and other inputs
- Extended shelf life and reduced staff time managing/checking/sorting stock and disposing of waste
- Reduced waste disposal costs
- Reduced customer complaints and health impacts

6.3 Summary

This reflection on the project and its conceptual underpinnings includes considerations for future research into energy use, productivity and efficiency, based on transformations and value chain analysis. The recommendations also address the need for impact measurement and appraisal methods that address the substantial gaps in the data available for productivity and energy use at a detailed level for Australian industry.

The industry consultation through workshops and interviews indicates that the opportunities for and barriers to improving energy performance are related to business models, markets and encouraging industries to shift their systems of production. This indicates the need for multi-disciplinary research teams and a continued focus on both industry-specific policy interventions as well as considerations of wider energy and innovation policy and institutional structures in Australia. This also concords with socio-technical transitions theory, which underscores the societal changes required for niche-innovations to enter the mainstream.

7 Research agenda

The main purpose of this research is to identify and prioritise opportunities to increase energy productivity in industry, based on investigation and analysis into seven value chains. The results were assessed by the project team and tested with the IRG to identify the priority research clusters, and projects within those clusters. As set out in Chapter 5, the priority research clusters are (1) **food systems** and (2) **housing monitoring and performance**. The first section of this chapter outlines the proposed research agenda for these two clusters. This discussion informs the research roadmap in the following section, which sets out sequences of projects that address issues identified within each cluster.

7.1 Food systems

This section summarises the two primary opportunities within the food systems cluster of research opportunities and the rationale for pursuing them.

7.1.1 Food transparency

The priority research opportunity within the food systems cluster is Opportunity 1: Food Transparency. A project in this topic area would promote the use of digital information gathering for consumers and participants in the industry. This project would serve to reduce energy use through improving traceability through supply chains, as well as adding value to food chains through provenance and information on the production systems.

An important aspect of the food transparency opportunity is that it provides an opportunity to develop a project that leads and informs the take-up of blockchain technologies in the agriculture and food product manufacturing, wholesaling and distribution systems. By developing a system of food information transfers along the supply chain from farm to consumer, further benefits can be leveraged through other opportunities identified in this research, such as shorter supply chains and reducing the energy consumption in transport and stationary cold chains, and reducing food waste. A blockchain-focused food value chain project would also allow for data generation that can be monetised for further value (see Section 4.1.4).

7.1.2 Reducing food waste

This opportunity responds to the aim of increased energy productivity in the food sector by reducing waste, either through improved processes in food handling, or for more productive reuses of food currently going to waste. The development of robotics for harvesting has the potential to increase yield, particularly in fruit growing, and thus providing a greater return to producers for their inputs to production, including energy.

While one industry representative questioned the extent of waste in the Australian food system, there is evidence that food waste is costly and reducing the sector's energy productivity. An important question for progressing this opportunity is whether the current systems for use of non-compliant and non-productive foods can be improved, especially with a focus on the energy implications of the existing systems. For example, the impact of food compliance regimes can be seen as reducing the value that results from production as foods are diverted to lower-value markets, rather than to landfill: waste is the loss of value add from production, not the disposal of food into landfill. The range of opportunities within the recommendation indicate further research into bio-packaging and biodiesel are two prospects for adaptive reuse of low-value foods and foods destined for landfill.

7.1.3 Other opportunities

Key aspects of the cold chain can be addressed within the two priority recommendations. The introduction of blockchains within the agricultural sector also provides the basis for improving cold chain logistics and energy use, through produce monitoring and also improving the efficiency of transport services. Improvements to monitoring systems within the cold chain also impacts on food loss, and the quality of produce being provided to consumers.

The estimates of more than 50% energy savings in the agriculture, water and energy sectors indicate that this opportunity should be included in future research priorities within RACE for 2030. Also, the use of IoT technologies and smart irrigation systems included in this opportunity would impact on food energy productivity, and can be seen as an aspect of reducing food waste.

7.2 Housing map systems

This section lists the two primary opportunities within the housing systems cluster of research opportunities and the rationale for pursuing them.

7.2.1 Innovative building materials and design

Improvements in building materials, such as SIPs and engineered timber, indicate that there are energy benefits to be realised in the shelter sector. Key barriers identified within this opportunity are industry education, and the provisions for new materials use within building codes, indicating the need for a focus on policy and institutions. However, in addressing these issues it is likely that as materials and design continue to innovate, the industry will be more receptive, and ready to adopt the innovations.

It is estimated that the savings in 2030 would equate to 16% energy reduction across new housing built during that period of time, or 1% of total residential energy consumption in 2035. The benefits would increase over time, as older housing stock is renovated or replaced, and the proportion of higher-performance stock in the market increases over time. This is also closely aligned with the RACE for Homes program, which may benefit from this value chain approach.

7.2.2 Building performance transparency

This opportunity addresses the lack of understanding of building energy performance, which means that it cannot be considered in housing transactions. While there are other initiatives underway that address these issues, there is an opportunity to address gaps and take a value chain approach to accounting for building energy performance in transactions in Australian housing.

The four elements of the proposal outline a multi-faceted approach to building performance transparency: assessment, transparency and incentives and performance monitoring, including water. The opportunity can be seen as the basis for a market transformation within the shelter sector, by increasing the provision and efficacy of data to inform housing choices and transactions. The longer-term implications are that housing costs take a greater account of operational costs, which in turn should be represented in rental agreements and mortgage repayment calculations. This opportunity has synergies with the projects within the RACE for Homes stream.

7.3 RACE for 2030 research roadmap

A roadmap has been prepared that sets out the research agenda for RACE for 2030 for the two priority clusters, drawing on the research included in Chapters 4 and 5 to construct sequential projects with input from project partners to respond to the primary opportunities identified. In addition, we have included an ongoing market transformation agenda relating to understanding of value-chain transformation and energy productivity. This latter program is needed to build and disseminate knowledge of these concepts within the market and to develop shared understanding of how they can be applied at the national scale through a transformative planning process.

For the projects within the food systems cluster, the initial projects are feasibility studies that address the need to undertake trials of technologies and systems to build the evidence base as a foundation for the development of business cases and industry adoption. The projects within the housing systems cluster are situation analysis projects, as the primary objective is to restructure the value chains and the ways of working within them to realise energy productivity benefits. The subsequent project recommendations follow the same structure for both clusters:

To 2023

- **Feasibility studies:** Testing technologies and innovative production systems to provide proof-of-concept and an evidence base for further development.
- **Situation analysis:** Establish a stronger evidence base and detailed understanding of the industry and its value chains, including transformation capacity.

To 2025

- **Transition studies:** Address key barriers to implementation and industry uptake, including social, technical and regulatory impediments identified in the feasibility or situation analysis studies.

To 2030 and beyond

- **Expansion and adaptation studies:** Facilitate the transition of industry to new and more energy productive ways of working

7.4 Final remarks

This project has undertaken research into the productivity and energy use of seven prominent value chains in the Australian economy, identifying 15 opportunities for energy productivity improvements. The opportunities address energy productivity from a range of perspectives, including the technology focus of energy use in irrigation systems and building materials, the market transformations facilitated by increased transparency in the food and shelter sectors and the demand diversion in telehealth and digital education delivery. These outcomes provide support for the IEA's (2015) observation that industry is varied, and as a result so are the opportunities to improve energy use, as well as the theories of socio-technical transformations and innovation. The four projects identified as priorities also serve to highlight this diversity, addressing energy productivity through technologies and markets, through including interactions with policy, regulation and industry education within their scopes.

In addition to the priority projects, a second outcome from this project has been to progress the understanding of energy productivity for industry and the associated concepts, frameworks and methods. The intent has been to provide constructive reflections and options for progress that consider the experiences of the research team, and inform future work in this important area.

8 References

The references are categorised into two sections. The first includes the references for the first three chapters, which set out the project and its methods. The second includes references for Chapter 4, organised by value chain.

8.1 Chapters 1, 2 and 3

A2EP, 2014. Australia's Energy Productivity Opportunity, Australian Alliance to Save Energy.

A2EP, 2015. National Energy Productivity Plan 2.0, Australian Alliance for Energy Productivity, Sydney.

A2EP, 2016a. A roadmap to double energy productivity in agriculture by 2030. Australian Alliance for Energy Productivity, Sydney.

A2EP, 2016b. A roadmap to double energy productivity in the built environment by 2030. Australian Alliance for Energy Productivity, Sydney.

A2EP 2016c, A roadmap to double energy productivity in manufacturing by 2030. Australian Alliance for Energy Productivity, Sydney.

A2EP, 2016d. A roadmap to double energy productivity in passenger transport by 2030. Australian Alliance for Energy Productivity, Sydney.

A2EP, 2017. Achieving 2xEP through leadership and ingenuity. Australian Alliance for Energy Productivity, Sydney.

A2EP, 2017a. A roadmap to double energy productivity in freight transport by 2030. Australian Alliance for Energy Productivity, Sydney

A2EP, 2017b. Innovation to Improve Energy Productivity in the Food Value Chain, Australian Alliance for Energy Productivity, Sydney.

A2EP 2017d, The Next Wave—Innovation to Double Energy Productivity by 2030. Australian Alliance for Energy Productivity, Sydney.

A2EP, 2020. Compressed air systems, emerging efficiency improvements and alternative technologies: Review, ground research and examples. Australian Alliance for Energy Productivity, Sydney.

Alliance to Save Energy, 2013. Doubling U.S. energy productivity by 2030, Alliance Commission on National Energy Efficiency Policy.

Arthur, WB 1989, 'Competing technologies, increasing returns, and lock-in by historical events', *The economic journal*, vol. 99, no. 394, pp. 116–131.

Atalla, T. and P. Bean, Determinants of energy productivity in 39 countries: An empirical investigation. Energy Economics, 2017. 62: p. 217–229.

Department of Industry, Science, Energy and Resources (2020), Australian Energy Update 2020, Australian Energy Statistics, September, Canberra. energy.gov.au/sites/default/files/Australian Energy Statistics 2020 Energy Update Report_0.pdf

Australian Bureau of Statistics, 2020. Energy Account, Australia 2018–2019. Australian Government, Canberra.

Autor, D & Reynolds, E 2020, The Nature of Work after the Covid Crisis: Too Few Low-Wage Jobs, Brookings Institute, Massachusetts.

Baran Saha, B., Worrell, E. and Fengqi, Z., 2000. Energy end-use efficiency (pp. 173–217). UNDP/UNDESA/WEC: Energy and the Challenge of Sustainability. World Energy Assessment. New York: UNDP, 173–217.

Berkhout, F, Smith, A & Stirling, A 2004, 'Socio-technological regimes and transition contexts', System innovation and the transition to sustainability: Theory, evidence and policy, vol. 44, no. 106, pp. 48–75.

Bhattacharya, M., J.N. Inekwe, and P. Sadorsky, Convergence of energy productivity in Australian states and territories: Determinants and forecasts. Energy Economics, 2020. 85: p. 104538.

CCI Grenoble, 2018. Energy market barometer report- winter 2018, Grenoble Ecole de Management.

Ceschin, F 2014, 'How the design of socio-technical experiments can enable radical changes for sustainability', International Journal of Design, 8(3), 1–21.

Chang, T.P. and Hu, J.L., 2010. Total-factor energy productivity growth, technical progress, and efficiency change: An empirical study of China. Applied Energy, 87(10), pp. 3262–3270.

Christensen, C & Raynor, M 2013, The innovator's solution: Creating and sustaining successful growth, Harvard Business Review Press.

ClimateWorks, 2015. Australia's energy productivity potential—Energy's growing role in Australia's productivity and competitiveness. 2015, Australia: Melbourne, Victoria.

COAG, 2015. National Energy Productivity Plan 2015–2030. Australian Governments Canberra.

von Danwitz, S., 2018. 'Managing inter-firm projects: A systematic review and directions for future research', International Journal of Project Management, vol. 36, no. 3, pp. 525–541.

David, PA 1985, 'Cilo and the Economics of QWERTY', viewed 15 March 2021, personal.utdallas.edu/~liebowit/knowledge_goods/david1985aer.htm

Department of Resources, Energy and Tourism, 2010. Systems optimisation to improve energy productivity—several companies, Australian Government, energy.gov.au/publications/systems-optimisation-improve-energy-productivity-several-companies

Dicken, P., 2003. Global shift: Reshaping the global economic map in the 21st century, Sage.

DISER, 2021. International Climate Change Commitments. Australian Government. Accessed 3 June 2021, industry.gov.au/policies-and-initiatives/australias-climate-change-strategies/international-climate-change-commitments

Doojav, G.-O. and Kalirajan, K. 2020. Sources of energy productivity change in Australian sub-industries. Economic Analysis and Policy, 2020. 65: p. 1–10.

Du, K. and B. Lin, International comparison of total-factor energy productivity growth: A parametric Malmquist index approach. Energy, a. 118: p. 481–488.

Elkomy S, Mair S and T Jackson 2020. Energy and Productivity: a review of the literature. CUSP Working Paper No 23. Guildford: University of Surrey. Online at: www.cusp.ac.uk/powering-productivity

Energia 2018, Australian Electric Vehicle Market Study, ARENA, CEFC.

Energy Efficiency Council 2017, Energy productivity skills and training pathway, Energy productivity skills and training pathway.

European Environment Agency 2015, Germany country briefing-the European environment -state and outlook 2015.
eea.europa.eu/soer/2015/countries/germany#:~:text=Energy%20productivity%20is%20considered%20an,primary%20energy%20consumption%20to%2093%25

Eurostat, 2013. Manual on regional accounts methods. Luxembourg: Publications Office of the European Union.

Eurostat, 2020. Energy consumption in 2018: primary and final energy consumption still 5% and 3% away from 2020 targets, European Union.

Fagerberg, J 2018, Innovation, Economic Development and Policy: Selected Essays, Edward Elgar Publishing.

Gans, J 2016, The disruption dilemma, MIT press.

Gasim, A. and Hunt, L.C., 2016. Policymakers Guide to the Various Ways of Calculating Energy Productivity (No. ks-1637-dp031a).

Geels, FW 2002, 'Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study', Research Policy, vol. 31, no. 8, pp. 1257–1274.

Geels, FW 2007, 'Analysing the breakthrough of rock 'n'roll (1930–1970) Multi-regime interaction and reconfiguration in the multi-level perspective', Technological Forecasting and Social Change, vol. 74, no. 8, pp. 1411–1431.

Geels, FW & Schot, J 2007, 'Typology of sociotechnical transition pathways', Research Policy, vol. 36, no. 3, pp. 399–417.

Gereffi, G & Fernandez-Stark, K 2011, 'Global value chain analysis: a primer', Center on Globalization, Governance & Competitiveness (CGGC), Duke University, North Carolina, USA.

Giddens, A 1984, 'The Constitution of Society', Cambridge: PolityPress.

Grabher, G 2002, 'Cool projects, boring institutions: temporary collaboration in social context', Regional studies, vol. 36, no. 3, pp. 205–214.

Green Grid, 2008. A framework for data center energy productivity.

Gretton, P., 2005.'Australian Input-Output Tables', Australian Economic Review, vol. 38, no. 3, pp. 319–332.

Gretton, P., 2013. On input-output tables: uses and abuses, Staff Research Note, Productivity Commission, Canberra.

Grönroos, C 1990, Service management and marketing, Lexington books Lexington, MA.

Guo, S., Li, Y., Hu, Y., Xue, F., Chen, B. and Chen, Z.M., 2020. Embodied energy in service industry in global cities: A study of six Asian cities. Land Use Policy, 91, p.104264.

Hasanbeigi, A., Price, L. and Lin, E., 2012. Emerging energy-efficiency and CO_2 emission-reduction technologies for cement and concrete production: A technical review. Renewable and Sustainable Energy Reviews, 16(8), pp.6220–6238.

Hekkert, MP, Suurs, RAA, Negro, SO, Kuhlmann, S & Smits, REHM 2007, 'Functions of innovation systems: A new approach for analysing technological change', Technological Forecasting and Social Change, vol. 74, no. 4, pp. 413–432.

Henderson, RM & Clark, KB 1990, 'Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms', Administrative science quarterly, pp. 9–30.

Hospers, G-J 2005, 'Joseph Schumpeter and his legacy in innovation studies', Knowledge, Technology & Policy, vol. 18, no. 3, pp. 20–37.

Humphrey, J & Schmitz, H 2000, Governance and upgrading: linking industrial cluster and global value chain research, Institute of Development Studies Brighton.

IEA (2015), Capturing the Multiple Benefits of Energy Efficiency, International Energy Agency, Paris www.iea.org/reports/capturing-the-multiple-benefits-of-energy-efficiency

IEA (2018) World Energy Outlook. iea.org/countries

Instinct and Reason, 2015. Energy Efficiency Information Grants Program Evaluation. Department of Industry, Science, Energy and Resources, Canberra.

Javid, M. and Khan, M., 2020. Energy efficiency and underlying carbon emission trends. Environmental Science and Pollution Research, 27(3), pp.3224–3236.

Kemp, R 1994, 'Technology and the transition to environmental sustainability', Futures, vol. 26, no. 10, pp. 1023–1046.

Kline, S & Rosenberg, N 1986, 'N.(1986): An overview of innovation', The Positive Sum Game, Washington. DC.

Klitkou, A, Bolwig, S, Hansen, T & Wessberg, N 2015, 'The role of lock-in mechanisms in transition processes: The case of energy for road transport', Environmental Innovation and Societal Transitions, vol. 16, pp. 22–37.

Koezjakov, A., Urge-Vorsatz, D., Crijns-Graus, W. and Van den Broek, M., 2018. The relationship between operational energy demand and embodied energy in Dutch residential buildings. *Energy and Buildings*, *165*, pp.233–245.

Kostoff, RN, Boylan, R & Simons, GR 2004, 'Disruptive technology roadmaps', Technological Forecasting and Social Change, vol. 71, no. 1–2, pp. 141–159.

Krarti, M., Dubey, K. and Howarth, N., 2019. Energy productivity analysis framework for buildings: a case study of GCC region. Energy, 167, pp.1251–1265.

Kremer, P.D. and Symmons, M.A., 2015. Mass timber construction as an alternative to concrete and steel in the Australia building industry: a PESTEL evaluation of the potential. International Wood Products Journal, 6(3), pp.138–147.

Makov, T., Meylan, G., Powell, J.T. and Shepon, A., 2019. 'Better than bottled water?—Energy and climate change impacts of on-the-go drinking water stations'. Resources, Conservation and Recycling, Vol. 143, p. 320–328.

Markard, J 2018, 'The next phase of the energy transition and its implications for research and policy', Nature Energy, vol. 3, no. 8, pp. 628–633.

Mbenefits, 2018. Multiple Benefits of Energy Efficiency. European Commission. Viewed 2 June 2021, mbenefits.eu

Morrison, S., 2020. A Gas Fired Recovery. Media Release, 15 Sep 2020. Prime Minister of Australia, Canberra.

Morrow, W.R., Carpenter, A., Cresko, J., Das, S., Graziano, D.J., Hanes, R., Supekar, S.D., Nimbalkar, S., Riddle, M. and Shehabi, A., 2017. US Industrial Sector Energy Productivity Improvement Pathways. Proceedings of ACEEE Summer Study on Energy Efficiency in Industry, August, pp.15–18.

Nadel, S. and Ungar, L., 2019. Halfway there: Energy efficiency can cut energy use and greenhouse gas emissions in half by 2050. Report u1907 American Council for an Energy-Efficient Economy.

Pande, P.P., Ganguly, A. and Chakrabarty, K., 2013. Design Technologies for Green and Sustainable Computing Systems. Springer.

Porter, M.E. 2001, 'The value chain and competitive advantage', in Barnes, D. ed., Understanding business: processes. Psychology Press, pp. 50–66.

Productivity Commission, 2017. Shifting the Dial Supporting Paper No.1: Productivity and Income—The Australian Story. Australian Government, Canberra.

Productivity Commission, 2020. Productivity Insights. Australian Government, Canberra.

PWC, 2021. Taking on tomorrow: the rise of circularity in energy, utilities and resources.

Raggio, R.D., Ekman, P. and Thompson, S.M., 2020. Making energy metrics relevant to service firms: from energy conservation to energy productivity. Journal of Cleaner Production, 256, p.120493.

Riddle, M. and Shehabi, A., 2017. US Industrial Sector Energy Productivity Improvement Pathways. Proceedings of ACEEE Summer Study on Energy Efficiency in Industry, August, pp.15–18.

Rip, A & Kemp, R 1998, 'Technological Change. In: Rayner S., Malone E.L. (editors)', Social Science & Medicine—SOC SCI MED, pp. 327–399.

Shipley, L 2020, 'How Tesla Sets Itself Apart', Harvard Business Review, viewed 13 January 2021, hbr.org/2020/02/how-tesla-sets-itself-apart.

Sood, A & Tellis, GJ 2011, 'Demystifying Disruption: A New Model for Understanding and Predicting Disruptive Technologies', Marketing Science, vol. 30, no. 2, pp. 339–354.

Taha, B. and Nounu, G., 2008. Properties of concrete contains mixed colour waste recycled glass as sand and cement replacement. Construction and Building Materials, 22(5), pp.713–720.

Taylor, C., Bradley, C., Dobbs, R., Thompson, F., & Clifton, D. (2012). Beyond the boom: Australia's productivity imperative. New York, NY: McKinsey and Co.

Trencher, G, Rinscheid, A, Duygan, M, Truong, N & Asuka, J 2020, 'Revisiting carbon lock-in in energy systems: Explaining the perpetuation of coal power in Japan', Energy Research & Social Science, vol. 69, p. 101770.

Ürge-Vorsatz, D., Kelemen, A., Tirado-Herrero, S., Thomas, S., Thema, J., Mzavanadze, N., Hauptstock, D., Suerkemper, F., Teubler, J., Gupta, M. and Chatterjee, S., 2016. Measuring multiple impacts of low-carbon energy options in a green economy context. Applied Energy, 179, pp.1409–1426.

VicRoads 2020, 'ZLEV Road User Charge', VicRoads, viewed 13 January 2021, vicroads.vic.gov.au:443/registration/registration-fees/zlev-road-user-charge

Visco, I. and Zevi, G., 2020. Bounded rationality and expectations in economics. Bank of Italy Occasional Paper, (575). sipotra.it/wp-content/uploads/2020/09/Bounded-rationality-and-expectations-in-economics.pdf

Vlahinić-Dizdarević, N. and Šegota, A., 2012. Total-factor energy efficiency in the EU countries. Zbornik radova Ekonomskog fakulteta u Rijeci: časopis za ekonomsku teoriju i praksu, 30(2), pp.247–265.

Voigt, S., *et al.*, Energy intensity developments in 40 major economies: Structural change or technology improvement? Energy Economics, 2014. 41: p. 47–62.

WEF & BCG 2021, Net-Zero Challenge: The supply chain opportunity, World Economic Forum, Cologny, Switzerland.

World Bank, 2018. Electric power transmission and distribution losses (% of output)- Australia, data.worldbank.org/indicator/EG.ELC.LOSS.ZS?locations=AU

Wright, S 2020, 'The battle within the electric-vehicle industry will intensify', The Economist.

8.2 Chapters 4 and 5

8.2.1 Data

ABS 2019, 'Internet Activity, Australia', Australian Government, Canberra. abs.gov.au/statistics/industry/technology-and-innovation/internet-activity-australia/latest-release

AGC Coombs Group June 2018, Improving Data Centre Infrastructure Efficiencies.

Alphabeta Advisors 2018, 'Digital Innovation: Australia's $315 B Opportunity', *Retrieved February*, vol. 1, p. 2020.

Anderson, D, Cader, T, Darby, T, Gruendler, N, Hariharan, R, Holler, A, Lindberg, C, Long, C, Morris, P & Rawson, A 2008, 'A Framework for Data Center Energy Productivity', *White Paper*, vol. 13.

Arm Insight report 2020, *Road Map to Safe Data Monetization*, paymentssource.com/whitepaper/road-map-to-safe-data-monetization.

ATIC Report 2018, 'Investment Opportunities in Digital Technologies in Australia', vol.

Avgerinou, M, Bertoldi, P & Castellazzi, L 2017, 'Trends in Data Centre Energy Consumption under the European Code of Conduct for Data Centre Energy Efficiency', *Energies*, vol. 10, no. 10, p. 1470.

Bodkhe, U, Tanwar, S, Parekh, K, Khanpara, P, Tyagi, S, Kumar, N & Alazab, M 2020, 'Blockchain for Industry 4.0: A Comprehensive Review', *IEEE Access*, vol. 8, pp. 79764–79800.

Bose, R, Roy, S, Mondal, H, Chowdhury, DR & Chakraborty, S 'Energy-Efficient Approach to Lower the Carbon Emissions of Data Centers', *Computing*, vol., pp. 1–19.

Calma, V June 16, 2020, *Cost of Electricity in Australia—How Are We Doing in 2020?*, leadingedgeenergy.com.au/news/cost-of-electricity-in-australia-in-2020.

Cioara, Tudor & Anghel, Ionut & Salomie, Ioan & Antal, Marcel & Antal, Claudia & Bertoncini, Massimo & Arnone, Diego & Pop, Florin., 2018. Exploiting Data Centres Energy Flexibility in Smart Cities: Business Scenarios. Information Sciences. 476. 10.1016/j.ins.2018.07.010.

Connect, D 2013, 'A European Strategy on the Data Value Chain', *European Commission*, vol.

Consumer Research Associates 2014, Energy Efficiency Policy Options for Australian and New Zealand Data Centres.

Costello, K & Omale, G 2019, 'Gartner Survey Reveals Digital Twins Are Entering Mainstream Use', *Gartner Inc.) Retrieved April*, vol. 30, p. 2020.

Costenaro, D & Duer, A 2012, 'The Megawatts Behind Your Megabytes: Going from Data-Center to Desktop', *Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings, ACEEE, Washington*, vol., pp. 13–65.

CSIRO Digitial twin, *Digital Twins at Csiro's Data61*, viewed data61.csiro.au/en/Our-Research/Our-Work/Future-Cities/NSW-Digital-Twin/NSW-Digital-Twin

CSIRO March, 2021, *T-Provenance: Blockchain Technology for Food Exports*, viewed csiro.au/en/work-with-us/funding-programs/programs/csiro-kick-start/t-provenance.

Data Economy, *Data Value Chain*, viewed dataeconomy.eu/data-value-chain/#page-content

Deloitte Access Report, 2019, 'The Economic Value of Cloud Services in Australia', vol.

Fred, J 2017, Data Monetization-How an Organization Can Generate Revenue with Data?, thesis.

G, D Oct 26, 2018, *How Blockchain Technology Is Revolutionizing Data Provenance*, viewed medium.com/blockpool/how-blockchain-technology-is-revolutionizing-data-provenance-e47610019390

Gleeson-Long, K Report April 2019, *Data Monetisation: Key to a Future Fit Retail Strategy*, retailbiz.com.au/contributor/data-monetisation-key-to-a-future-fit-retail-strategy

Goworek, K Report October 2019, *What Is Your Data Value? Data Monetization Examples*, tasil.com/insights/data-monetization-examples

Grid, G 2007, 'The Green Grid Data Center Power Efficiency Metrics: Pue and Dcie', *Green Grid report*, vol.

Hullangala, S 2019, 'Data, Data Everywhere: How Can It Be Monetized?', vol.

Infosys Report 2018, *Perspective Monetize Data*, I Ltd.

IT Brief May 2020, *Australia within Grasp of Sustainable Data Centre Ecosystem*, viewed itbrief.com.au/story/australia-within-grasp-of-sustainable-data-centre-ecosystem-report

Jones, N 2018, 'How to Stop Data Centres from Gobbling up the World's Electricity', *Nature*, vol. 561, no. 7722, pp. 163–167.

Knowledge Sourcing Intelligence LLP 2019, Australia Data Monetization Market—Forecasts from 2019 to 2024.

Latif, A, Saeed, AU, Hoefler, P, Stocker, A & Wagner, C 'The Linked Data Value Chain: A Lightweight Model for Business Engineers', pp. 568–575.

Liang, X, Shetty, S, Tosh, D, Kamhoua, C, Kwiat, K & Njilla, L 'Provchain: A Blockchain-Based Data Provenance Architecture in Cloud Environment with Enhanced Privacy and Availability', IEEE, pp. 468–477.

Market Analysis Report 2020, 'Data Monetization Market Size, Share & Trends Report: Data Monetization Market Size, Share & Trends Analysis Report by Organization Size, by Method (Analytics-Enabled Platform as a Service, Embedded Analytics), by Vertical, by Region, and Segment Forecasts, 2020–2027', vol.

Market Research group 2020, 'Blockchain Market by Component (Platform and Services), Provider (Application, Middleware, and Infrastructure), Type (Private, Public, and Hybrid), Organization Size, Application Area (Bfsi, Government, It & Telecom), and Region—Global Forecast to 2025', vol.

MKM Repot April 2018, 'Digital Twins Market Worth 16.6 Billion Usd by 2023', vol.

Najjar, MS & Kettinger, WJ 2013, 'Data Monetization: Lessons from a Retailer's Journey', *MIS Quarterly Executive*, vol. 12, no. 4.

Rado Kotorov 2018, *The Data Value Chain: Steps for Monetizing Your Data*, viewed idevnews.com/stories/6998/The-Data-Value-Chain-Steps-for-Monetizing-Your-Data

Report Linker Global Newswire, 2021, *Blockchain in Agriculture and Food Supply Chain Global Market Report 2021: Covid-19 Growth and Change*, viewed globenewswire.com/news-release/2021/03/08/2188585/0/en/Blockchain-In-Agriculture-And-Food-Supply-Chain-Global-Market-Report-2021-COVID-19-Growth-And-Change.html

Shamgunov, N April 2020, 'Digital Twins: An Important Next Step in the Data Economy', vol., p. Forbes Technology Council.

Simmhan, YL, Plale, B & Gannon, D 2005, 'A Survey of Data Provenance in E-Science', *ACM Sigmod Record*, vol. 34, no. 3, pp. 31–36.

NY Times 2018, *Cambridge Analytica and Facebook: The Scandal and the Fallout So Far*, nytimes.com/2018/04/04/us/politics/cambridge-analytica-scandal-fallout.html

Watch Open Data 2018, 'The Data Value Chain: Moving from Production to Impact', *Data2X*. opendatawatch.com/publications/the-data-value-chain-moving-from-production-to-impact, vol.

8.2.2 Education

AEMO, Report June ,2020, Australian Energy market Report, Quarterly Energy Dynamics (QED).

Australian Government (2020), Labour market Information Portal. Viewed 20 April 2021. lmip.gov.au/default.aspx?LMIP/GainInsights/IndustryInformation/EducationandTraining#:~:text=Education%20and%20Training%20employs%20approximately,increased%20by%2017.6%20per%20cent

Brown, N., *et al.* 2020, Learning at home during COVID-19: effects on vulnerable young Australians, Peter Underwood Centre for Educational Attainment, viewed 19 April 2021, apo.org.au/node/303561

Buchs, M. 2020, University sector must tackle air travel emissions. the conversation, viewed 21 April 2021, theconversation.com/university-sector-must-tackle-air-travel-emissions-118929

Budget 2019, Australian Government, Budget Strategy and Outlook: Budget Paper No. 1: 2019–20, p. 5–17.

Burgess, S., *et al.* 2018, 'Interventions in entrepreneurial learning: Blended learning and ICT capacity.' Australasian Journal of Information Systems, vol. 22, viewed 20 April 2021, journal.acs.org.au/index.php/ajis/article/view/1226

CEFC 2016, Clean energy opportunities for universities, viewed 18 April 2021, cefc.com.au/media/218729/CEFC-market-report-Clean-energy-opportunities-for-universities.pdf

Chung, W. and I. M. Yeung 2021, 'A two-stage regression-based benchmarking approach to evaluate school's energy efficiency in different tariff regions.' Energy for Sustainable Development, Volume 61, Pages 15–27, April 2021.

Council of Australian Governments (CoAG) 2012, Baseline Energy Consumption and Greenhouse Gas Emissions in Commercial Buildings in Australia, Canberra. viewed 2 April 2020, energy.gov.au/publications/baseline-energy-consumption-and-greenhouse-gas-emissions-commercial-buildings-australia

Cowden, G., *et al.* 2020, 'Remote learning rapid literature review', Association of Independent Schools NSW & Australian Council for Educational Research, viewed 20 April 2021, doi.org/10.37517/978-1-74286-610-9

Curtin Report, November 2020, 'How online study became the new norm.' viewed 21 April 2021, news.curtin.edu.au/stories/how-online-study-became-the-new-norm.

Dabrowski, A., *et al.* 2020, 'Mitigating the impacts of COVID-19: Lessons from Australia in remote education,' Australian Council for Educational Research, viewed 20 April 2021, 10.37517/978-1-74286-618-5

DECD Report 2020, Department of Education and Early Childhood Development, Blended learning A synthesis of research findings in Victorian education, 2012 viewed 20 April 2021, education.vic.gov.au/documents/about/research/blendedlearning.pdf

Deloitte 2020, Where to now? Blended futures Higher education for a changed world, viewed 20 April 2021, www2.deloitte.com/au/en/pages/public-sector/articles/where-now-blended-futures.html

DESE 2020, Department of Education, Skills and Employment, Research Snapshot, August, 2020, viewed 19 April 2021, internationaleducation.gov.au/research/research-snapshots/Documents/Education%20infographic%20Australia%202019–20.pdf

DISR 2020, Department of Industry, Science, Energy and Resources, Australian Energy Statistics, Page-19, Table E. S. Department of Industry, Energy and Resources (2020).

DJSB 2019, Australian Jobs, 2019 , Department of Jobs and Small Business, Australian Government,Page-5.

Energy & Environment 2020, '4 Unsung Environmental Benefits of Online Education.', viewed 20 April 2021, triplepundit.com/story/2015/4-unsung-environmental-benefits-online-education/35151.

Gwilym Croucher, K. E., William Locke and Edward Yencken 2020, 'Australia's higher education delivery offshore and online trends, barriers and opportunities.' Melbourne Centre for the Study of Higher Education, viewed 21 April 2021, melbourne-cshe.unimelb.edu.au/__data/assets/pdf_file/0009/3568275/Australias-higher-education-delivery-offshore-and-online.pdf

Hanushek, E. A. and E. Ettema 2017, 'Defining productivity in education: Issues and illustrations.' The American Economist, Vol 62, Issue 2, 2017.

HESC 2018, 'Data on the Offshore Delivery of Australian Courses.' Higher Education Statistics Collection, viewed 20 April 2021, internationaleducation.gov.au/research/offshoreeducationdata/pages/transnational-education-data.aspx

Hueske, A.K. & Guenther, E. 2021, 'Multilevel barrier and driver analysis to improve sustainability implementation strategies: towards sustainable operations in institutions of higher education', Journal of Cleaner Production, vol 291, pp. 125,899.

Hurley, P. April 2020, 'Australian universities could lose $19 billion in the next 3 years. Our economy will suffer with them', viewed 19 April 2021, theconversation.com/australian-universities-could-lose-19-billion-in-the-next-3-years-our-economy-will-suffer-with-them-136251

Katić, D., *et al.* 2021, 'Energy Performance of School Buildings by Construction Periods in Federation of Bosnia and Herzegovina.' Buildings 2021, 11(2), 42; doi.org/10.3390/buildings11020042.

Kidson, P. 2020, Some private schools need to change their models — they were losing students even before COVID, The Conversation, viewed 5 April 2021, theconversation.com/some-private-schools-need-to-change-their-models-they-were-losing-students-even-before-covid-146745

McGivney, E. and K. Foda 2018, Productivity Measurement in the Education Sector, viewed 19 April 2021, brookings.edu/wp-content/uploads/2017/12/productivity-measurement-in-education.pdf

McLaughlin, M. W. and J. E. Talbert 1993, 'Contexts that matter for teaching and learning: Strategic opportunities for meeting the nation's educational goals,' Office of Educational Research and Improvement (ED), Washington, DC, viewed 20 April 2021, files.eric.ed.gov/fulltext/ED357023.pdf

Monash Zero Initiative 2019, Monash Net Zero Inititative, viewed 18 April 2021, monash.edu/__data/assets/pdf_file/0020/1140365/Monash-Net-Zero-Brochure.pdf

Nguyen, O. T. K. and V. D. Balakrishnan 2020, 'International students in Australia–during and after COVID-19.' Higher Education Research & Development 39(7): 1372–1376.

NWF 2008, 'Campus Environement 2008' A National Report Card on Sustainability in Higher Education, viewed 19 April 2021, .nwf.org/-/media/PDFs/Global-Warming/CampusReportFinal.ashx

Phillips, R. and P. Burgess 2016, Australian transnational higher education and onshore student flows, viewed 20 April 2021, ieaa.org.au/documents/item/797

Pitt & Sherry 2012. Baseline Energy Consumption and Greenhouse Gas Emission in Commercial Buildings in Australia Part 1—Report. Department of Climate Change and Energy Efficiency, Canberra.

Productivity Commission 2021, Things you can't drop on your feet An overview of Australia's services sector productivity, PC Productivity Insight, viewed 21 April 2021, pc.gov.au/research/ongoing/productivity-insights/services/productivity-insights-2021-services.pdf

PWC, August 2020, Where next for tertiary education? How the COVID-19 crisis can be the catalyst to reboot towards a stronger sector, viewed 22 April 2021, www.pwc.com.au/government/where-next-for-tertiary-education.html

QS Report 2020, 'The Process of Becoming Carbon Neutral: How Universities Can Hit Net Zero Emissions', viewed 21 April 2021, www.qs.com/the-process-of-becoming-carbon-neutral-how-universities-can-hit-net-zero-emissions

Roy, R., *et al.* 2008, 'Designing low carbon higher education systems.' International Journal of Sustainability in Higher Education, 9(2) pp. 116–130.

Roy, Potter *et al.* 2005, 'Towards Sustainable Higher Education: Environmental impacts of campus-based and distance higher education systems', The Design Innovation Group, The Open University. Viewed on 23rd April 2021 from www3.open.ac.uk/events/3/2005331_47403_01.pdf

Siegel, D.S. & Leih, S. 2018, 'Strategic management theory and universities: An overview of the Special Issue', Strategic Organization, vol. 16, no. 1, pp. 6–11.

UniMelb, 2019, Sustainability Report, viewed 17 April 2021, sustainablecampus.unimelb.edu.au/__data/assets/pdf_file/0009/3444192/Sustainability-Report-2019.pdf

University Australia 2020a, 2020 HIGHER EDUCATION FACTS AND FIGURES, Universities Australia Report, viewed 18 April 2021, www.universitiesaustralia.edu.au/wp-content/uploads/2020/11/200917-HE-Facts-and-Figures-2020.pdf

University Australia 2020b, 'COVID-19 TO COST UNIVERSITIES $16 BILLION BY 2023', viewed 19 April 2021, www.universitiesaustralia.edu.au/media-item/covid-19-to-cost-universities-16-billion-by-2023/

UTAS GHG Report 2018, Greenhouse gas emissions data, , viewed 19 April 2021, www.utas.edu.au/infrastructure-services-development/sustainability/greenhouse-gas-emissions

UTS Energy 2016, UTS ENERGY AND GREENHOUSE PLAN: 5, viewed 20 April 2021, www.uts.edu.au/sites/default/files/ENERGY_GREENHOUSE_PLAN.140301.pdf

Whitchurch, C. 2009, 'The rise of the blended professional in higher education: a comparison between the United Kingdom, Australia and the United States.' Higher Education 58(3), pp 407–418.

Ziguras, C. and G. McBurnie 2011, 'Transnational higher education in the Asia-Pacific region: From distance education to the branch campus', Higher education in the Asia-Pacific, Springer, Vol. 36, pp 105–122.

8.2.3 Food

Aamer, A.M., Al-Awlaqi, M.A., Affia, I., Arumsari, S. and Mandahawi, N. (2021), 'The internet of things in the food supply chain: adoption challenges', Benchmarking: An International Journal, Vol. ahead-of-print No. ahead-of-print. doi.org/10.1108/BIJ-07-2020-0371

ABARES. (2016). Land Use of Australia 2010–11 Summary Statistics. Retrieved from: www.agriculture.gov.au/abares/aclump/land-use/land-use-of-australia-2010-11

ABS, 2021. Water Use on Australian Farms. Australian Government, Canberra. www.abs.gov.au/statistics/industry/agriculture/water-use-australian-farms/latest-release

Adekomaya, O., *et al.*, Sustaining the shelf life of fresh food in cold chain—A burden on the environment. Alexandria Engineering Journal, 2016. 55(2): p. 1359–1365.

Astill, J., Dara, R.A., Campbell, M., Farber, J.M., Fraser, E.D.G., Sharif, S., Yada, R.Y., 2019. Transparency in food supply chains: A review of enabling technology solutions. Trends Food Sci. Technol. 91, 240–247. doi.org/10.1016/j.tifs.2019.07.024

A2EP, 2017. The Next Wave Innovation to double energy productivity by 2030. Australian Alliance for Energy Productivity, Sydney. doi.org/10.13140/RG.2.2.20285.26083

A2EP, 2017b. Food cold chain optimisation: Improving energy productivity using real time food condition monitoring through the chain. Australian Alliance for Energy Productivity, Sydney.

A2EP, 2017c, Innovation to improve energy productivity in the food value chain. Australian Alliance for Energy Productivity, Sydney.

Australian Food and Grocery Council, 2017. Australian Cold Chain Guidelines 2017.

Australian Government, 2019. National Waste Policy Action Plan, Australian Government, Canberra.

Australian Government, 2020. The National Blockchain Roadmap: Progressing towards a blockchain empowered future. Canberra.

Australian Government, 2021a. Delivering Ag2030, Australian Government, Canberra.

Australian Government, 2021b. National Plastics Plan 2021, Australian Government, Canberra.

Australian Government, 2021c. Refridgeration, Australian Government, Canberra. Available from: energy.gov.au/business/equipment-and-technology-guides/refrigeration.

Australian Trade and Investment Commission, 2019. Australia: shaping the future of food and agriculture. Retrieved from austrade.gov.au/ArIcleDocuments/1358/Agriculture40- brochure.pdf.aspx

Barta, R.B., E.A. Groll, and D. Ziviani, Review of stationary and transport CO_2 refrigeration and air conditioning technologies. Applied Thermal Engineering, 2021. 185: p. 116422.

Beca Consultants. (2015). Opportuni8es for renewable energy in the Australian water sector. Retrieved from arena.gov.au/assets/2016/01/Opportuniles-for-renewable-energy-in-the- Australian-water-sector.pdf

Berthiaume, D., Walmart keeps store operations cool with IoT, in Chain Store Age 2021.

Brizga, J., Hubacek, K., Feng, K., 2020. The Unintended Side Effects of Bioplastics: Carbon, Land, and Water Footprints. One Earth 3, 45–53. doi.org/10.1016/j.oneear.2020.06.016

Brodribb, P. and M. McCann, A study of waste in the cold food chain and opportunities for improvement, 2020.

Chen, G., Maraseni, T., Banhazi, T., & Bundschuh, J. (2015). Benchmarking energy use on farm. Rural Industries Research and Development Corpora8on (RIRDC) Publica8on(15/059).

Chen, S., Brahma, S., Mackay, J., Cao, C., Aliakbarian, B., 2020. The role of smart packaging system in food supply chain. J. Food Sci. 85, 517–525. doi.org/10.1111/1750-3841.15046

Coley, D., Howard, M., Winter, M., 2009. Local food, food miles and carbon emissions: A comparison of farm shop and mass distribution approaches. Food Policy 34, 150–155. doi.org/10.1016/j.foodpol.2008.11.001

Crawford, E., 2018. From 7 days to 2 seconds: Blockchain can help speed trace-back, improve food safety & reduce waste.

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F.N., Leip, A., 2021. Food systems are responsible for a third of global anthropogenic GHG emissions. Nat. Food 2, 198–209. doi.org/10.1038/s43016-021-00225-9

Cutter, C.N., 2006. Opportunities for bio-based packaging technologies to improve the quality and safety of fresh and further processed muscle foods. Meat Sci. 74, 131–142. doi.org/10.1016/j.meatsci.2006.04.023

DAWE (2021). Water policy and resources. Retrieved from agriculture.gov.au/water

Department of Agriculture, Water and the Environment. *Food demand in Australia: trends and issues 2018*. 2020; Available from: agriculture.gov.au/abares/research-topics/food-demand/trends-and-issues-2018.

Devin, B. and Richards, C., 2018. Food waste, power, and corporate social responsibility in the Australian food supply chain. Journal of Business Ethics, 150(1), pp.199–210.

DISER, 2017. Australian start-up AgriDigital embraces blockchain to make agricultural supply chains simple. Australian Government, Canberra. www.industry.gov.au/data-and-publications/australian-start-up-agridigital-embraces-blockchain-to-make-agricultural-supply-chains-simple

DISER. (2019). Australian Energy Update Retrieved from Canberra: energy.gov.au/sites/default/files/Australian%20Energy%20StaIsIcs%202020%20Energy%20Update%20Report_0.pdf

DISER, 2020a. The National Blockchain Roadmap, Australian Government, Canberra.

Edwards, F., & Mercer, D. (2012). Food waste in Australia: The freegan response. The Sociological Review, 60, 174–191.

Energy Rating, 2020a. *Refrigeration—Commercial*. Available from: www.energyrating.gov.au/products/refrigeration-commercial.

Energy Rating, 2020b. *Refrigeration—Domestic*. Available from: www.energyrating.gov.au/products/domestic-refrigeration.

Estrada-Flores, S. and Platt, G., 2007. Electricity usage in the Australian cold chain. Food Australia, 59(8), pp.382–389.

Fairbrother, P., Denham, T., and West, M., 2018. Gippsland Food value chain: Data-driven regional development. Food Agility CRC, Armidale.

Foley, J., Sandell, G., Szabo, P., Scobie, M., & Ballie, C. (2015). Improving energy efficiency on irrigated Australian cotton farms: benchmarking report. In Agriculture.

Food Logistics, 2008. *Thinking Out Of The Box*. Accessed from www.foodlogistics.com/transportation/cold-chain/article/10315594/thinking-out-of-the-box

Food Logistics. The future of cold food chains report—How wearables, robotics and automation drive food logistics forward. 2021; Available from: cdn.base.parameter1.com/files/base/acbm/fl/document/2021/04/FLOG___The_Future_of_Cold_Chains_Report__HVA.608060a66a41a.pdf

Fortune, 2020. 'Bioplastics Market Size to Worth USD 19.93 Billion at 16.2% CAGR Forecast till 2027', Fortune Business Insights. www.globenewswire.com/fr/news-release/2020/09/09/2090657/0/en/Bioplastics-Market-Size-to-Worth-USD-19-93-Billion-at-16-2-CAGR-Forecast-till-2027-Fortune-Business-Insights.html

Frangoul, A., 2019. Blockchain to 'save food industry $31 billion,' new research says. CNBC.

Ghobakhloo, M., Fathi, M., Iranmanesh, M., Maroudhani, P., & Morales, M. E. (2021). Industry 4.0 ten years on: A bibliometric and systemaIc review of concepts, sustainability value drivers, and success determinants. Journal of Cleaner Produc8on, 127052.

Glaciem cooling. glaciemcooling.com/projects/.

Green Truck Partnership 2015, *Case Study: Battery- electric distribution truck*. Accessed from roads-waterways.transport.nsw.gov.au/documents/about/environment/air/case-study-electric-distribution-truck.pdf

Hallwright, J., Carnaby, E., 2019. Complexities of Implementation: Oxfam Australia's Experience in Piloting Blockchain. Front. Blockchain 2, 1–6. doi.org/10.3389/fbloc.2019.00010

Hartmann, C., Siegrist, M., 2020. Our daily meat: Justification, moral evaluation and willingness to substitute. Food Qual. Prefer. 80, 103799. doi.org/10.1016/j.foodqual.2019.103799

Hawken, P., 2017. Drawdown: The most comprehensive plan ever proposed to reverse global warming. Penguin.

Honma, S. and Hu, J.L., 2009. Total-factor energy productivity growth of regions in Japan. Energy Policy, 37(10), pp.3941–3950.

IEA. (2021). Electricity generaIon by source-Australia. Retrieved from www.iea.org/subscribe-to-data-services/electricity-staIsIcs

Jackson, T. (2009). An appraisal of the on-farm water and energy nexus in irrigated agriculture (Doctor of Philosophy). Charles Sturt University

Kakadellis, S. and Harris, Z.M., 2020. Don't scrap the waste: the need for broader system boundaries in bioplastic food packaging life-cycle assessment–a critical review. Journal of Cleaner Production, Vol. 274, p.122831.

Kang, H., Zhou, H., Wang, X., Chen, C., 2020. Real-time fruit recognition and grasping estimation for robotic apple harvesting. Sensors (Switzerland) 20, 1–15. doi.org/10.3390/s20195670

Kollewe, J., Davies, R., 2019. Robocrop: world's first raspberry-picking robot set to work. Guard

KPMG. (2018). Talking 2030: growing agriculture into a $100 bilion industry. Retrieved from hTps://www.talking2030.com/discussion-paper

Lombardi, A., Vecchio, R., Borrello, M., Caracciolo, F., Cembalo, L., 2019. Willingness to pay for insect-based food: The role of information and carrier. Food Qual. Prefer. 72, 177–187. doi.org/10.1016/j.foodqual.2018.10.001

Majewski, E., Komerska, A., Kwiatkowski, J., Malak-Rawlikowska, A., Was, A., Sulewski, P., Goła, M., Pogodzinska, K., Lecoeur, J.L., Tocco, B., Török, Á., Donati, M., Vittersø, G., 2020. Are short food supply chains more environmentally sustainable than long chains? a life cycle assessment (LCA) of the eco-efficiency of food chains in selected EU countries. Energies 13. doi.org/10.3390/en13184853

Marsden, T, Banks, J & Bristow, G 2000, 'Food supply chain approaches: exploring their role in rural development', *Sociologia ruralis*, vol. 40, no. 4, pp. 424–38.

McCarthy, A., Smith, R., & Hancock, N. (2013). OpImal irrigaIon of coTon via real-Ime, adapIve control.

McCool, C., Perez, T., Upcroft, B., 2017. Mixtures of Lightweight Deep Convolutional Neural Networks: Applied to Agricultural Robotics. IEEE Robot. Autom. Lett. 2, 1344–1351. doi.org/10.1109/LRA.2017.2667039

Mohamed, S.A.A., El-Sakhawy, M., El-Sakhawy, M.A.M., 2020. Polysaccharides, Protein and Lipid -Based Natural Edible Films in Food Packaging: A Review. Carbohydr. Polym. 238, 116178. doi.org/10.1016/j.carbpol.2020.116178

Ndraha, N., Hsiao, H.I., Vlajic, J., Yang, M.F. and Lin, H.T.V., 2018. Time-temperature abuse in the food cold chain: Review of issues, challenges, and recommendations. Food Control, 89, pp.12–21

Onishi, Y., Yoshida, T., Kurita, H., Fukao, T., Arihara, H., Iwai, A., 2019. An automated fruit harvesting robot by using deep learning. ROBOMECH J. 6, 2–9. doi.org/10.1186/s40648-019-0141-2.

Oxford Cold Storage, *Reducing Energy Use in the Cold Storage Industry—A Case Study*. 2013.

Pang, Z., *et al*., *Value-centric design of the internet-of-things solution for food supply chain: Value creation, sensor portfolio and information fusion.* Information Systems Frontiers, 2015. 17(2): p. 289–319.

Perez, T., Mccool, C., Bawden, O., Kulk, J., 2017. Robotic weeding—from concept to trials, in: 7th Asian-Australasian Conference on Precision Agriculture. pp. 2–7.

Productivity Commission 2005, Trends in Australian Agriculture, Productivity Commission Research Paper Commonwealth of Australia, Canberra.

Productivity Commission 2014, Relative Costs of Doing Business in Australia: Dairy Product Manufacturing, Research Report. Australian Government, Canberra.

PWC. (2019). Powering the Global Food Bowl: How cap8ve energy solu8ons are growing Australia's rural investments. Retrieved from www.pwc.com.au/infrastructure/powering-the-global- food-bowl-july-2019.pdf

QFF. (2021). CASE STUDIES. Retrieved from www.qff.org.au/newsroom/case-studies/

Ramos, R. (2016). Sundrop Farms: Harnessing Renewable Energy and the Future of Agriculture. Retrieved from www.futuredirecIons.org.au/publicaIon/sundrop-farms-harnessing- renewable-energy-future-agriculture/

Razza, F., Innocenti, F.D., 2012. Bioplastics from renewable resources: the benefits of biodegradability. Asia-Pacific J. Chem. Eng. 7, S301–S309. doi.org/10.1002/apj

Rogers, E., 2019. How can blockchain save energy? Here are three possible ways. GreenBiz.

Salama, J., 2018. Blockchain will work in trucking but only if these three things happen. TechCrunch.

Sarrab, M., S. Pulparambil, and M. Awadalla, Development of an IoT based real-time traffic monitoring system for city governance. Global Transitions, 2020. 2: p. 230–245.

Selvnes, H., *et al.*, Review on cold thermal energy storage applied to refrigeration systems using phase change materials. Thermal Science and Engineering Progress, 2021. 22: p. 100807.

Shakhbulatov, D., Arora, A., Dong, Z., Rojas-Cessa, R., 2019. Blockchain implementation for analysis of carbon footprint across food supply chain. Proc.—2019 3rd IEEE Int. Conf. Blockchain, Blockchain 2019 546–551. doi.org/10.1109/Blockchain.2019.00079

Sharma, V., 2019. An Energy-Efficient Transaction Model for the Blockchain-Enabled Internet of Vehicles (IoV). IEEE Commun. Lett. 23, 246–249. doi.org/10.1109/LCOMM.2018.2883629

Song, J.H., Murphy, R.J., Narayan, R., Davies, G.B.H., 2009. Biodegradable and compostable alternatives to conventional plastics. Philos. Trans. R. Soc. B Biol. Sci. 364, 2127–2139. doi.org/10.1098/rstb.2008.0289

Spierling, S., Knüpffer, E., Behnsen, H., Mudersbach, M., Krieg, H., Springer, S., Albrecht, S., Herrmann, C. and Endres, H.J., 2018. Bio-based plastics-A review of environmental, social and economic impact assessments. Journal of Cleaner Production, 185, pp.476–491.

Stalsta. (2021). Global water withdrawals per capita as of 2018, by select country. Retrieved from www.stalsta.com/stalslcs/263156/water-consumplon-in-selected-countries/

Szaśz, L., Demeter, K., Raćz, B.-G., & Losonci, D. 2020. Industry 4.0: a review and analysis of conlngency and performance effects. Journal of Manufacturing Technology Management.

Tassou, S.A., G. De-Lille, and Y.T. Ge, Food transport refrigeration—Approaches to reduce energy consumption and environmental impacts of road transport. Applied Thermal Engineering, 2009. 29(8): p. 1467–1477.

Tomiyama, A.J., Kawecki, N.S., Rosenfeld, D.L., Jay, J.A., Rajagopal, D., Rowat, A.C., 2020. Bridging the gap between the science of cultured meat and public perceptions. Trends Food Sci. Technol. 104, 144–152. doi.org/10.1016/j.tifs.2020.07.019

Vermeulen, S.J., Park, T., Khoury, C.K., Béné, C., 2020. Changing diets and the transformation of the global food system. Ann. N. Y. Acad. Sci. 1478, 3–17. doi.org/10.1111/nyas.14446

Vlaeminck, P., Jiang, T., Vranken, L., 2014. Food labeling and eco-friendly consumption: Experimental evidence from a Belgian supermarket. Ecol. Econ. 108, 180–190. doi.org/10.1016/j.ecolecon.2014.10.019

Wang, L., 2014. Energy efficiency technologies for sustainable food processing. Energy Effic. 7, 791–810. doi.org/10.1007/s12053-014-9256-8

Weber, C.J., Haugaard, V., Festersen, R., Bertelsen, G., 2002. Production and applications of biobased packaging materials for the food industry. Food Addit. Contam. 19, 172–177. doi.org/10.1080/02652030110087483

Welsh, J. M., & Powell, J. W. (2017). Opportunites for energy innovation in Australian irrigated sugarcane.

World Economic Forum, McKinsey & Company, 2019. Innovation with a Purpose : Improving Traceability in Food Value Chains through Technology Innovations. World Econ. Forum 1–33.

Wang, S., 2018. Developing value added service of cold chain logistics between China and Korea. Journal of Korea Trade.

Wu, J.-Y. and H.-I. Hsiao, Food quality and safety risk diagnosis in the food cold chain through failure mode and effect analysis. Food Control, 2021. 120: p. 107501.

Wynn, K., & Sebastian, B., 2019. Growth opportunities for Australian food and agribusiness Economic analysis and market sizing.

8.2.4 Health

ABS 2011, Census of Population and Housing, Australian Government, Canberra.

ABS 2015, 5216.0 Australian System of National Accounts: Concepts, Sources and Methods, Australian Bureau of Statistics, Canberra.

ABS 2016, Census of Population and Housing, Australian Government, Canberra.

ABS 2020, Labour Force Survey—SA4 Employment by Industry Time Series, November 2020, Australian Government, Canberra.

AIHW 2018, Australia's Health 2018: In Brief, Australian Institute of Health and Welfare, Canberra.

AIHW 2019, 'Health expenditure Australia 2018–19, Summary', Australian Institute of Health and Welfare, viewed 23 March 2021, www.aihw.gov.au/reports/health-welfare-expenditure/health-expenditure-australia-2018–19/contents/summary

AIHW 2020, 'Overweight & obesity', viewed 9 April 2020, www.aihw.gov.au/reports-data/behaviours-risk-factors/overweight-obesity/overview

Atalla, T & Bean, P 2017, 'Determinants of energy productivity in 39 countries: An empirical investigation', Energy Economics, vol. 62, pp. 217–229.

Blandford, A, Wesson, J, Amalberti, R, AlHazme, R & Allwihan, R 2020, 'Opportunities and challenges for telehealth within, and beyond, a pandemic', The Lancet Global Health, vol. 8, no. 11, pp. e1364–e1365.

Burger, B & Newman, P 2010, Hospitals and Sustainability, Construction Innovation CRC, Curtin University, Perth.

Centre for Online Health 2021, 'Telehealth and coronavirus: Medicare Benefits Schedule (MBS) activity in Australia', viewed 8 April 2021, coh.centre.uq.edu.au/telehealth-and-coronavirus-medicare-benefits-schedule-mbs-activity-australia

Denham, T, Dodson, J & Lawson, J 2019, 'The business case for social housing as infrastructure'.

DISER 2020, Australian Energy Update, Australian Government, Canberra.

DJPR 2020, 'A new vaccine facility for Melbourne', viewed 25 March 2021, djpr.vic.gov.au/about-us/news/a-new-vaccine-facility-for-melbourne

Fairbrother, P & Denham, T 2019, 'Future Jobs and Regional Workforce Development: Foundations and Analysis'.

IIER 2020, Inquiry into the implications of the COVID-19 pandemic for Australia's foreign affairs, defence and trade Submission 13, Institute for Integrated Economic Research—Australia, Canberra.

Malik, A, Lenzen, M, McAlister, S & McGain, F 2018, 'The carbon footprint of Australian health care', The Lancet Planetary Health, vol. 2, no. 1, pp. e27–e35.

Masters, R, Anwar, E, Collins, B, Cookson, R & Capewell, S 2017, 'Return on investment of public health interventions: a systematic review', J Epidemiol Community Health, vol. 71, no. 8, pp. 827–834.

Müller, G, Sugiyama, H, Stocker, S & Schmidt, R 2014, 'Reducing energy consumption in pharmaceutical production processes: framework and case study', Journal of Pharmaceutical Innovation, vol. 9, no. 3, pp. 212–226.

PHAA 2018, Top 10 Public Health Successes Over the Last 20 Years, Public Health Association of Australia, Canberra.

PHAA 2019, Immediate Policy Priorities 2019, Public Health Association of Australia, Canberra.

Productivity Commission 2021, Things you can't drop on your feet: An overview of Australia's services sector productivity, Australian Government, Canberra.

RACGP 2020, General Practice: Health of the Nation 2020, Royal Australian College of General Practitioners, Melbourne.

Sheiner, L. & Malinovskaya, A. 2016, 'Measuring productivity in healthcare: an analysis of the literature', Hutchins Center on Fiscal and Monetary Policy at Brookings.

Smith, JA, Crawford, G & Signal, L 2016, 'The case of national health promotion policy in Australia: where to now?', Health Promotion Journal of Australia, vol. 27, no. 1, pp. 61–65.

Soltanisehat, L, Alizadeh, R, Hao, H & Choo, K-KR 2020, 'Technical, Temporal, and Spatial Research Challenges and Opportunities in Blockchain-Based Healthcare: A Systematic Literature Review', IEEE Transactions on Engineering Management.

Zuberi, MJS & Patel, MK 2019, 'Cost-effectiveness analysis of energy efficiency measures in the Swiss chemical and pharmaceutical industry', International Journal of Energy Research, vol. 43, no. 1, pp. 313–336.

8.2.5 Infrastructure

ABS 2016, Census—Counting employed persons, place of work. MTW06P Method of Travel to Work (6 travel modes), Australian Government, Canberra.

ABS 2019, Survey of Motor Vehicle Use, Australia: 12 months ended 30 June 2018, Australian Government, Canberra.

ABS 2020, 'Energy Account, Australia 2018–2019', viewed 12 April 2021, www.abs.gov.au/statistics/industry/energy/energy-account-australia/latest-release

Adeney, R 2018, Structural Change in the Australian Economy| Bulletin–March Quarter 2018, Reserve Bank of Australia, Canberra.

Atkinson, G & Mourato, S 2008, 'Environmental cost-benefit analysis', Annual review of environment and resources, vol. 33, pp. 317–344.

Autor, D & Reynolds, E 2020, The Nature of Work after the Covid Crisis: Too Few Low-Wage Jobs, Brookings Institute, Massachusetts.

Beyond Zero Emissions 2018, Rethinking Cement.

Casey, D 2019, 'Busiest routes in the world—the top 100 | Routesonline', viewed 25 March 2021, www.routesonline.com/news/29/breaking-news/286313/busiest-routes-in-the-world-the-top-100/

De Rus, G 2021, Introduction to cost–benefit analysis: looking for reasonable shortcuts, Edward Elgar Publishing.

Denham, T & Dodson, J 2018, 'Cost Benefit Analysis: The State of the Art in Australia'.

Dobes, L, Leung, J & Argyrous, G 2016, Social cost-benefit analysis in Australia and New Zealand. The state of current practice and what needs to be done, ANU press.

Flyvbjerg, B 2008, 'Curbing optimism bias and strategic misrepresentation in planning: Reference class forecasting in practice', European planning studies, vol. 16, no. 1, pp. 3–21.

Flyvbjerg, B 2014, 'What you should know about megaprojects and why: An overview', Project management journal, vol. 45, no. 2, pp. 6–19.

Flyvbjerg, B 2017, The Oxford handbook of megaproject management, Oxford University Press.

Fourcroy, C., Gallouj F., & Decellas, F., 2012. Energy consumption in service industries: Challenging the myth of non-materiality. Ecological Economics, Volume 81, Pages 155–164, ISSN 0921-8009.

Grene, M 1971, 'Knowing and being: essays by Michael Polanyi'.

Hanley, N, Barbier, EB & Barbier, E 2009, Pricing nature: cost-benefit analysis and environmental policy, Edward Elgar Publishing.

Infrastructure Australia 2016, Western Sydney Airport Project Business Case Evaluation, Infrastructure Australia, Canberra.

Infrastructure Australia 2018a, Infrastructure Decision-making Principles, Australian Government, Canberra.

Infrastructure Australia 2018b, Assessment Framework For initiatives and projects to be included in the Infrastructure Priority List, Australian Government, Canberra.

Infrastructure Australia 2021, Infrastructure Priority List: Project and Initiative Summaries, Australian Government, Canberra.

Infrastructure Australia n.d., 'Business Case Examples', viewed www.infrastructureaustralia.gov.au/business-case-examples

Infrastructure Partners Australia (IPA) 2020, Australian Infrastructure Budget Monitor 2020–21. Viewed 20 June 2021, infrastructure.org.au/budget-monitor-2020–21/

Kikken, N 2021, 'Seeing green: low carbon steel and aluminium target reduced emissions', ECOS, viewed 6 April 2021, ecos.csiro.au/seeing-green-low-carbon-steel-and-aluminium-target-reduced-emissions/

Litman, T 2009, 'Transportation cost and benefit analysis', Victoria Transport Policy Institute, vol. 31, pp. 1–19.

Müller, DB, Liu, G, Løvik, AN, Modaresi, R, Pauliuk, S, Steinhoff, FS & Brattebø, H 2013, 'Carbon emissions of infrastructure development', Environmental Science & Technology, vol. 47, no. 20, pp. 11739–11746.

Nyborg, K 2012, The ethics and politics of environmental cost-benefit analysis, Routledge.

Pavement Interactive 2012, 'Energy and Road Construction-What's the Mileage of Roadway?', Pavement Interactive.

Productivity Commission 2014, Public Infrastructure: Inquiry Report, Australian Government, Canberra.

Sims, R 2013, 'A future regulatory outlook', Australian Competition and Consumer Commission, viewed 25 March 2021, www.accc.gov.au/speech/a-future-regulatory-outlook

Snowy Hydro Limited 2020, 'Snowy Hydro 2.0—About', Snowy Hydro, viewed 29 March 2021, www.snowyhydro.com.au/snowy-20/about/

Terrill, M 2019, Why it's time for congestion charging, Grattan Institute, Melbourne.

Terrill, M, Emslie, O & Moran, G 2020, 'The rise of mega-projects: counting the costs.' Grattan Institute, Melbourne.

Thomas, A, Boyle, E, Butler, W, Decker, G & Peters, J 2020, 'Organizational Politics and Teleworkers: A Case Study'.

8.2.6 Shelter

ABS, 2017. 2071.0—Census of Population and Housing: Reflecting Australia—Stories from the Census, 2016. abs.gov.au/ausstats/abs@.nsf/Lookup/2071.0main+features22016

ABS. (2020a). 8752.0 Building Activity, Australia. TABLE 35. Number of Dwelling Unit Commencements, States and Territories. Canberra: Australian Bureau of Statistics Retrieved from abs.gov.au/statistics/industry/building-and-construction/building-activity-australia/dec-2020/87520035.xls, abs.gov.au/ausstats/abs@.nsf/mf/4940.0

ABS. (2020b). Characteristics of new residential dwellings—A 15 year summary. Canberra: Australian Bureau of Statistics Retrieved from abs.gov.au/articles/characteristics-new-residential-dwellings-15-year-summary#:~:text=The%20average%20floor%20area%20of,2018%2D19%20at%20229.8m%C2%B2

ACIL-Allen study for Energy Consumers Australia. energyconsumersaustralia.com.au/wp-content/uploads/Supporting-Households-to-Manage-Their-Energy-Bills-a-Strategic-Framework.pdf

ACOSS (2019) acoss.org.au/wp-content/uploads/2019/09/Joint-statement-for-Healthy-Affordable-Homes.pdf

ACIL-Allen, 2018. Supporting households to manage their energy bills: A strategic framework.

Aliento, W., 2018. Energy equity in rental housing—time for change, including in the tax system. The fifth estate.

Arts, D. of the E.W.H. and the, 2008. Energy Use in the Australian Residential Sector 1986—2020. Canberra.

Australian Alliance for Energy Productivity, 2017. The Next Wave Innovation to double energy productivity by 2030. doi.org/10.13140/RG.2.2.20285.26083

Australian Building Codes Board, 2019. Energy efficiency—NCC 2022 and beyond scoping study. Viewed 7 June, consultation.abcb.gov.au/engagement/energy-efficiency-scoping-study-2019/

Australian Council of Social Service (ACOSS), 2019. All Australians deserve a healthy, safe, affordable home-Community organisations call for a national.

Australian Government, 2010. Report of the Prime Minister's Task Group on Energy Efficiency. Commonwealth of Australia, Canberra.

Australian Government, 2021a. Your Home—Appliances. Canberra Retrieved from yourhome.gov.au/energy/appliances

Australian Government, 2021b. Energy Rating Calculator. Retrieved from energyrating.gov.au/calculator

Beefledger, 2021. About Beefledger. Accessed 2 June 2021. beefledger.io/

Bryant, L., Eves, C., 2011. Assessing the Awareness and Importance of Housing Sustainability in Queensland 27–29.

Building Codes Queensland, 2012. Building and Plumbing Newsflash 506. Department of Housing and Public Works. Accessed from hpw.qld.gov.au/__data/assets/pdf_file/0016/4642/newsflash506withdrawlfromcoagcommitmentsforsixstarunits.pdf

Christensen, S., 2012. Queensland property legislation update. Aust. Prop. Law Bull. 27, 18–21.

COAG Energy Council, 2018. Report for Achieving Low Energy Homes 1–130.

COAG 2018. Trajectory for low energy buildings. Commonwealth of Australia, Canberra.

Daly, D., Kokogiannakis, G., Zwagerman, M., Burton, C., Cooper, P., Malgorzata, L., 2019. What are the effects of residential building energy performance disclosure policies on property values? | APO 29.

de Wilde, P., 2018. Building Performance Analysis, Building Performance Analysis. doi.org/10.1002/9781119341901

Dellow, K. 2021. REA Insights Energy Efficiency Housing Report—June 2021. Viewed 6 June 2021, realestate.com.au/insights/rea-insights-energy-efficiency-housing-report-june-2021/

Dignam, J., 2019. Now more than ever, we need minimum energy efficiency standards for rental properties. Renew Econ.

DISER, n.d. Commercial Buildings. Accessed 2 June 2021. energy.gov.au/government-priorities/energy-productivity-and-energy-efficiency/commercial-buildings

DISER, 2020. Australian Energy Statistics, Table A: Australian energy supply and consumption, energy units. Australian Government, Canberra.

Environment Victoria, 2020. Shine a light on inefficient homes environmentvictoria.org.au/campaign/shine-a-light-on-inefficient-homes

Fouche, M., Crawford, R.H., 2017. Towards an Integrated Approach for Evaluating both the Life Cycle Environmental and Financial Performance of a Building: A Review. Procedia Eng. 180, 118–127. doi.org/10.1016/j.proeng.2017.04.171

Gagan, O.2018. How AI can help meet global energy demand. Raconteur.

HIA. (2016). Research Snapshot February 2016. An Insight into Knockdown-rebuild Activity. In. Canberra: HIA. hia.com.au/-/media/HIA-Website/MiniSite/ACI/PDF/market-research/KDR_Feb2016.ashxHoen

B., Wiser, R., Cappers, P., & Thayer, M. (2011). An Analysis of the Effects of Residential Photovoltaic Energy Systems on Home Sales Prices in California.

IPEEC. (2019). Building energy performance gap issues. An international review. Retrieved from Paris: ipeec.org/upload/publication_related_language/pdf/1626.pdf

Khazal, A., Sønstebø, O.J., 2020. Valuation of energy performance certificates in the rental market—Professionals vs. nonprofessionals. Energy Policy 147. doi.org/10.1016/j.enpol.2020.111830

Mehmood, M.U., Chun, D., Zeeshan, Han, H., Jeon, G., Chen, K., 2019. A review of the applications of artificial intelligence and big data to buildings for energy-efficiency and a comfortable indoor living environment. Energy Build. 202, 109383. doi.org/10.1016/j.enbuild.2019.109383

Moore, T. (2012). Facilitating a transition to zero emission new housing in Australia: Costs, benefits and direction for policy. RMIT University, Melbourne

Moore, T., Berry, S., & Ambrose, M. (2019). Aiming for mediocrity: The case of Australian housing thermal performance. Energy Policy, 132, 602–610. doi.org/10.1016/j.enpol.2019.06.017

Moore, T., Hurst, N., 2018. Is the sustainability message coming home?, in: Proceedings of the 2018 International Conference Zero Energy Mass Custom Home. pp. 531–544.

Murray, D. 2021. A big week for energy efficiency standards in Australia. The Fifth Estate. Accessed from thefifthestate.com.au/innovation/residential-2/a-big-week-for-energy-efficiency-standards-in-australia/

NatHERS. (2021). Nationwide House Energy Rating Scheme (NatHERS). Retrieved from nathers.gov.au

Pears, A., & Moore, T. (2019). Decarbonising Household Energy Use: The Smart Meter Revolution and Beyond. In Decarbonising the Built Environment (pp. 99–115): Springer.

Pommeranz, C., Steininger, B.I., 2021. What Drives the Premium for Energy-Efficient Apartments—Green Awareness or Purchasing Power? J. Real Estate Financ. Econ. 62, 220–241. doi.org/10.1007/s11146-020-09755-8

Ryan, P., Pears, A., 2019. Unravelling home energy use across Australia. ReNew Technol. a Sustain. Futur. 41–45.

Saddler, H. & Jotzo, F., 2021. 'Tracking the transition: the 'forgotten' emissions undoing the work of Australia's renewable energy boom'. The Conversation, 11 June 2021, Melbourne.

Sanders, D.A., Robinson, D.C., Hassan, M., Haddad, M., Gegov, A., Ahmed, N., 2018. Making decisions about saving energy in compressed air systems using ambient intelligence and artificial intelligence. Adv. Intell. Syst. Comput. 869, 1229–1236. doi.org/10.1007/978-3-030-01057-7_92.

Simble, 2020. SimbleHome App to be offered to customers at Mirvac's Georges Cove masterplanned community in Sydney. Accessed from simblegroup.com/simble/simblehome-app-to-be-offered-to-customers-at-mirvacs-georges-cove-masterplanned-community-in-sydney

Sustainability Victoria. 2021. Reduce fridge and freezer costs at home. Victoria Retrieved from sustainability.vic.gov.au/energy-efficiency-and-reducing-emissions/save-energy-in-the-home/reduce-fridge-and-freezer-costs-at-home

Teh S.H., Wiedman T., Crawford, R., Xing, K. 2019. Assessing Embodied Greenhouse Gas Emissions in the Built Environment. In Newton *et al.* 2019. *Decarbonising the Built Environment* pp.119–141.

VPA, 2020. Guidelines for Precinct Structure Planning in Melbourne's Greenfields: Draft for Public Engagement. Victorian Government, Melbourne.

Wong, S.Y., Susilawati, C., Miller, W., Mardiasmo, D., 2020. Perspectives of Australian property practitioners on sustainability features in residential property. J. Hous. Built Environ. doi.org/10.1007/s10901-019-09726-3

Wong, S.Y., Susilawati, C., Miller, W., Mardiasmo, D., 2019. Involving property practitioners for improving information gathering and distribution of sustainability features. Lect. Notes Mech. Eng. 717–725. doi.org/10.1007/978-3-319-95711-1_70

8.2.7 Water

Abadia, R., Rocamora, C., Ruiz, A., & Puerto, H. (2008). Energy efficiency in irrigation distribution networks I: theory. *Biosystems engineering, 101*(1), 21–27.

ABS. 2018. 6202.0—Labour Force, Australia. Retrieved from abs.gov.au/statistics/labour/employment-and-unemployment/labour-force-australia/latest-release

ABS, 2020. Energy account, Australia. Commonwealth of Australia, Canberra abs.gov.au/statistics/industry/energy/energy-account-australia accessed on 28 May 2021.

ABS, 2019, 4610.0—Water Account, Australia, 2016–17, Commonwealth of Australia, Canberra abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4610.0Main+Features22016-17?OpenDocument

ABS., 2020, Water Use on Australian Farms 2019–20. Commonwealth of Australia, Canberra. Retrieved from abs.gov.au/statistics/industry/agriculture/water-use-australian-farms/2019-20

Beca Consultants, 2015, Opportunities for renewable energy in the Australian water *sector*. Retrieved from arena.gov.au/assets/2016/01/Opportunities-for-renewable-energy-in-the-Australian-water-sector.pdf

Binks, A.N., Kenway, S.J., Lant, P.A. and Head, B.W., 2016. Understanding Australian household water-related energy use and identifying physical and human characteristics of major end uses. Journal of Cleaner Production, 135, pp.892–906.

Boyle, T., Giurco, D., Mukheibir, P., Liu, A., Moy, C., White, S., and Stewart, R. (2013). Intelligent metering for urban water: A review. Water, 5 (3), 1052–1081.

Briggs, C., Nagrath, K., Mey, F., Wyndham, J., (2018) Irrigators—the flow on benefits of regionally embedded generation, Final Report, prepared for Energy Consumers Australia, Institute for Sustainable Futures, UTS

Broccardo, L., Culasso, F., & Truant, E. (2017). Unlocking value creation using an agritourism business model. *Sustainability, 9*(9), 1618.

Chen, K., Cheng, J., Lee, J.-M., Li, L.-Y., & Peng, S.-Y. (2020). Energy Efficiency: Indicator, Estimation, and a New Idea. *Sustainability, 12*(12), 4944.

Cheong, SM., Choi, GW. & Lee, HS. Barriers and Solutions to Smart Water Grid Development. Environmental Management 57, 509–515 (2016).

Crittenden, P., Grant, C., & Dessi, A. (2016). *Energy Management in Mining*. Retrieved from industry.gov.au/sites/default/files/2019-04/lpsdp-energy-management-in-mining-handbook-english.pdf

Cook, S., Hall, M., & Gregory, A. (2012). *Energy use in the provision and consumption of urban water in Australia: an update* (1835-095X). Retrieved from publications.csiro.au/rpr/download?pid=csiro:EP122271&dsid=DS4

DISER, 2020. Australian Energy Update Retrieved from Canberra: energy.gov.au/sites/default/files/Australian%20Energy%20Statistics%202020%20Energy%20Update%20Report_0.pdf

DISER, 2021. Water efficiency, Australian Government. energy.gov.au/households/water-efficiency

Dong, L. (2020). Toward Resilient Agriculture Value Chains: Challenges and Opportunities. *Production and Operations Management*.

Geissdoerfer, M., Vladimirova, D., & Evans, S. (2018). Sustainable business model innovation: A review. *Journal of Cleaner Production, 198*, 401–416.

Haller, L., Hutton, G. and Bartram, J., 2007. Estimating the costs and health benefits of water and sanitation improvements at global level. Journal of water and health, 5(4), pp.467–480.

Harrison, S. and Eng, P., 2017. The potential and challenges of solar boosted heat pumps for domestic hot water heating. In 12th IEA Heat Pump Conference.

Honma, S. and Hu, J.L., 2009. Total-factor energy productivity growth of regions in Japan. Energy Policy, 37(10), pp.3941–3950.

Hrustek, L. (2020). Sustainability Driven by Agriculture through Digital Transformation. *Sustainability, 12*(20), 8596.

Islam, M.R., Sumathy, K. and Khan, S.U., 2013. Solar water heating systems and their market trends. Renewable and Sustainable Energy Reviews, 17, pp.1–25.

Kenway, S.J., Priestley, A., Cook, S., Seo, S., Inman, M., Gregory, A. and Hall, M., 2008. Energy use in the provision and consumption of urban water in Australia and New Zealand. Water Services Association of Australia (WSAA): Sydney, Australia.

Kenway, S.J., Lam, K.L., Stokes-Draut, J., Sanders, K.T., Binks, A.N., Bors, J., Head, B., Olsson, G. and McMahon, J.E., 2019. Defining water-related energy for global comparison, clearer communication, and sharper policy. Journal of Cleaner Production, 236, p.117502.

Kenway, S.J., Binks, A., Lane, J., Lant, P.A., Lam, K.L. and Simms, A., 2015. A systemic framework and analysis of urban water energy. Environmental Modelling & Software, 73, pp.272–285.

Lam, K.L., Kenway, S.J. and Lant, P.A., 2017. City-scale analysis of water-related energy identifies more cost-effective solutions. Water research, 109, pp.287–298.

March, J. G. (1991). Exploration and exploitation in organizational learning. *Organization science, 2*(1), 71–87.

McNabola, A., Coughlan, P., &, & Williams, A. (2011). *The technical and economic feasibility of energy recovery in water supply networks*. Paper presented at the Proceedings of International Conference on Renewable Energy and Power Quality, Las Palmas de Gran Canaria, Spain.

Bharambe, G. and McKewen, C., 2020. Feasibility of Waste to Energy at Gladstone Wastewater Treatment Plant. Water e-journal.

Morrow, W.R., Carpenter, A., Cresko, J., Das, S., Graziano, D.J., Hanes, R., Supekar, S.D., Nimbalkar, S., Riddle, M. and Shehabi, A., 2017. US Industrial Sector Energy Productivity Improvement Pathways. Proceedings of ACEEE Summer Study on Energy Efficiency in Industry, August, pp.15–18.

Moretti, S.M.L., Bertoncini, E.I. and Abreu-Junior, C.H., 2015. Composting sewage sludge with green waste from tree pruning. Scientia Agricola, 72(5), pp.432–439.

Nolet, 2018. Seeds of success: advancing digital agriculture from point solutions to platforms. The United States Studies Centre, the University of Sydney.

Plappally, A.K., Lienhard J.H., 2012. Energy requirements for water production, treatment, end use, reclamation, and disposal. Renewable and Sustainable Energy Reviews, 16(7), pp.4818–4848

Prosser, I., Wolf, L., & Littleboy, A., 2011. Water in mining and industry. *Water: Science and Solutions for Australia*, 135–146.

Queensland Government, 2021. Environmental values and water quality objectives. Department of Environment and Science.

Randall, T. and Koech, R., 2019. Smart water metering technology for water management in urban areas. Water e-Journal, 4.

Roshan, A. and Kumar, M., 2020. Water end-use estimation can support the urban water crisis management: a critical review. Journal of environmental management, 268, p.110663.

Schellekens, J., Heidecke, L., Nguyen, N. and Spit, W., 2018. The economic value of water–water as a key resource for economic growth in the EU. Rotterdam: ECORYS.

Sarni, W., White, C., Webb, R., Cross, K. and Glotzbach, R., 2019. Digital Water: Industry leaders chart the transformation journey. International Water Association and Xylem Inc.

Smil, V. (2008). *Energy in nature and society: general energetics of complex systems*: MIT press.

Sonderlund, A. L., Smith, J. R., Hutton, C., & Kapelan, Z. (2014). Using Smart Meters for Household Water Consumption Feedback: Knowns and Unknowns. Procedia Engineering, 89, 990–997

Teece, D. J. (2010). Business models, business strategy and innovation. *Long range planning, 43*(2), 172–194.

Victorian Goverment, 2021. www.solar.vic.gov.au/solar-hot-water-buyers-guide/section-1-what-efficient-hot-water-system-and-why-should-i-install-one, accessed on 28 May 2021.

Vieira, A.S., Beal, C.D. and Stewart, R.A., 2014. Residential water heaters in Brisbane, Australia: Thinking beyond technology selection to enhance energy efficiency and level of service. Energy and Buildings, 82, pp.222–236.

8.3 Chapter 6

A2EP 2017, The Next Wave—Innovation to Double Energy Productivity by 2030. Australian Alliance for Energy Productivity, Sydney.

A2EP, 2020. Compressed air systems, emerging efficiency improvements and alternative technologies: Review, ground research and examples. Australian Alliance for Energy Productivity, Sydney.

Atalla, T. and P. Bean, Determinants of energy productivity in 39 countries: An empirical investigation. Energy Economics, 2017. 62: p. 217–229.

Australian Government, 2020. Department of Industry, S., Energy and Resources, Australian Energy Update 2020.

Blakers, 2021. Solar and wind are leading fastest energy transition the world has seen. Renew Economy, accessed from reneweconomy.com.au/solar-and-wind-are-leading-the-fastest-energy-transition-the-world-has-seen

Chatterjee, S., Ürge-Vorsatz, D., Thema, J. and Kelemen, Á., Synthesis Methodology D2. 4 Final report, Wuppertal.

Clean Energy Council, 2021. Clean Energy Australia Report 2021.

COAG Energy Council, 2015. National Energy Productivity Plan 2015–2030. Australian Governments, Canberra.

COMBI, 2015. Calculating and Operationalising the Multiple Benefits of Energy Efficiency in Europe. Accessed 2 June 2021. combi-project.eu

Cranney, K., 2020. Renewables still the cheapest new-build power in Australia. CSIRO. Accessed 2 June 2021. www.csiro.au/en/news/news-releases/2020/renewables-still-the-cheapest-new-build-power-in-australia

Denham, T. and Dodson, J., 2018, December. Cost Benefit Analysis: The State of the Art in Australia. Presentation to the Australian Transport Research Forum (ATRF), Darwin.

Department of Resources, Energy & Tourism, 2011. Energy Efficiency Opportunities Assessment Handbook 2011. Accessed 10 June 2021, www.energy.gov.au/publications/energy-efficiency-opportunities-assessment-handbook

Elkomy S, Mair S and T Jackson 2020. Energy and Productivity: a review of the literature. CUSP Working Paper No 23. Guildford: University of Surrey. Online at: www.cusp.ac.uk/powering-productivity

Fawcett, T., Killip, G. and Schlegel, A.J., 2018. M-Benefits D2. 1 Literature Review-methodology and preliminary findings.

Geels, FW, 2011. ‘Socio-technical transitions towards sustainability: Dynamics and policy implications’. Presentation to the 12th International Conference on Industrial Innovation, 25–26 August 2011. Taipei, Tiawan.

Geels, FW & Schot, J, 2007, ‘Typology of sociotechnical transition pathways’, Research Policy, vol. 36, no. 3, pp. 399–417.

Gretton, P., 2013. On input-output tables: uses and abuses, Staff Research Note, Productivity Commission, Canberra.

Instinct and Reason, 2015. Energy Efficiency Information Grants Program Evaluation. Department of Industry, Science, Energy and Resources, Canberra.

IEA, 2015. Capturing the Multiple Benefits of Energy Efficiency, International Energy Agency, Paris www.iea.org/reports/capturing-the-multiple-benefits-of-energy-efficiency

IEA, 2018. Quantifying the Multiple Benefits of Energy Efficiency and Renewable Energy: A Guide for State and Local Governments. International Energy Agency, Paris.

IEA, 2019. Multiple Benefits of Energy Efficiency: from “hidden fuel” to “first fuel”. International Energy Agency, Paris.

Karo, E. and Kattel, R., 2015. Innovation Bureaucracy: Does the organization of government matter when promoting innovation? (No. 2015/38). Lund University, CIRCLE-Center for Innovation, Research and Competences in the Learning Economy.

Karo, E and Kattel, R., 2016. How to Organize for Innovation: entrepreneurial state and organizational variety. Working Papers in Technology Governance and Economic Dynamics, University of Tallinn.

Kostoff, R.N., Boylan, R. and Simons, G.R., 2004. Disruptive technology roadmaps. *Technological Forecasting and Social Change*, *71*(1–2), pp.141–159.

Mbenefits, 2018. Multiple Benefits of Energy Efficiency. European Commission. Viewed 2 June 2021, www.mbenefits.eu/

Parkinson, G., 2019. Why network operators will take thousands of customers off the grid. *Renew Economy*, reneweconomy.com.au/why-network-operators-will-take-thousands-of-customers-off-the-grid-70149

Saddler, H. & Jotzo, F., 2021. ‘Tracking the transition: the ‘forgotten’ emissions undoing the work of Australia’s renewable energy boom’. The Conversation, 11 June 2021, Melbourne.

Sood, A & Tellis, GJ 2011, ‘Demystifying Disruption: A New Model for Understanding and Predicting Disruptive Technologies’, Marketing Science, vol. 30, no. 2, pp. 339–354.

Thema, J., 2018. The COMBI online tool for multiple impacts visualisation: D8.1 Quick guide and documentation. Accessed 2 June 2021. combi-project.eu/wp-content/uploads/D8.1_tool-guide.pdf

Ürge-Vorsatz, D., Kelemen, A., Tirado-Herrero, S., Thomas, S., Thema, J., Mzavanadze, N., Hauptstock, D., Suerkemper, F., Teubler, J., Gupta, M. and Chatterjee, S., 2016. Measuring multiple impacts of low-carbon energy options in a green economy context. Applied Energy, 179, pp.1409–1426.

WEF & BCG 2021, Net-Zero Challenge: The supply chain opportunity, World Economic Forum, Cologny, Switzerland.

RACE for 2030

www.racefor2030.com.au

Australian Government
Department of Industry, Science, Energy and Resources

AusIndustry
Cooperative Research Centres Program