Finding a place for organic waste-to-energy in Australian agribusiness

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This thesis is submitted in total fulfilment of the requirements

for the degree of Doctor of Philosophy

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Submitted in August 2023

Abstract

This thesis seeks to understand Australian agribusiness engagement with approaches to generate energy from organic waste materials. Applications of modern bioenergy technologies, utilising agriculture residues to produce electrical, thermal and transport energy, have been well established in many parts of the world. There has been enthusiasm for bioenergy from agriculture to make a substantial contribution to Australia's energy mix, but the agriculture sector, like Australia more generally, has been slow to transition to bioenergy technologies.

Adopting the pragmatism research philosophy, this study applies the Multi-Level Perspective and Social Practice Approach frameworks to explore Australian agribusiness engagement with bioenergy systems, to produce energy from organic waste. A multi-methods qualitative research methodology is used to analyse the adoption of organic waste-to-energy approaches by Australian agribusiness, and to identify the critical drivers and barriers impacting these transitions.

Except for sugar processors, Australian agribusiness adoption of organic waste-to-energy approaches is in its very early stages. The main drivers prompting agribusinesses to explore their organic waste-to-energy options are, agribusinesses experiencing problems with the cost and/or quality of their energy supplies, and/or problems with the social acceptance of their existing organic waste management practices.

The main barriers to agribusinesses making the transition to bioenergy technologies, include financial factors such as the high capital costs of bioenergy plants and low returns on investment. Other barriers include a low level of awareness and understanding of bioenergy approaches in the agriculture industry, and in Australia more broadly, and a lack of consultative expertise to develop and service bioenergy systems.

For organic waste-to-energy to play a more substantial role in Australian agriculture, support is needed to overcome critical barriers. This study finds policy and support mechanisms are required to encourage greater collaboration of small-scale agribusinesses and other relevant stakeholders. Investment is also needed to increase Australia's awareness and understanding of organic waste-to-energy approaches, and to build the consultative expertise and skills-base to support the development of bioenergy systems.

Statement of Authorship

Except where explicit reference is made in the text of the thesis, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma.

No other person's work has been relied upon or used without due acknowledgement in the main text and bibliography of the thesis.

Signed:	Signed:
Dated:	Dated:
21 August 2023	21 August 2023
Craig Anthony Hurley	Associate Professor Jerry Courvisanos
Candidate	Principal Supervisor

Statement of Ethics Approval

Approval
Human Research Ethics Committee

Federation UNIVERSITY•AUSTRALIA

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Project Number:	**B18-127**
Project Title:	**Finding a place for waste-to-energy in Australian agribusiness.**
For the period:	20/11/2018 **to** 20/12/2021

Quote the Project No: B18-127 in all correspondence regarding this application.

Approval has been granted to undertake this project in accordance with the proposal submitted for the period listed above.

Please note: It is the responsibility of the Principal Researcher to ensure the Ethics Officer is contacted immediately regarding any proposed change or any serious or unexpected adverse effect on participants during the life of this project.

In Addition: Maintaining Ethics Approval is contingent upon adherence to all Standard Conditions of Approval as listed on the final page of this notification

COMPLIANCE REPORTING DATES TO HREC:

Annual project report:
20 November 2019
20 November 2020
20 November 2021

Final project report:
20 January 2022

The combined annual/final report template is available at:

http://federation.edu.au/research/support-for-current-students-and-staff/ethics/human-ethics/human-ethics3

Fiona Koop
Coordinator Research Ethics
20 November 2018
Please note the standard conditions of approval on Page 2:

Acknowledgements

Over my PhD experience, I have received substantial support from many people, and I would like to thank each and every person who has played a role in and made a contribution to my journey.

Firstly, I would like to acknowledge my supervision team; Associate Professor Jerry Courvisanos and Dr Alan Labas. It was my privilege to study under you both and I am grateful for your guidance, wisdom, patience and professionalism. I also wish to acknowledge the other supervisors who were part of my PhD journey; Dr Michelle Graymore, Dr Jackie Tuck and Dr Ben Wills. I thank my Federation Business Discipline colleagues for your interest, encouragement, and collegiality, and I am also appreciative of the support and advice of my colleagues in the wider Federation University research community, especially in the Research Services office.

I also acknowledge everybody who agreed to participate in this study. I am thankful for your generosity in sharing your time, knowledge, expertise and experience to contribute to this research project.

Finally, I would like to thank my wife Andrea and son Flynn for your patience and support, and for allowing me the time and space to invest in this journey.

Craig Hurley was supported by an Australian Government Research Training Program (RTP) Fee-Offset Scholarship through Federation University Australia.

Dedication

In memory of Kerrin Irene Hurley.

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1. Introduction

1.1 Overview of research

Over the last 200 years, advances in farming techniques and technologies have dramatically improved the efficiency of agriculture and increased the productive capacity of many of the world's farms and processors to meet the food and fibre demands of the expanding global population. In many countries, the mechanisation and intensification of agricultural production and processing has also resulted in substantial increases in the energy consumed by farmers and the energy-intensity of agricultural inputs, such as fertilisers, herbicides and pesticides (Rokicki et al., 2021). In addition, increases in agricultural production have also led to a corresponding increase in the waste generated by farming businesses (Holm-Nielsen et al., 2009; Sam et al., 2017), with much of this waste being organic plant and animal materials, which are forms of biomass. Biomass is any organic matter from biological sources that is available on a renewable basis (IEA & FAO, 2017).

Various forms of organic by-products are productively utilised by many farms around the world. However, the management of large volumes of organic waste can be problematic for agribusinesses, where for a range of reasons, the traditional approaches to the collection, handling, treatment and/or disposal of this waste may no longer be appropriate or desirable (Hou et al., 2018; Westerman & Bicudo, 2005). With Australian agricultural production projected to increase over the next 25 years (Grundy et al., 2016), the effective and safe management of organic waste streams will be important considerations for Australian agribusinesses (Steinfeld et al., 2006).

Some agribusinesses have sought to address their waste management challenges and opportunities by utilising their organic waste to produce various forms of energy, which are known as biomass energy, more commonly known as bioenergy. By adopting bioenergy technologies, such agribusinesses can contribute to the on-site energy needs of their operation and/or the energy needs of local communities and other businesses.

Bioenergy has been viewed with considerable interest by some governments, non-government organisations (NGOs) and industry bodies as a reliable form of baseload energy generation that can utilise lower-value organic waste streams to generate higher value thermal, electrical and transport energy. Also, bioenergy has been identified as a low-carbon renewable energy option that is able to play a role in reducing global greenhouse gas emissions. With most of the world's countries agreeing to substantially reduce their emissions of the greenhouse gases contributing to anthropogenic climate change (United Nations, 2023), bioenergy has been promoted as a waste management strategy to reduce carbon emissions from agricultural production, and as a renewable energy generation technology that can displace some of the energy that would otherwise be generated from more carbon-intensive sources.

Bioenergy technologies refer to plant and equipment designs and units that utilise various technological processes to convert biological agribusiness waste streams such as animal manures, plant materials, straw/stalks and cropping residues, animal carcasses, agroforestry waste and food production waste, into useable forms of energy. While some bioenergy technologies are still being refined, others are mature, and their use is relatively common in Europe and the Americas. Organic waste-to-energy is a form of bioenergy that applies bioenergy technologies and approaches to generate energy from organic waste materials.

Bioenergy systems refer to the socio-technical configurations of social, economic, and technical elements (such as technologies, regulations, user practices and markets, cultural values, infrastructure, maintenance networks and production systems) that link to facilitate the effective adoption and operation of biomass energy technologies. This definition adopts the broad systems approach by Geels (2005b) and is applied in this study to organic waste-to-energy in Australian agribusiness.

Despite some enthusiasm for the development of organic waste-to-energy and bioenergy more broadly, the bioenergy industry in Australia is considered to be underdeveloped and the application of bioenergy technologies has been surprisingly modest, given the large volumes of waste biomass at the industry's disposal (McKenzie, 2020). In this context, the agribusiness sector has been identified as having great potential for growth in terms of bioenergy investment and development, particularly in the area of organic waste-to-energy (Clean Energy Council, 2008; IEA Bioenergy, 2016a). The focus of this study is on engagement of Australian agribusinesses with bioenergy systems and their adoption of specific technologies for on-site generation of energy from organic waste materials.

1.2 Research objective

The problem this research seeks to address is that the Australian agribusiness sector has been slow to engage with bioenergy systems and technologies as a central part of their organic waste management practices and/or energy profiles. The objective of this study is to explore reasons for this and to identify the critical factors that influence agribusiness decision-making on organic waste-to-energy investments. This study aims to identify the drivers inducing agribusiness investment in on-site biomass waste-to-energy technologies with accompanying social and economic configurations, and the barriers affecting this transition.

1.3 Research questions

The major research question that underpins this study is: How does Australian agribusiness engage with bioenergy systems through the adoption of integrated organic waste-to-energy technologies?

In order to address this major question, the following sub-questions need to be examined:

i. What are the characteristics of Australian agribusinesses that have invested in on-site organic waste-to-energy technologies?

ii. What are the major drivers that prompt Australian agribusiness managers to consider investing in organic waste-to-energy technologies with accompanying social and economic configurations?

iii. What are the critical barriers impacting the adoption of on-site organic waste-to-energy technologies by Australian agribusinesses?

iv. How do these drivers and barriers impact agribusinesses transitioning to organic waste-to-energy systems?

1.4 Bioenergy and organic waste-to-energy

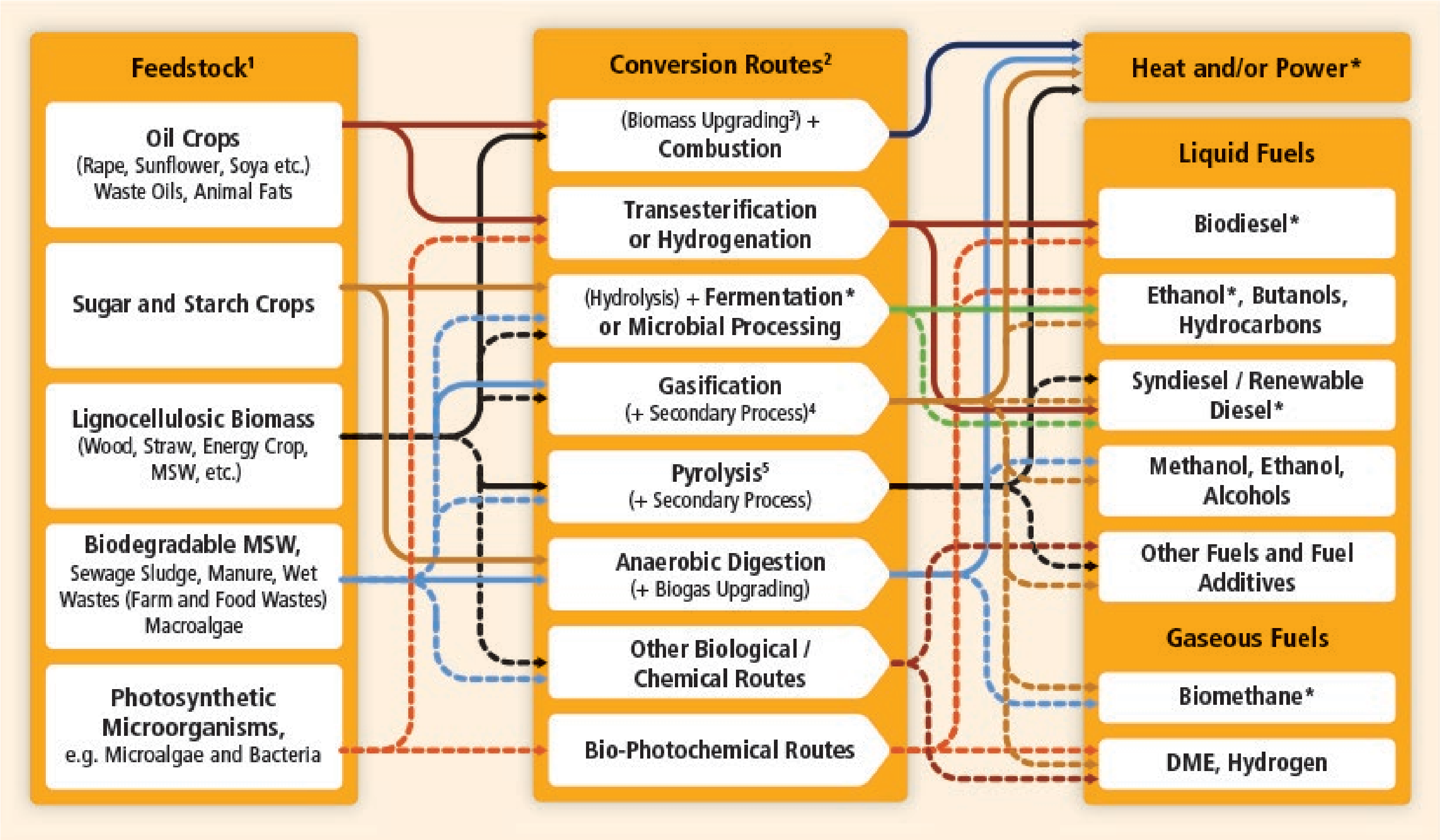
This section provides an introduction to the concepts of bioenergy and organic waste-to-energy. Biomass materials are derived from the living tissue of plants and animals, are organic, putrescible, decomposable and available on a renewable basis. Biomass includes wood and agricultural crops, herbaceous and woody crops, municipal organic wastes, as well as manure (IEA, 2016). The useful energy derived from biomass is known as biomass energy, or bioenergy (Ruppert et al., 2013). Bioenergy is the largest of the renewable energy sources yet provides only approximately 10% of the world's primary energy supply (IEA, 2016; World Energy Council, 2013). Most of this bioenergy is utilised in developing countries, where the combustion of traditional biomass resources such as firewood, animal dung and other organic materials remains the primary source of basic energy needs for heating, cooking and lighting. Ruppert et al. (2013) refer to this as traditional bioenergy, which remains an important energy source for millions of people worldwide.

Modern biomass energy includes the application of various technologies and processes that convert the chemical energy in biological material into other useful forms of energy, such as thermal energy (heat), transport fuels and electrical energy (Ruppert et al., 2013). Biomass feedstocks are raw materials from biological sources to which various production processes or technologies (conversion routes) can be applied to produce heat and/or power. Organic feedstocks can also be converted into a range of solid, liquid or gaseous fuels (also known as biogas and/or biofuels), that can be used to fuel energy generation.

Figure 1.1 provides a schematic view of possible technological pathways to convert biomass feedstocks into energy. This diagram features three columns: feedstocks, conversion routes and the fuel products or outputs of the conversion processes. The conversion pathways presented in this schematic begin with a range of biomass feedstock types in the column on the left side of the diagram. These feedstocks follow technological pathways, represented by the coloured solid and dotted lines, to one or more of the conversion routes identified in the figure's central column.

Conversion routes apply technological processes to the raw biomass feedstocks, with the outputs of these conversion processes being heat and/or power, and liquid or gaseous fuels. These outputs may be used to fuel various forms of energy generation. The coloured solid and dotted lines in Figure 1.1 indicate the maturity and commercial availability of the conversion technologies, as of 2009 (Chum et al., 2011). Since the publication of this figure, there has been substantial variability in the rates of development of these technologies in different parts of the world. However, the maturity and availability of the bioenergy technologies in Figure 1.1 are still broadly applicable to the current Australian context (IEA Bioenergy, 2021).

The established commercial conversion pathways are represented by the solid lines, while the dotted lines indicate technologies for which commercial applications are still being developed. Similarly, the conversion process outputs marked with an asterisk (i.e. heat and/or power, biodiesel, ethanol, renewable diesel and biomethane) have commercial applications, while applications are still being developed for the remaining output products.



Notes: 1. Parts of each feedstock, for example, crop residues, could also be used in other routes. 2. Each route also gives coproducts. 3. Biomass upgrading includes any one of the densification processes (palletisation, pyrolysis, torrefaction, etc.). 4. Anaerobic digestion processes release methane and CO2 and removal of CO2 provides essentially methane, the major component of natural gas; the upgraded gas is called biomethane. 5. Could be other thermal processing routes such as hydrothermal, liquefaction, etc. DME=dimethyl ether.

Source: Chum et al., (2011, p. 218)

Figure 1.1 Variety of commercial and developing bioenergy conversion routes

As a study of agribusiness use of organic waste for energy generation, this research is primarily focussed on the food and fibre production biomass by-products that feature in two of the broad feedstock types in Figure 1.1; lignocellulosic biomass and biodegradable MSW. The two conversion routes suitable for both feedstocks and have established commercial applications, are combustion and anaerobic digestion, and as a result, these two bioenergy technologies feature prominently in this research.

Modern bioenergy is an important contributor to global energy needs, providing four times the energy of solar photovoltaic (PV) and wind energy combined (IEA, 2018), but it is still considered 'the overlooked giant of renewables' (IEA, 2018, p. 13). However, global production of bioenergy is projected to grow substantially as the world transitions to sustainable energy generation and food and fibre production (Calvin et al., 2021). The main driver of this transition is the urgent need for the nations of the world to drastically reduce emissions of greenhouse gases that cause anthropogenic climate change. With many countries, including Australia, committing to reduce their emissions of greenhouse gases to net zero by 2050, fundamental and transformational changes are required in the way societies and economies operate.

To realise the sustainability transitions required, substantial change is needed in agriculture, with the Food and Agriculture Organization of the United Nations (FAO) declaring agribusiness-as-usual is not an option:

> High-input, resource-intensive farming systems, which have caused massive deforestation, water scarcities, soil depletion and high levels of greenhouse gas emissions, cannot deliver sustainable food and agricultural production. Needed are innovative systems that protect and enhance the natural resource base, while increasing productivity. Needed is a transformative process towards 'holistic' approaches, such as agroecology, agro-forestry, climate-smart agriculture and conservation agriculture, which also build upon indigenous and traditional knowledge. Technological improvements, along

> with drastic cuts in economy-wide and agricultural fossil fuel use, would help address climate change and the intensification of natural hazards, which affect all ecosystems and every aspect of human life. (FAO, 2017, p. xi)

An example of a holistic approach to help achieve such transformational change is the creation of a circular economy (CE). CE is an emerging subject area (Velenturf et al., 2019) that has been advanced as a sustainable alternative to the current linear economic system, which is widely regarded as being unsustainable (Chodkowska-Miszczuk et al., 2021; Ellen MacArthur Foundation, 2013; Frosch & Gallopoulos, 1989; Jurgilevich et al., 2016; Korhonen et al., 2018). This linear system, also known as the materials economy, has dominated economic development across the globe and describes a linear process of Extraction → Production/Processing → Distribution → Consumption → Disposal (Leonard, 2007). Through this process, natural resources are converted into waste, via production and consumption, causing serious environmental harm (Korhonen et al., 2018; Leonard, 2007; Murray et al., 2017). The CE approach connects Disposal with Extraction, to 'close the loop' and create a materials cycle, in which the value contained in by-product resources is not disposed of or wasted, but is extracted to be used again or serve another purpose (Leonard, 2007).

CE emphasises 'product, component and material reuse, remanufacturing, refurbishment, repair, cascading and upgrading as well as solar, wind, biomass and waste-derived energy utilization throughout the product value chain and cradle-to-cradle life cycle' (Korhonen et al., 2018, p. 37). The aim is to create a more sustainable socioeconomic model that eases demand for raw materials and resources from the natural environment and eliminates waste. This concept is linked to a biomimicry principle, that in nature there is no such thing as waste – the by-product of every biological process is food/fuel for another biological process or organism, which represents a cyclical – not linear, flow of materials and resources (Benyus, 1997).

This transition from linear to circular economies has emerged as a priority for several countries, such as in Europe and some parts of China, and corporations around the world (Barquete et al., 2022; Gottinger et al., 2020; Halog et al., 2021; Korhonen et al., 2018; Murray et al., 2017). Australia's development of CE has been conservative, but there have been some elements of CE observed in the mining, waste management and recycling industries (Melles, 2021). There has also been some activity at State and Local Government levels, with the development of policies, regulations and actions to support some CE components such as waste reduction and resource recovery through increased recycling (Halog et al., 2021; Levitzke, 2020; Melles, 2021).

For the modern agriculture sector, CE involves reducing inputs and reducing waste. CE has a focus on agriculture supply chains and energy-intensive inputs such as machinery, transport fuels, electricity, gas, synthetic fertilisers and herbicides/pesticides (Barros et al., 2020; Jurgilevich et al., 2016; Poponi et al., 2022). Waste valorisation is a CE priority that aims to both reduce inputs and reduce waste, through the beneficial re-use of by-products (Barros et al., 2020; Jurgilevich et al., 2016; Poponi et al., 2022). The benefit of waste valorisation is the re-use of waste materials, which can improve the efficiency and sustainability of an operation, by reducing the requirement to source virgin/raw materials for production, while also reducing the costs and other risks associated with managing by-products.

One of the clearest examples of an agriculture practice that aligns with CE approach is bioenergy generation – and organic waste-to-energy more specifically (Chodkowska-Miszczuk et al., 2021). For more than 20 years, a plethora of reports, case studies, discussion papers and how-to guides have been published by governments, NGOs and industry bodies around the world, with a focus on bioenergy. These publications highlight the potential of organic waste-to-energy to help address agriculture's energy and waste challenges, and to deliver the desired win-win-win of social, environmental and economic benefits of a CE (Korhonen et al., 2018).

In addition, many of the transition pathways identified by the Intergovernmental Panel for Climate Change (IPCC) feature substantial utilisation of a range of bioenergy technologies to mitigate climate change by displacing more carbon intensive energy sources, such as energy derived from fossil fuels (Calvin et al., 2021; Li et al., 2020). This is also the case in Australia, with the Commonwealth Government's 2021 release of Australia's Bioenergy Roadmap. This document acknowledges bioenergy's potential for growth and its role in Australia's future energy mix, and provides a vision and framework to enhance the development of the bioenergy sector (ENEA Consulting and Deloitte Financial Advisory, 2021).

Despite the enthusiasm for sustainable bioenergy utilisation around the world, this has not translated into widespread adoption of organic waste-to-energy technologies by Australian agribusinesses. Australia's bioenergy industry is underdeveloped (CEFC, 2015), with Australia positioned in the bottom quartile of Organisation for Economic Cooperation and Development (OECD) countries, in terms of bioenergy's contribution to total energy supply (KPMG, 2018; Li et al., 2020; McCabe, 2020). Also, the development of the bioenergy industry in Australia is considered to be about 10-15 years behind other developed countries (McKenzie, 2020).

While it currently plays only a minor role in Australia's energy landscape, bioenergy has a long history of producing low-carbon, cost-competitive, reliable, baseload renewable energy in Australia. The sugar industry has been a pioneer in Australia's bioenergy sector, producing electricity and heat from sugar cane waste (known as bagasse) in Northern Queensland for over 100 years (Clean Energy Regulator, 2023). Sugar processors remain the dominant players in Australia's bioenergy industry, contributing almost 60% of Australia's installed bioenergy electricity generation capacity (CEFC, 2015).

Much of Australia's recent growth in bioenergy has been in the capture and utilisation of biogas (methane) produced by decomposing putrescible material buried in municipal landfill sites and wastewater treatment facilities (Dastjerdi et al., 2022). However, according to the Clean Energy Council (see Figure 1.2), energy generated from agricultural waste streams has the potential to overtake significantly both sugarcane processors and municipal landfill sites combined as Australia's largest contributor of bioenergy to electricity generation by 2050.

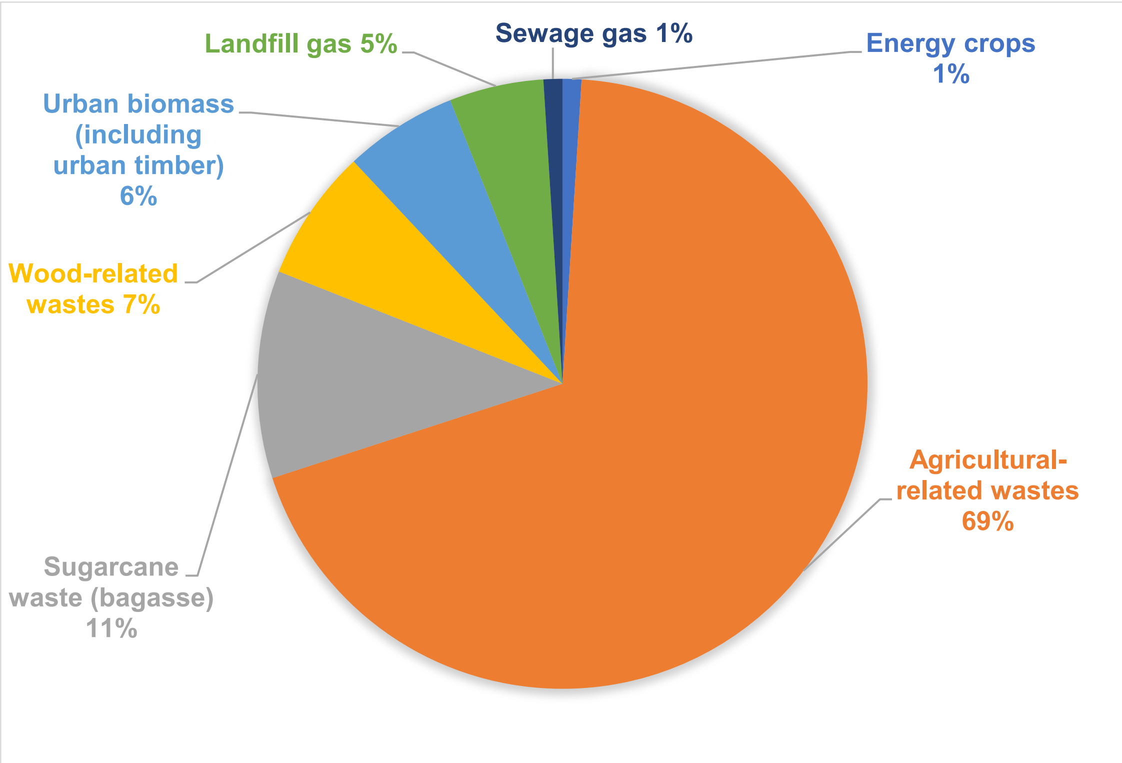


Figure 1.2 Australia's potential 2050 bioenergy contribution to electricity

Source: Adapted from Clean Energy Council (2008, p. 23)

While there is debate about the extent to which bioenergy could sustainably and reliably contribute to a renewable energy mix for carbon-neutral energy production in Australia, modelling generally agrees there is a significant role for bioenergy, and for organic waste-to-energy in particular. Conservative estimates suggest bioenergy could contribute 5% of a 100% renewable energy mix, which would require a 5-fold increase in bioenergy production in Australia (Jayarathna et al., 2020; Li et al., 2020). To achieve such an increase in bioenergy production, a substantial contribution will be required from the agriculture/forestry sector, utilising organic waste-to-energy approaches to generate energy from organic by-products. Figure 1.2 indicates the Australian agribusiness sector could make such a contribution, given its significant untapped potential for organic waste-to-energy development. The next section explores Australian agribusinesses and their management of the organic by-products that could be utilised for organic waste-to-energy generation.

1.5 Agribusiness and waste management in Australia

The term ‘Agribusiness’ refers to ‘the sum total of all operations involved in the manufacture and distribution of farm supplies; production operations on the farms; and the storage, processing, and distribution of farm commodities and items made from them’ (Davis & Goldberg, 1957, p. 2). For the purposes of this thesis, agribusiness refers to the businesses involved in the growing and/or processing of Australia’s food and fibre production. Over the next four decades, Australia’s agricultural production is projected to grow strongly, particularly in the beef, poultry and grain sectors (Centre for International Economics, 2015). As Australia’s agricultural production continues to grow, so too will the volumes of organic by-products and wastes these sectors will need to manage.

The Victorian Environment Protection Act 1970 (s 4) defines waste as ‘any matter whether solid, liquid, gaseous or radio-active which is discharged, emitted or deposited in the environment in such volume, constituency or manner as to cause an alteration in the environment’. Agribusiness operations produce a wide variety of organic and inorganic waste materials in solid, liquid, and gaseous forms as by-products of their food and fibre production. Inorganic waste products such as metals, wire, plastics, synthetic fibres and glass, are not suitable for organic waste-to-energy production and so are not the focus of this study.

Organic by-products from food and fibre production can vary widely depending on the nature of the agribusiness operation, but may include animal manure, hair, feathers, wool, hides, carcasses; treated and untreated timber; greenhouse gases (methane, carbon dioxide, nitrous oxide), cropping residues such as straw stubble, sugar cane bagasse, grain/seed screenings (hulls/husks, shells, stems, stalks and leaves); fruit and vegetable stems, skins, stones, pits and flesh; tree branches, leaves, seed cases, weeds, saw dust, wood shavings and other agroforestry residues; excess, unwanted and/or spoiled produce, stock feed; processing by-products such as process water, whey, milk, oils, nutrients and salts; and other chemicals contained in wash-down water, farm run-off, leaks, leachate and spray drift. These waste products may still have value in terms of their energy, nutrient and moisture content, and a range of processes have been successfully applied by farmers for thousands of years to utilise this value (Lopez-Real & Baptista, 1996).

The decisions made by agribusinesses concerning the management of their organic waste streams are influenced by a broad range of economic, social, and environmental variables and the consideration of these factors can be complex. Economic factors include the value and volumes of organic wastes produced; the existence and strength of local demand for organic wastes, waste storage and transport costs; the availability of suitable waste handling equipment and waste storage spaces and infrastructure; and the availability and cost of time and/or labour for handling, processing and/or transporting particular waste streams (Bluemling et al., 2013).

Environmental considerations on organic waste management may include local weather conditions; soil profile and ability of farmland to absorb additional nutrients and moisture; requirement for weed and/or pest control; agribusiness location and proximity to water courses, townships, neighbours, transport infrastructure and/or environmentally sensitive areas; local fire risk conditions, restrictions, environmental legislation and regulations (Birchall, 2008). Social factors related to waste management that may be considered include occupational health and safety issues; amenity and/or comfort of animals, employees, neighbours and local communities; stakeholder perceptions of, and attitudes towards, organic farm waste management practices (Ehlers, 2008; McCormick, 2010).

Many of these regional factors can vary greatly from farm to farm and from season to season. They are often specific to the type of agricultural production and processing and dependent on local regulatory, environmental and weather conditions.

Agribusiness operations such as dairies, livestock transport and saleyards, abattoirs, intensive approaches to animal production (such as sheep and cattle feedlots, pig and poultry sheds and aquaculture), fruit and vegetable production, cereal cropping and food processing plants can all generate large volumes of organic waste. Depending on the type of waste and local regulations, these wastes can be burned, buried, composted, dried/treated on-site or transported off-site for sale, treatment or disposal. Dried solid waste and diluted liquid waste can be spread/sprayed onto surrounding farmland to fertilise the soil and replenish some of the nutrients depleted by the farming of food and fibre (EPA Victoria, 2009). However, organic wastes cannot always be readily managed in such a way that is environmentally responsible and cost effective (Stegelin, 2010). Current organic waste management practices are substantial contributors to a range of serious environmental problems, such as climate change, soil acidification, freshwater and marine eutrophication (build-up of excessive nutrients), particulate pollution and fossil fuel depletion (De Vries et al., 2012; Steinfeld et al., 2006).

Increasingly, Australian agribusinesses are having to consider their operations and the emissions of greenhouse gases that result from their food and fibre production and processing practices (ABARES, 2023). The agriculture sector is responsible for about 15% of Australia’s greenhouse gas emissions (CSIRO, 2021). Most of these emissions (68%) are from digestive processes in ruminant livestock (known as enteric fermentation emissions, or enteric methane emissions), and almost 10% are from the management of animal wastes (manure and urine) (DISER, 2021).

With the agribusiness sector being a significant contributor to land, water and air pollution in Australia, waste management standards, industry guidelines and local environmental regulations are increasingly requiring farmers and food and fibre manufacturers to effectively manage and monitor their organic waste streams. A failure to do so risks significant environmental degradation (Mehta et al., 2016), financial costs associated with fines that may be applied and remediation works required, and a deterioration in their relationships with neighbouring communities and regulators. The focus of the following section is Australian agribusiness generation and consumption of energy.

1.6 Agribusiness and energy in Australia

The types of energy consumed by the agriculture sector in its production and processing of food and fibre can vary substantially depending on the type of agribusiness operation and its specific energy needs. Traditional approaches to agriculture typically rely on energy from humans and animals to provide the labour for many of the functions associated with the agricultural production and processing. For centuries, traditional farmers have also used renewable sources of energy, such as wind and running water, to pump water (windmills) and mill grain (waterwheels). However, the mechanisation of agriculture in many countries, particularly economically developed countries, has seen most of these traditional sources replaced by machines, reducing labour inputs to 1/100th of traditional agriculture approaches (Pimentel, 2019). These labour-saving machines are generally powered by energy from fossil fuels such as diesel and petrol, liquid petroleum gas (LPG) and natural gas, and coal/gas fired electricity. As a result, modern agricultural production and processing is now heavily reliant on fossil energy (FAO, 2017; Harchaoui & Chatzimpiros, 2018; Pimentel, 2019).

Agribusinesses can consume energy directly and indirectly. Direct energy consumption refers to the on-site use of energy for food and fibre production, transport and processing, and may include the use of liquid fuels to power trucks, tractors, harvesters and other farm vehicles and machinery; LPG and natural gas used to generate thermal energy (heaters/boilers); and electricity used to run electrical machinery and appliances, pumps, heaters/coolers, refrigerators/chillers and lighting (DISER, 2022). Indirect energy consumption describes the energy ‘embedded’ off-site, in the inputs used by agribusinesses. This consumption is part of agriculture supply chains, and the manufacture/production and transport of products and services used by agribusinesses. Agriculture inputs with substantial indirect energy embedded - generally fossil-based energy, include machinery, plant and equipment, fertilisers, herbicides and pesticides (Rokicki et al., 2021). Modern agriculture’s reliance on direct and indirect fossil energy inputs is seen as problematic from both economic and environmental perspectives (FAO, 2017; Iles, 2021). This is also the case in Australia, as agribusinesses are major consumers of energy, and energy costs have emerged as one of the main and fastest growing input costs for some Australian farmers (DISER, 2022). While Australian agriculture has focussed on improving resource efficiency and maximising production, there has been less emphasis on the application of alternative approaches (Iles, 2021; Santhanam-Martin et al., 2015).

1.7 Focus of the study

This study focuses on the engagement of Australian agribusiness with organic waste-to-energy systems and technologies, and the critical factors influencing their decision-making on investments in bioenergy. It researches the food and fibre producers and processors adopting organic waste-to-energy technologies and seeks to identify the drivers that have prompted their interest in incorporating these approaches into their agribusiness operations. This study also examines the key barriers impacting Australian agribusiness adoption of on-site waste-to-energy technologies and explores how these impact agribusiness transitions to the adoption of organic waste-to-energy systems.

1.8 Significance of the research

The contribution that bioenergy approaches can make towards more sustainable food and fibre production is substantial. There is potential for growth in the application of organic waste-to-energy technologies in the agribusiness sector and thus enhance Australia’s existing slow progress in developing its bioenergy capacity. To establish this growth potential there is a need for research examining why Australian agribusinesses do (and do not) adopt organic waste-to-energy technologies as an integral part of their waste management processes and energy profile. This study aims to address a gap in research exploring the engagement of Australian food and fibre producers with organic waste-to-energy systems and the drivers and barriers that impact their investment in bioenergy technologies. While a wealth of literature exists exploring bioenergy applications and potential development from mainly technological and/or environmental standpoints (Iakovou et al., 2010), the business of bioenergy and its relevance to the agribusiness sector has been overlooked (Jensen & Govindan, 2014; Sam et al., 2017).

This has also been the case in Australia, where numerous studies explore the state of bioenergy development, the theoretical potential for bioenergy generation in particular agriculture sub-sectors and/or the application of specific bioenergy technologies and feedstocks (Brinsmead et al., 2015; Crawford et al., 2016; Farine et al., 2012; Hamawand et al., 2016; Herr & Dunlop, 2011; Herr, O'Connell, Dunlop, et al., 2012; Herr, O'Connell, Farine, et al., 2012; Kingwell & Abadi, 2014; McCabe, 2016, 2020; McGrath et al., 2017; Mofijur et al., 2021; Ngugi et al., 2018; Puri et al., 2012; Rodriguez, 2011; Tait et al., 2021; Yan et al., 2020). Other studies analyse the possible positive and negative environmental impacts of increased bioenergy development in Australia (Dastjerdi et al., 2022; Dastjerdi et al., 2021; Grundy et al., 2016; Middelhoff et al., 2022; Zhao et al., 2015). While many of these studies provide some comment and analysis on the requirements for (and risks of) further development of bioenergy in Australia, few academic studies explore the drivers and barriers impacting bioenergy development by Australian farmers and processors of agricultural production (Mofijur et al., 2021; Tait et al., 2021; Wilkinson, 2011). In light of these gaps in the literature, this study provides a contribution to the overall body of research exploring the adoption of organic waste-to-energy technologies by Australian agribusiness.

The findings of this study also provide key industry stakeholders with an understanding of the transition processes of Australian agribusinesses engaging with bioenergy systems. Stakeholders such as agricultural producers, processors, supply chains, bioenergy and agriculture industry bodies, regional and rural communities and Government authorities all have an interest in this engagement and the transition of the agribusiness sector to sustainable production approaches. The primary significance of this research is the identification of the key drivers and barriers impacting this engagement. This research is also significant in its contribution to the broader understandings of CE and sustainability transitions in agriculture.

1.9 Organisation of the thesis

This thesis presents research exploring Australian agribusiness transitions to the adoption of organic waste-to-energy approaches and has been organised as follows. Chapter 2 provides a review of the literature relevant to this study's research question and sub-questions. This section begins with a broad overview of literature describing innovations theory and transition studies and how these apply to food and fibre production. The literature review also provides a summary of key themes from bioenergy studies and the factors affecting the adoption of organic waste-to-energy technologies in the agriculture sector.

Chapter 3 outlines the conceptual approach that underpins this research; a framework combining Multi-Level Perspective (MLP) (Geels, 2002, 2005a, 2010; Geels & Schot, 2007; Geels et al., 2017) and Social Practice Approach (SPA) (Hinrichs, 2014; Keller et al., 2022; Liedtke et al., 2017; Svennevik, 2022). This description also introduces a heuristic providing a visual representation of the drivers and barriers impacting the transition processes of agribusinesses adoption organic waste-to-energy technologies. Chapter 4 details the research methodology employed by this study. This section adopts the research 'onion' framework (Saunders et al., 2015) to identify and justify the methodological choices made in this study's multi-methods qualitative research design.

Chapter 5 details the key findings from the three stages of the research methodology. This includes data collected in Stage 1 of this study, on the state of agribusiness utilisation of bioenergy technologies for organic waste-to-energy generation, and the basic characteristics of the agribusiness types that have engaged with these approaches. The findings also synthesise the key themes to emerge from Stages 2 and 3, the qualitative interviews held with industry experts and agribusiness managers with experience with organic waste-to-energy systems. These themes are organised around their status as drivers encouraging organic waste-to-energy adoption or barriers to agribusiness transitions to these approaches.

The findings detailed in Chapter 5 are explored further in Chapter 6 of this thesis; the discussion chapter. This chapter analyses the key findings and discusses them in terms of the conceptual framework adopted by this study; a hybrid approach combining the MLP and SPA socio-technical transitions theories. The research findings are also discussed in the context of their relevance and insights for this study's research question and sub-questions.

Chapter 7 is the thesis's concluding chapter, which summarises the study's responses to the research questions, the significance of the key findings and the implications of the research. This chapter also identifies the study's methodological limitations and opportunities for future research.

1.10 Summary

This chapter provided an outline to this research. This included an overview of the study, its research objectives and the key questions it seeks to answer, and the significance of this research. Also, this chapter presented the key areas and concepts that feature in this thesis. The next chapter will expand on these concepts to provide a review of the literature relevant to this study.

2. Literature review

2.1 Introduction

This chapter provides a review of the literature relevant to the transition of Australian agribusinesses to more sustainable organic waste management and energy practices, in the context of their adoption of on-site organic waste-to-energy technologies. This literature review begins with an overview of the literature exploring the theory of innovation, transition pathways taken, and particularly transitions in agriculture. It will then explore bioenergy literature; the contexts in which this term is applied, and the scope of the key themes researched. Finally, literature exploring the organic waste-to-energy approaches applied in the agribusiness sector will be reviewed, with a specific focus on this study's research questions on the drivers and barriers to the adoption of on-site waste-to-energy technologies by Australian agribusiness.

2.2 Emergence of technological innovation theory

In making the transition from 'business as usual' waste management and energy practices to the adoption of innovative technologies, agribusinesses need to engage in a transformative process. Over the last 100 years, many evolutionary theories have been developed to describe the innovation pathways taken by businesses as they develop and adopt new technologies. Joseph A. Schumpeter, a key innovation researcher in the first half of the 20th century, was one of the first theorists to identify the critical role of innovation as a central driver of the economy (Gaziulusoy & Twomey, 2014; Greenacre et al., 2012; Žižlavský, 2013).

Many of the 20th century innovations theories describe the relationship between technology and the economy as being a linear innovation process (Gaziulusoy & Twomey, 2014; Godin, 2006; Rothwell, 1994). The linear models suggest businesses progress sequentially through innovation processes, entering the process at one end and exiting at the other, with some form of technological innovation; new products, new methods of production, new markets, new sources of raw materials, or new market structures (Schumpeter, 1934). Godin (2006, p. 658) identifies 16 Taxonomies of Innovation, published between 1920 and 1974, that feature very similar linear pathways. These models generally begin with research and invention of a new product or technology, which is then developed for production, before being distributed or diffused. These taxonomies are relatively simple and usually feature only minor differences in the sequence of the key phases identified.

2.3 Evolution of innovation process

In the period after the Second World War, innovation theories continued to develop, with Roy Rothwell identifying five generations (5G) in the evolution of innovation process (Rothwell, 1994). The five generations evolved over several decades, and while they became more complex and sophisticated, they still described a largely linear process.

First-generation

The first-generation literature spanned the 20 years following World War II and was characterised by 'technology push' innovation, which was driven by technology developers such as universities, government laboratories and research and development (R&D) sections of manufacturing companies. The commercialisation of technological change and scientific advances were 'generally perceived as a linear progression from scientific discovery, through technological development in firms, to the marketplace' (Rothwell, 1994, p. 7); Basic research ➔ Applied research ➔ Development ➔ (Production and) Diffusion (Godin, 2006; Greenacre et al., 2012). New technologies were developed by the inventers, further developed by researchers and manufacturers, and 'pushed' to the market, via businesses.

Second-generation

The second generation of the innovation process, from the mid-1960s to the early 1970s, was a variation on the first generation, but the dominant feature of these models was the emergence of market-pull as the main influence on this process, instead of technology push (Godin, 2006; Greenacre et al., 2012; Rothwell, 1994; Schmookler, 1966). In the context of innovation process and technological change, market-pull, also known as need-pull or demand-pull, refers to an innovation initiated by a need or demand from the market. This shift resulted from an increased focus on the impact of marketing, increased competition for market share from large and highly efficient companies, and a marked shift in the perception of demand-side factors. That is, the market was recognised as not just being the passive consumer and beneficiary of technological change, but it could also be an important source of ideas to guide the direction of R&D activities (Rothwell, 1994).

Third-generation

Innovation processes continued to evolve through the 1970s and early 1980s; a period Rothwell (1994) identified as the third generation of innovation process. The process continued to be linear and sequential, but featured a meeting of technical capabilities and market need. Rothwell (1985, p. 50) called this coupling a 'linking together the various in-house functions and linking the firm to the broader scientific and technological community and to the marketplace'. The development of interactions between technology developers, businesses and the market via feedback loops, enabled businesses to better tailor innovation to meet market need. Businesses could also increase successful innovation, reduce 'wasteful failures', and reduce the costs of innovation (Rothwell, 1994). While these feedback loops did provide communication between the actors, this was still a linear model with limited functional integration (Du Preez & Louw, 2008).

Fourth-generation

Greater integration between actors did emerge with the rise of the fourth generation of the innovation process, from the early 1980s to the early 1990s. The main features of this evolution were increased integration between actors and the introduction of substantial overlap of various development functions, which operated in parallel, rather than in sequence (Du Preez & Louw, 2008; Rothwell, 1994; Žižlavský, 2013). Improved communication between actors and concurrent development of new technologies and products, enabled innovators to reduce costs and improve efficiency, as well as reducing development time and responding more quickly to market demands (Rothwell, 1994).

Fifth-generation

The final generation in Rothwell's 5G Innovation Process began in the early 1990s and was characterised by its emphasis on networking and efficiency, which was supported by an increase in computer-assisted means (Du Preez & Louw, 2008; Rothwell, 1994; Žižlavský, 2013). The further integration of actors into the innovation process - a feature of the previous generation, continued and accelerated in the 1990s, with the rapid and widespread adoption of information and communications technologies (ICT), computers and the Internet. The speed and efficiency with which a business could take technological innovations to market became an increasingly important factor in a company's competitiveness at this time (Rothwell, 1994; Žižlavský, 2013).

The intensive utilisation of ICT and electronically supported product development (such as computer-aided design) enabled advanced businesses to support and speed-up innovation (Rothwell, 1994; Žižlavský, 2013). Similarly, advances in ICT helped further enhance systems integration and networking (SIN) with internal and external actors and supported the development of strategic alliances (Rothwell, 1994; Žižlavský, 2013). This also contributed to 'lean innovation'; an increase in efficiency in terms of cost, time and other resources (Rothwell, 1994).

Rothwell's description of the five generations of the innovation process provides an overview of the evolution of innovation theory in the fifty years following the Second World War. The traditional progressions featured in Rothwell's summary are characterised as being linear processes for the development of new products and services, pushed by inventors and/or product developers or pulled by consumers and the market. These approaches provided the foundations for the emergence of a new strand in innovation studies in the 1990s, which expanded its scope of analysis from the development of new products and the organisations that develop them, to the systems and networks of actors involved in the development, diffusion and use of technological innovation (Darnhofer, 2015; Geels, 2004; Lachman, 2013). This systems approach to innovation represents '… a more nuanced and richer picture, with a wider set of implications for those hoping to assist, shape or direct the innovation process and system change' (Gaziulusoy & Twomey, 2014, p. 1). Amongst these implications are global concerns about the declining health of the natural environment and the need for societies to transition to a more sustainable footing (Lachman, 2013; Rothwell, 1994; WCED, 1987; Žižlavský, 2013). As a result, the term 'transition' has become synonymous with systems innovation (Gaziulusoy & Twomey, 2014) and transition studies has emerged as an important field of research in innovation literature.

2.4 Transition studies

Serious environmental challenges such as climate change, biodiversity loss and resource depletion have prompted calls for major changes in the way our societies and economies function (European Environment Agency, 2018; Geels, 2010; Lachman, 2013). To develop solutions to sustainability challenges, our societies need to 'fundamentally restructure systems of consumption and production by initiating so-called sustainability transitions' (Farla et al., 2012, p. 991). The concept of 'transitions' has featured in several fields of research and was originally used to describe changes in biology and population demographics (Davis, 1945; Nesari et al., 2022; Rotmans et al., 2001). More recently, transitions has also been used in the context of social, economic and environmental sustainability, and is defined as 'a gradual, continuous process of change where the structural character of a society (or a complex sub-system of society) transforms' (Rotmans et al., 2001, p. 16). The primary objective of transitions research is to conceptualise and explain how radical transformations can be achieved in the way our societies operate (Köhler et al., 2019).

Sustainability transitions refer to systemic change of technologies so they are environmentally non-destructive; the 'long-term, multi-dimensional and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption' (Markard et al., 2012, p. 956). Sustainability transitions emerged as a major focus of innovations theory in the mid-1990s, as researchers tried to understand the theoretical foundations of transitions to a sustainable future (Farla et al., 2012; Lachman, 2013). This was considered a new field of innovations research, as sustainability transitions were unprecedented in human history due to the scale and complexity of the transitions needed, the ubiquitous nature of unsustainable approaches embedded in society's systems (Rip & Kemp, 1998), and the persistence of major environmental problems such as climate change (Köhler et al., 2019; Lachman, 2013). It was also considered that historical transition processes may not be suited to achieving sustainability transitions, and so new approaches would be required (Kemp & van Lente, 2011; Köhler et al., 2019).

The first papers exploring sustainability transitions appeared in the 1990s and sustainability transitions research developed substantially through the 2000s, as did the community of scholars publishing in this field (El Bilali, 2019b; Farla et al., 2012; Markard et al., 2012). Initially, this research was fragmented and it was noted that environmental innovation and transition processes were not addressed by a specialised academic journal (van den Bergh et al., 2011). However, the field of transitions research expanded rapidly after 2005 (El Bilali, 2019b; Markard et al., 2012; Nesari et al., 2022), with the development of several prominent frameworks to describe society's transition to a sustainable future (Farla et al., 2012; Geels, 2004) and the launch of a new journal "Environmental Innovation and Societal Transitions" (van den Bergh et al., 2011). This expansion also saw a strong increase in publications on transition studies (Markard et al., 2012; Nesari et al., 2022); and the establishment of the Sustainable Transitions Research Network (STRN) to support the maturation of this field of research (El Bilali, 2019b; Farla et al., 2012; Markard, 2020).

Early sustainability transitions publications were dominated by researchers based in Europe, with authors such as Frank Geels, Johan Schot, M.P. Hekkert, Bernhard Truffer, Jochen Markard and Derk Loorbach (Netherlands); Adrian Smith (United Kingdom); and Rob Raven (Australia) particularly influential (Nesari et al., 2022). Over the last 10 years, sustainability transitions literature has grown substantially in volume, breadth (geographic and thematic) and depth (El Bilali, 2019a; Nesari et al., 2022; STRN, 2021). While the scholars previously mentioned have continued to lead the development of this field, they have been joined by the next generation of researchers such as Niki Frantzeskaki (Netherlands/Australia); and Florian Kern and Benjamin Sovacool (United Kingdom) (Nesari et al., 2022). In this period, the research leadership provided by the Sustainability Transitions Research Network (STRN) also grew, with its membership expanding to more than 3000 scholars (STRN, 2021) and the volume of sustainability transitions-related journal articles and citations increasing substantially (Nesari et al., 2022).

Sustainability transitions represent radical systems changes that address the serious nature of environmental sustainability challenges (European Environment Agency, 2018; Geels, 2010; Köhler et al., 2019; Raven, 2007; Rotmans et al., 2001). According to Ika Darnhofer (2015, p. 23);

> To initiate a 'transition to sustainability' an established niche would need to seek radical change. This is change that:
>
> - affects a whole sector, a whole value chain, or a whole territory;
> - leads to a new alignment of actors, networks, or regimes;
> - is based on rules and values that are clearly distinct from those of the regime;
> - addresses a sustainability issue that is clearly defined by the actors involved in the emerging transition.

While sustainability transitions are purposeful, purposive and intended (Farla et al., 2012), they are complex, difficult, contested and uncertain; and cannot be ‘designed, blueprinted or imposed from the outside … they cannot be managed in a controlling sense. Rather, transitions can be steered, triggered, and stimulated’ (Lachman, 2013, p. 270). Sustainability transitions are not so much planned and implemented, but instead evolve over time (Weber et al., 2020). Sustainability transitions have profound impacts on society’s technological, material, organisational, institutional, political, economic, and socio-cultural systems (European Environment Agency, 2018; Geels et al., 2020; Lachman, 2013; Markard et al., 2012); as well as major implications for multiple socio-technical systems.

Socio-technical systems describe the social and technical systems featured in a society; the ‘(networks of) actors (individuals, firms, and other organizations, collective actors) and institutions (societal and technical norms, regulations, standards of good practice), as well as material artifacts and knowledge’ (Markard et al., 2012, p. 956). Socio-technical systems are ‘complex, multifunctional systems combining diverse elements which evolve interdependently’ (European Environment Agency, 2018, p. 10), such as energy supply, water supply, transport and agro-food systems. Given the interdependence of these socio-technical systems, sustainability transitions require the cooperation of a range of actors from across a range of different groups in society (Geels, 2010; Lachman, 2013; Markard et al., 2012).

The complexity of these systems and networks of actors is captured in broad focus of the STRN research priorities. STRN has provided substantial leadership on transitions research, adopting research on the following key themes (El Bilali, 2019b; Köhler et al., 2019): Understanding transitions; Politics and power in transitions; Governing transitions; Civil society, culture, and social movements in transitions; Business and industries in sustainability transitions; Transitions in practice and everyday life; Geography of transitions: Spaces, scales, and places; Ethical aspects of transitions: Distribution, justice, and poverty; Methodologies for transitions research.

These themes represent the breadth of the sustainability transitions field of research and point to the need for interdisciplinary approaches to explore these priorities. This is relevant to this study, as it provides the theoretical foundation underpinning this thesis's exploration of a sustainability transition occurring in the agribusiness sector; the adoption of organic waste-to-energy technologies by Australian agribusinesses.

2.5 Socio-technical transitions models

Over the last 25 years, several heuristic frameworks have been developed to describe socio-technical transitions, with the most notable being; Transition Management (TM), Strategic Niche Management (SNM), Technological Innovation Systems (TIS), Social Practice Approach (SPA) and Mutli-Level Perspective (MLP) (Barquete et al., 2022; El Bilali, 2019a; Lachman, 2013; Markard et al., 2012). Some of these frameworks, such as SNM, TIS and MLP, are closely related in their theoretical origins and conceptual features, but have developed into their own independent approaches for analysing radical technological change (Markard & Truffer, 2008). The MLP approach, developed by Rip and Kemp (1998) and refined by Geels and Schot (Geels, 2002; Geels & Schot, 2007), has emerged as the dominant framework to explain the dynamics of transition processes (European Environment Agency, 2018; Sovacool & Hess, 2017), although this dominance has been questioned by some proponents of other socio-technical transition models (Markard & Truffer, 2008; Shove & Walker, 2010). The following section describes the MLP framework and its application to explore sustainability transitions.

2.5.1 Multi-Level Perspective

MLP, and sustainability transition studies more broadly, rely heavily on case study analyses to explore transformational processes (El Bilali, 2018; Hansen et al., 2019; Köhler et al., 2019). Studies of sustainability transitions frequently identify and analyse the drivers and barriers that can affect transition processes; the critical factors 'that can enhance or hinder the desired development' (Barquete et al., 2022, p. 1). The MLP heuristic developed by Frank Geels is reproduced as Figure 2.1 to assist the explanation that follows. This MLP explains many historical socio-technical transitions in transport and energy systems (Arranz, 2017); such as mobility (Geels, 2005a; Nesari et al., 2022), energy and water supply, sanitation and food production (Geels, 2019; Miremadi, 2021; Smith et al., 2010). More recently, MLP has been applied to explore contemporary sustainability transitions, such as the transition to low-carbon electricity generation (Geels et al., 2020); biomass district heating (Dzebo & Nykvist, 2017), electric vehicles (Berkeley et al., 2017), sustainable food production (Bui et al., 2016; Deviney et al., 2023; El Bilali, 2019a) and the transition away from the use of single-use plastic bags and packaging (Little et al., 2019).

MLP draws on evolutionary economics and sociology of technology to describe the nature of and timing of interactions of actors across three socio-technical regime levels; micro (niche), meso (regime) and macro (landscape) levels (Geels, 2002, 2004, 2010; Geels & Schot, 2007; Lachman, 2013; Raven, 2007; Sovacool & Hess, 2017). The niche level is the 'locus of radical innovation' (Geels, 2005a, p. 450); a safe or protected space at a micro or local level, in which innovative activity occurs and radical innovations are developed, nurtured and improved (Geels, 2010; Geels & Schot, 2007; Markard et al., 2012; Markard & Truffer, 2008; Raven, 2007; Rip & Kemp, 1998). These 'incubation labs' or 'breeding spaces' include university and hospital laboratories, technology manufacturer R&D (research and development) departments, business start-up incubators and workshops in which small networks of actors are able to design, experiment, develop and refine their niche innovations in an environment protected from dominant rules of the socio-technical regime, such as time or financial constraints, market forces, consumer preferences and competition (European Environment Agency, 2018; Geels, 2004; Lachman, 2013).

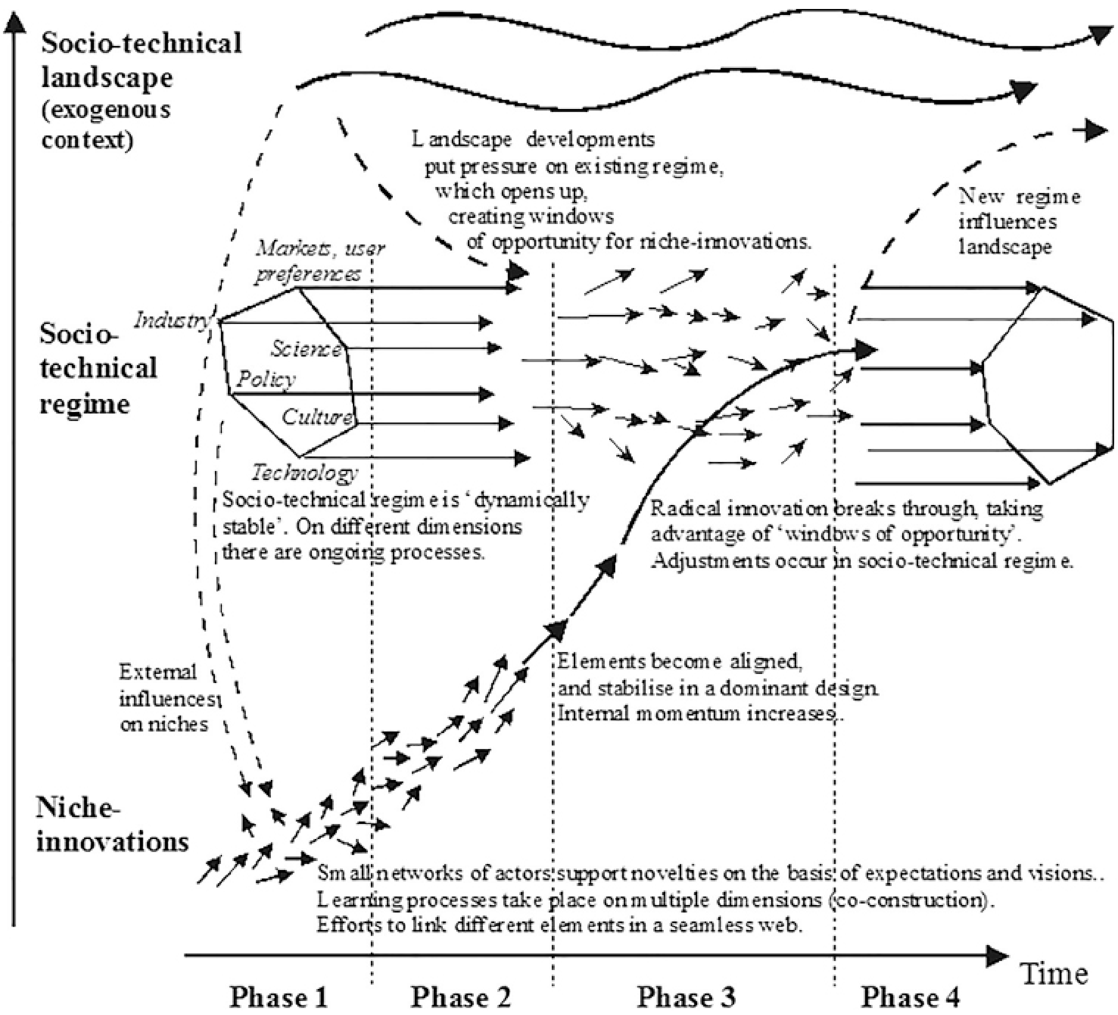


Figure 2.1 Multi-Level Perspective on Socio-Technical Transitions

Source: Geels et al. (2017, p. 466)

MLP's meso (regional or national) level is the socio-technical regime, into which is embedded the incumbent and dominant actors and institutions, networks and infrastructures, technologies and products, rules and regulations, policies and policy-makers, norms and existing user practices; which form the selection environment in which systems function (European Environment Agency, 2018; Geels, 2004, 2005a; Lachman, 2013; Markard & Truffer, 2008). Interactions between the niche and regime levels are critical in sustainability transitions, where sustainable niche innovations may transition into established regimes to replace less sustainable approaches. However, the actors and organisations established in regimes are often indifferent or resistant to major system changes (Geels, 2004; Lachman, 2013; Nesari et al., 2022). This can have the effect of locking-in established modes of production and consumption, maintaining the stability of the existing sociotechnical regime and making the diffusion of radical niche innovations difficult (European Environment Agency, 2018; Geels et al., 2020; Lachman, 2013; Markard & Truffer, 2008). Stable regimes tend to block niche innovations, which can have difficulty attracting exposure and funding, but as regimes become unstable, niche innovations can experience greater interest and fewer barriers to the regime (Geels, 2005a; Markard & Truffer, 2008).

The final level of the Multi-Level Perspective (MLP) is the macro level or socio-technical landscape, which sits above both niche and regime levels. The socio-technical landscape describes the high-level, exogenous environment that affects socio-technical transitions, over which regime actors have little or no influence (Geels, 2005a; Geels et al., 2017; Little et al., 2019); the global-scale factors that can impact the regime and influence the demand for or direction of transition processes and niche innovations. This landscape includes slow-changing global trends (e.g. cultural and demographic shifts, political and macro-economic trends, climate change) and sudden shocks (such as geopolitical upheaval and wars; economic crises; humanitarian emergencies and disease/pandemics; environmental crises and natural disasters/events) (Geels, 2019).

Socio-technical transitions are enabled by top-down and bottom-up interactions across the three levels of the Multi-Level Perspective. Geels et al. (2017, pp. 465-466), building on the work of Geels and Schot (2007), identify four phases in the MLP on socio-technical transitions (see Figure 2.1):

> Phase 1 Radical innovations are developed in niches, on the periphery of established regimes. This is an uncertain and experimental phase, in which innovators develop new designs, approaches and products, but many will fail.

Phase 2 An innovation enters small market niches, with access to resources for further development and refinement. A dominant design emerges, along with the stabilisation of expectations and rules.

Phase 3 The radical innovation moves from the innovation niche to begin to compete ‘head-on’ with the established actors and structures of the regime. This phase is dependent on at least one of two factors; firstly, the existence of key drivers such as the innovation having attractive price/performance benefits, complementary technologies and infrastructures, and supportive attitudes from actors and organisations in the regime. Alternatively, a window of opportunity for niche innovations can be created if the established regime becomes destabilised because of problems from within the regime, or pressures from the landscape.

Phase 4 A socio-technical transition is completed by the widespread adoption of the innovation, and radical changes to the regime itself. This new regime completely replaces the incumbent regime and becomes the new normal.

Since its emergence in the late 1990s, there has been considerable debate on the strengths and weaknesses of the MLP heuristic. It is generally agreed MLP can be an effective tool for the analysis of technical innovation-based transitions, but is less suited to social innovation processes (El Bilali, 2019a), with the main criticism of MLP being its weakness in engaging with human agency (El Bilali, 2018; Hinrichs, 2014). Smith et al. (2010) posit that politics, power and hegemony could be incorporated more centrally into MLP analysis. Shove and Walker (2010) suggest MLP is particularly powerful in understanding the structure of historical transitions, but dynamic processes are not sufficiently explored and MLP ‘comes a bit unstuck’ when attempting to guide or propose future transition processes (Gordon Walker, in Sovacool & Hess, 2017, p. 711).

Smith et al. (2005) also discuss the MLP's emphasis on bottom-up niche-driven innovation, arguing incremental reforms in the regime can achieve radical transitions over time, and Hommels et al. (2007) question the need for and desirability of a protected environment for the nurturing of niche innovations. Steinhilber et al. (2013, p. 532) argue that socio-technical transitions theory has neglected the diverse evolutionary pathways of embedded regimes, and 'perhaps those concerned with the management of socio-technical transitions need to focus more on the dismantling of the existing regime rather than the nurturing of a new one'. In 2019, Franks Geels published an article dedicated to responding to these and other criticisms of MLP (Geels, 2019) and the exploration of socio-technical transitions continues to be an important and growing field of research.

In more recent studies, scholars have developed hybrid approaches that are based on MLP but include features of other transition models, including SNM and TM (El Bilali, 2018, 2019a; Melchior & Newig, 2021). Given MLP's perceived weaknesses with human agency and the role of civil society in sustainability transitions, researchers are increasingly combining MLP with agency-oriented transition frameworks, such as Social Practice Approach (SPA) (El Bilali, 2018). The SPA framework is explained further in the following section.

2.5.2 Social Practice Approach

SPA, also known as social practice theory (SPT), is focussed primarily on analysing people's everyday practices (Hinrichs, 2014) and has been a useful framework for theorists exploring sustainable consumption and production, combining human agency (consumers) and social structures (provision systems) (El Bilali, 2018; Liu et al., 2016; Svennevik, 2022). Building on the work of social sciences researchers such as Giddens and Bourdieu (Halkier et al., 2011; Maller, 2015), Andreas Reckwitz (2002) and Theodore Schatzki (Schatzki, 1996) led the development of a theory of social practices in the late 1990s and early 2000s. Emerging 'as a range of interpretations of social practice theory' (Keller et al., 2022, p. 16) , social practice approaches seek to overcome the dualisms of agency at a structural level and agency at an individual level (Keller et al., 2022; Köhler et al., 2019).

For SPA, the focus is not on the individual, nor on socio-technical systems, but instead, practices are the units of analysis (Spaargaren, 2011; Spaargaren et al., 2013; Spurling et al., 2013).Practices are shared behavioural routines (Spaargaren, 2011); established collections of 'doings and sayings' (Warde, 2005); 'commonly shared routinised way[s] of performing something' (Svennevik, 2022, p. 164), and 'their performance entails the reproduction of cultural meanings, socially learnt skills and common tools, technologies and products' (Spurling et al., 2013, p. 4). Shove et al. (2012) refer to practices as being comprised of these three elements; competences, materials and meanings.

Competences refers to skills and know-how; materials are things, technologies and physical objects; and meanings are symbolic ideas, aspirations and understandings (Huttunen & Oosterveer, 2017; Laakso et al., 2021; Shove et al., 2012). Examples of elements in agribusiness feature in research by Huttunen and Oosterveer (2017, p. 193), in which farmer fertiliser application practices are analysed, The authors identify a typical meaning as being a farmer's understanding of 'good growth of plants'. Materials relevant to this practice include the fertiliser products, machinery and fields/lands on which plants are grown and fertilisers are applied; and competences include the knowledge and skills to know what type of fertiliser to apply, and when and how it should be applied. For reconfiguration of practices, change is required in these elements (Laakso et al., 2021), and it is through analysis of interactions of these elements, researchers can observe differences and changes in the same practice (Huttunen & Oosterveer, 2017).

SPA has been used by scholars in many countries to explore social practices across a range of research topics, including food, energy, housing, transport, and urban planning (Keller et al., 2022). Habits and routines that consume resources are the focus of many studies, with everyday activities such as shopping, cooking, showering, commuting, washing dishes/clothes, and home heating/cooling being of particular interest to researchers. These studies seek to recognise and explain patterns of resource consumption and identify opportunities for interventions for sustainability transitions (El Bilali, 2018; Köhler et al., 2019; Paddock, 2015).

In Australia, SPA has been applied to a similar range of sustainability transitions as studies from abroad, exploring consumption habits and routines associated with urban planning and construction (Binder & Boldero, 2012), energy smart homes (Strengers, 2012; Strengers & Maller, 2011; Strengers et al., 2019), and household consumption practices (Maller & Strengers, 2018). In addition to the exploration of sustainability transitions to reduce the resource intensity of social practices, SPA has also been applied in Australia to analyse a range of public health issues, such as the dynamics of alcohol consumption (Supski et al., 2017; Wright et al., 2022), the oral health of pre-school children (Durey et al., 2021), HIV prevention practices in vulnerable communities (Kippax et al., 2013), injecting drug use (Schroeder et al., 2022), the use of e-cigarettes, or vaping (Keane et al., 2017), and general health and wellbeing research approaches (Maller, 2015).

Some of the early research into social practices in agricultural contexts explored their role in supporting innovation (Engel, 1995), and more recent applications of SPA in agriculture have centred on food consumption; especially consumer practices concerning the production, provision, purchase, storage, preparation, consumption and/or disposal of food (El Bilali, 2018). This approach includes many transition studies exploring alternative agriculture approaches (Balázs et al., 2016; Blättel-Mink et al., 2017; Cohen & Ilieva, 2015; Crivits & Paredis, 2013; Jansma & Wertheim-Heck, 2021; Kontothanasis, 2017; Poulsen, 2017); renewable energy generation in agriculture (Pascaris et al., 2020); sustainable application of fertilisers (Huttunen & Oosterveer, 2017); sustainable use of pesticides (Aniah et al., 2021; Asmare et al., 2022; Mengistie et al., 2017); and climate change adaptation (Crane et al., 2011).

2.5.3 Combining MLP and SPA

The combination of MLP and SPA has been identified as a particularly useful pairing (Hargreaves et al., 2013; Hinrichs, 2014; Keller et al., 2022; Svennevik, 2022), that when 'Taken together, these approaches offer different and useful ways to think about the dynamics, durability and significance of innovations in food and agriculture, and the part they play in transitions to sustainability' (Hinrichs, 2014, p. 143). MLP and SPA are seen as being complementary approaches that can provide more complex understandings of sustainability transitions, to go beyond individual behaviour change and technological change (Keller et al., 2022).

One of the key strengths of combining SPA and MLP is its potential to provide greater scope to analyses. In their review of 51 papers using combined SPA and MLP approaches, Keller et al. (2022, p. 20) identify:

> … the two approaches are most often combined in sustainability and consumption studies in order to zoom in to the level of mundane daily activities through SPA and zoom out to analyse the bigger picture with a bird's eye view through the MLP.

Zooming in with SPA provides a close-up, granular view of mundane practices and how they unfold; while zooming out with MLP provides a broader view of systems change (Keller et al., 2022)

This study utilises this hybrid approach partnering MLP and SPA to explore socio-technical transitions in the agribusiness sector, with a focus on the adoption of organic waste-to-energy technologies by Australian food and fibre producers and processors. The bottom-up niche-driven technology in waste-to-energy and the social practices surrounding such technology is appropriate from which to develop a framework of analysis for agribusiness transition.

2.6 Socio-technical transitions and agribusiness

Given the contribution of food and fibre production to major environmental problems, the agro-food sector has been identified as a key area for socio-technical transitions (Bui et al., 2016; European Environment Agency, 2018; Gaziulusoy & Twomey, 2014; Geels, 2019; Markard et al., 2012; Marsden, 2013; Melchior & Newig, 2021; Santhanam-Martin et al., 2015), but the achievement of significant change in this area is yet to be seen (Belmin, Meynard, et al., 2018; Darnhofer, 2015). The field of research exploring sustainability transitions in agro-food systems is still in its infancy and largely ill-defined, with some scholars suggesting agro-food sustainability transitions have been overlooked by the literature (El Bilali, 2018, 2019b). The volume of research exploring sustainability transitions in the agro-food sector does lag that of papers exploring energy transitions (electricity generation and transport) (Arranz, 2017; Markard et al., 2012). However, there is still a significant body of research with a focus on transitions in the agro-food sector and this is particularly the case when focussing on rural development in Europe (Darnhofer, 2015).

Research publications with a focus on the field of socio-technical transitions in agriculture increased steadily from 2010, and then experienced substantial growth after 2016, with most of the studies having a regional focus (on one or more countries), and most of them analysing the agricultural systems of European or North American countries (El Bilali, 2018; Köhler et al., 2019; Melchior & Newig, 2021; Stræte et al., 2022; Weber et al., 2020). The north-south divide is evident in sustainability transition studies, with substantial differences in approaches and impacts of food and fibre production in mainly northern hemisphere countries where industrialised agricultural systems are widely used, as opposed to mainly southern hemisphere countries where traditional farming practices have endured (El Bilali, 2019b; Melchior & Newig, 2021).

Since 2016, several comprehensive and systematic reviews of agro-food sustainability transitions have been published, including studies by Bui et al. (2016), El Bilali (2018, 2019a, 2019b), Köhler et al. (2019), Weber et al. (2020), de Boon et al. (2021), and Melchior and Newig (2021). These reviews identify MLP as the main framework used to analyse sustainability transitions in agro-food systems. Criticisms of MLP around its weaknesses involving human agency also apply to its exploration of food and fibre production (Darnhofer, 2015). Much of the research focus has been on the role of technical innovations in agriculture, while ‘soft factors’ such as human agency, consumer preferences, beliefs and power structures have received less attention (Darnhofer, 2015; El Bilali, 2019a; Elzen et al., 2004). El Bilali (2019b) also contends that while the literature focusses on transition management and sustainable consumption, the roles of geography, civil society, industries and businesses in transitions are largely ignored.

Several studies have (pragmatically) modified the MLP framework and its application, or complemented this framework with other transition approaches, to adapt to agro-food systems; for example, Bui et al. (2016), Hassink et al. (2013), Keller et al. (2022), Hargreaves et al. (2013), Crivits and Paredis (2013), Pitt and Jones (2016), Belmin, Casabianca, et al. (2018), and Diaz et al. (2013). There is substantial support for the combination of MLP with other approaches and El Bilali and Probst (2017, p. 30) argue that to better adapt sustainability transitions frameworks to agro-food systems, further integration is needed ‘to refine and test the framework in different contexts in industrialized food systems and those of the Global South’. This is an important consideration for this research project, which aims to provide practical insights into the sustainability transitions in the Australian agro-food sector.

Much of the literature exploring socio-technical transitions in the agro-food sector has featured case study analyses of specific technical and/or social transformations in specific locales (Belmin, Meynard, et al., 2018; El Bilali, 2019a, 2019b; Minas, 2019; Stræte et al., 2022), but ‘very few papers explicitly aim to contribute to the conceptual literature on sustainability transitions’ (Melchior & Newig, 2021, p. 528). In their review of 153 papers examining sustainability transitions in agriculture literature, Melchior and

Newig (2021) describe two main perspectives in this research field; papers that analyse existing agricultural systems and practices and identify and/or describe factors contributing to the lock-in of these practices; and papers that explore potential transition pathways.

The development of local niche innovations and approaches for elevating these to the regime, rather than regime change itself, are significant (Darnhofer, 2015; de Boon et al., 2021; Melchior & Newig, 2021). These studies identify seven main themes; application of socio-technical transitions theory; governance and regulation of transitions, knowledge and learning; practical strategies to reduce the environmental footprint of agricultural systems; urbanisation, urban food and fibre production and local food networks; the role of agricultural businesses; and the role of gender (Melchior & Newig, 2021).

A review study of food systems change literature (Weber et al., 2020) identifies five distinct clusters in the research themes/approaches featured: alternative food movements, sustainable diets, sustainable agriculture, healthy and diverse societies, and food as commons. In this analysis of more than 200 peer-reviewed papers, a framework explorers each cluster's sustainability problems and vision for sustainable food systems; possible strategies for change towards sustainability; and their spheres of interaction (practical, political, or personal). From this analysis, four key components for change in food systems are identified by Weber et al. (2020, p. 12. Emphasis in original):

- *Political action* to support inclusive and participatory governance structures that enable citizen consumers, empower (small-scale) farmers, and allow for an active role of grassroots movements.
- *Close collaboration* of stakeholders in food systems (consumers, farmers, politics, industry, NGOs, researchers) in new networks and platforms.

- *Education* to support consumers in adopting sustainable consumption behaviour, to help farmers in adopting diversified farming practices, and to inform policy makers how to advance healthy diets.
- *A deep value shift* regarding food and food systems informing actions.

Weber et al. (2020) confirm that research on sustainable food systems is a relatively young field and with most of the articles reviewed published in 2016 or later, and the four key components stressing the importance of social processes. The study also indicates researchers may have heeded earlier calls for greater emphasis on the social aspects of sustainability transitions in agro-food systems (Weber et al., 2020). The authors found considerable overlap exists between their defined agro-food clusters and that each cluster features promising strategies for transformational change, but also suggest greater integration and interconnectedness of the clusters (as well as the spheres) may help accelerate progress towards sustainable food and fibre systems. In the following section, literature on applications of two prominent transitions frameworks, MLP and SPA, are reviewed. The focus of this section is on the application of these approaches to Australian transitions, and those in Australian agriculture in particular.

2.7 MLP & SPA in Australia & Australian agriculture

The publication of MLP literature is led by researchers from the United Kingdom, the Netherlands and Germany, but the popularity of MLP has also extended to Australia, with Australian scholars frequently collaborating with researchers from other countries on MLP-related studies (Wang et al., 2022). The MLP framework has also been applied to explore transitions in the Australian context and, as is the case in other countries, energy transitions form a substantial proportion of these studies.

MLP applications exploring Australian transitions to low-carbon energy systems include research focussing on transitions to solar energy systems (Mathur et al., 2023), rooftop photo-voltaic (PV) energy systems (Horne, 2018; Wilkinson et al., 2021; Wilkinson &

Morrison, 2019), effective product stewardship of PV panels (Salim et al., 2021), electric vehicles and vehicle-to-grid approaches (Lucas-Healey et al., 2022) and peer-to-peer energy markets (Wilkinson, Hojckova, et al., 2020); and smart-grid technologies (Lovell et al., 2023). Other studies take a wider view of Australian energy systems transitions, applying MLP to transitions of Australia's energy systems (Cheung, 2022; Jehling et al., 2019; Wilkinson, Davidson, et al., 2020); electricity demand management (Chandrashekeran, 2016; Quezada et al., 2014); closure of coal-fired power stations (Wainstein & Bumpus, 2016); climate and energy policies (Warren et al., 2016) and the role of the finance sector in supporting low-carbon niche technologies (Geddes & Schmidt, 2020).

Other applications of MLP in the Australian context focus on a range of sustainability transitions, including analyses of the transitions of the Australian manufacturing industry (Skellern et al., 2017) and metals sector (Jackson et al., 2014) towards circular economy models, and the construction sector's transition to the use of more sustainable steel in Australian buildings (Santos & Lane, 2017). MLP has also been applied to areas concerning Australia's urban development, exploring the role of design in transition projects (Gaziulusoy & Ryan, 2017) and sustainability governance (Moloney et al., 2018); strategic spatial planning, urban transition and housing (Doyon, 2018; Horne, 2018; Larbi, 2018; Moloney & Horne, 2015; Moore et al., 2014; Morrissey et al., 2018; Newton, 2018; Smoleniec et al., 2017); and sustainable management of urban water resources (Fuenfschilling & Truffer, 2014; Quezada et al., 2016) and marine resources (Kelly et al., 2018).

Literature exploring the MLP framework's application to Australian transitions is dominated by research on energy and urban development themes. No Australian MLP studies focus on transitions to the adoption of bioenergy technologies. Several papers mention waste, including waste from agriculture, in the context of recycling and transition to circular economy models (Jackson et al., 2014; Mathur et al., 2023; Melles, 2021;

Santos & Lane, 2017), but a gap exists in Australian transitions literature concerning transitions to bioenergy and organic waste-to-energy approaches.

Another area that appears under-researched is the application of MLP to sustainability transitions in the Australian agriculture industry. Academic papers applying MLP to Australian agriculture transitions are limited to fewer than ten studies, but from this small group of papers, two main approaches are apparent. The first is the application of MLP with a narrow focus, to analyse specific technologies, approaches or developments in Australian farming. These studies include analyses of the privatisation of extension services on Agricultural Innovation Systems (AIS) (Paschen et al., 2017), the digitalisation of AIS (Fielke et al., 2019) and the adoption of Smart Farming and Big Data approaches in the grains industry (Jakku et al., 2019; Klerkx et al., 2019).

The second theme has a broader focus on Australia's agriculture systems and their ability to transition to sustainable approaches, such as agroecology (Iles, 2021). Insights from Iles (2021) and Santhanam-Martin et al. (2015) are particularly relevant to this research project. Santhanam-Martin et al. (2015, p. 207) identify Australia's food and fibre production as being dominated by a 'productivist trajectory in landscape change'. Approaches to landscape development are large-scale, input-intensive, specialised and yield-maximising, but are also regarded as being 'unsustainable' due to negative impacts on the natural environment and rural communities (Santhanam-Martin et al., 2015). The authors recognise the role of communities in agricultural landscapes and explore the concepts of place-making and 'community sustainability' as approaches for sustainability transitions in agriculture. The authors' application of MLP to analyse transitions in a dairy farming community in the Australian state of Victoria, confirms that 'the productivist agricultural development trajectory is embedded in individual and collective farming identities', which remain strong, although under pressure (Santhanam-Martin et al., 2015, p. 215).

Interestingly, this research also identifies a mismatch in understandings of sustainability, with academics and activists viewing productivist agriculture as being fundamentally unsustainable, yet 'it nevertheless continues to be viewed positively by community members and policy-makers alike in discussions about community sustainability (Santhanam-Martin et al., 2015, p. 216). The authors suggest this tension is a barrier to reimagining and creating alternative agricultural futures, and as a result, sustainability transitions in agriculture are likely to continue to develop incrementally.

In his article 'Can Australia transition to an agroecological future?', Iles (2021, p. 3 & 34) expands on Australia's productivist agricultural regime, describing Australia as a 'difficult case', facing 'seemingly impossible barriers to transitioning to agroecology'. Iles describes the factors that have contributed to the shaping of Australia's existing productivist agriculture regime and focusses on the lock-ins that impede systemic change to agroecological approaches. The author is critical of IPES-Food's (International Panel of Experts on Sustainable Food Systems) focus on political, technical, economic and policy lock-ins that protect and support industrial agriculture, and suggests Australia represents a case for socio-ecological lock-ins to be included as well. Iles (2021, p. 7) posits that these lock-ins are particularly important in Australia, where:

> … histories, ecologies, land use regimes, cultural beliefs, philosophies of government, and scientific and technological visions can converge to make alternative agricultures seem impossible, anachronistic, or impractical. For example, settler colonialism created a particular agrarian trajectory in Australia, eradicated agroecosystem potentials through massive land clearing, and erased indigenous farming systems that could have inspired alternative agricultures. Geographical and environmental conditions have made – and are making – it hard for farmers to adopt agroecological practices. Strong beliefs among scientist, industry, and government elites in

the power of science and technology to overcome climate constraints are leading to agroecology being ignored.

In this application of MLP, Iles summarises the key socio-ecological and political-economic lock-ins affecting agroecology development in Australia and explores opportunities to enhance alternatives to industrial agriculture that are isolated at the niche level (Iles, 2021; Santhanam-Martin et al., 2015). To address these lock-ins, Iles applies eight key drivers of the massification process of taking agroecology to scale, as identified by Mier y Terán Giménez Cacho et al. (2018). These drivers are: '(1) recognition of a crisis that motivates the search for alternatives, (2) social organisation, (3) constructivist learning processes, (4) effective agroecological practices, (5) mobilising discourses, (6) external allies, (7) favourable markets, and (8) favourable policies' (Mier y Terán Giménez Cacho et al., 2018, p. 637).

This application of the Mier y Terán Giménez Cacho et al.'s agroecology massification drivers to Australia's key lock-ins, provides insights into how each driver has been applied in other countries, examples of niche agroecology approaches in Australia, and strategies needed to address the lock-in of productivist agriculture. This also highlights the complexity of Australia's food systems and that multiple transitions across a variety of agribusiness functions are needed, not just one grand transition.

2.8 Sustainability transitions in agriculture and organic waste-to-energy

The transition of energy systems has been identified as a priority area for sustainability transitions research and for sustainable development. Systems currently in place for the production and consumption of energy to meet society's electricity, heat and transport demands are major contributors to climate change and there is a substantial body of literature with a focus on transition to sustainable energy systems. This area of research includes exploration of the drivers of and barriers to investment in renewable energy generation, including bioenergy approaches. There are many studies that explore the various subsets of bioenergy, including research into bioenergy development in the global forestry sector, municipal green waste, and wastewater treatment processes, as well as agribusiness engagement with energy crops and biofuels for transportation. While these areas are part of the broader literature on bioenergy-related themes, they are not the focus of this review. Instead, this section of this literature review focusses on the drivers and barriers impacting on farmers and food processors wishing to utilise the biological waste materials from their agribusiness operations to generate organic waste-to-energy.

There is a wealth of grey literature published by NGOs, governments, and industry bodies supporting bioenergy development in Australia and overseas. This literature provides high-level introductions to the potential of modern bioenergy and general advice for decision-makers on the sustainable development of this bioenergy sector. Over the last 15 years, the United Nations and its related organisations have been at the forefront of global efforts to increase the adoption of modern bioenergy generation and have published numerous reports advising decision-makers in both developed and developing countries of the benefits of modern bioenergy. Table 2.1 lists global organisations to have released major reports on the development of this sector, or to have initiated programs outlining the potential for substantial growth in the contribution of bioenergy to meet the growing global demand for energy.

Most of these reports identify key opportunities for the sustainable generation of energy from agricultural residues. In Australia, a range of reports has also been published with a focus on the development of bioenergy in Australia. Table 2.2 lists Australian reports and initiatives that provide information on possible bioenergy applications, assess biomass resources, and/or outline pathways for bioenergy development in Australia.

As with grey literature from international sources, Australian reports generally identify substantial potential for bioenergy development in the agri-food sector, given the industry's production of large volumes of organic wastes that are suitable for organic waste-to-energy production.

Table 2.1 International reports and initiatives with a bioenergy focus			
Author	**Year**	**Initiative/Report Title**	**Reference Type**
International Energy Agency (IEA)	2022	Bioenergy	Website
IEA	2021	Bioenergy Power Generation	Report
IEA Bioenergy	2021	IEA Bioenergy Countries' Report – update 2021	Report
World Bioenergy Association	2021	Global Bioenergy Statistics 2021	Report
International Renewable Energy Agency (IRENA)	2020	Recycle: Bioenergy	Report
Food and Agriculture Organisation (FAO) & Global Bioenergy Partnership (GBEP)	2019	Global Bioenergy Partnership	Website
Global Sustainability Bioenergy Initiative	2017	Global Sustainable Bioenergy Initiative – Feasibility & Implementation Paths	Website
IEA & FAO	2017	How2Guide for Bioenergy	Report
Sustainable Energy for All	2017	Sustainable Bioenergy	Website
World Bank	2017	Converting Biomass to Energy – A Guide for Developers and Investors	Report
IRENA	2014	Global Bioenergy Supply and Demand Projections - A working paper for REmap 2030	Report
World Energy Council (WEC)	2013	World Energy Resources - Bioenergy	Report
GBEP	2011	The Global Bioenergy Partnership Sustainability Indicators for Bioenergy – Executive Summary	Report
Intergovernmental Panel on Climate Change (IPCC)	2011	Bioenergy	Report
FAO & UNEP	2010	A Decision Support Tool for Sustainable Bioenergy	Report
World Bank	2010	Bioenergy Development	Report
United Nations Development Program (UNDP)	2000	Bioenergy Primer – Modernised Biomass Energy for Sustainable Development	Report

The academic literature published on bioenergy and organic waste-to-energy is generally more specific in scope, often focussing on social, environmental and/or economic sustainability of the generation of bioenergy, using specific feedstocks and conversion processes in specific industries or regions.

Table 2.2 Australian reports and initiatives with a bioenergy focus			
Author	**Year**	**Initiative/Report Title**	**Reference Type**
Australian Renewable Energy Agency (ARENA)	2022	Bioenergy/Energy from waste	Webpage
Clean Energy Finance Corporation	2022	Australia's bioenergy transformation	Online Factsheet
AgriFutures Australia	2021	Australian Biomass for Bioenergy Assessment 2015-2021 Final Report	Report
Clean Energy Council	2021	Clean Energy Australia Report 2021	Report
ENEA Consulting and Deloitte Financial Advisory	2021	Australia's Bioenergy Roadmap	Report
ARENA	2019	Renewable energy options for industrial process heat	Report
KPMG	2018	Bioenergy state of the nation (Australia)	Report
Clean Energy Finance Corporation	2015	Transforming Australian agribusiness with clean energy technology	Online Factsheet
Johnson, Brown, Brown, Harridge and Johnson	2015	A Bioenergy Roadmap for South Australia	Report
Rural Industries Research and Development Corporation (RIRDC)	2014	Opportunities for Primary Industries in the Bioenergy Sector (Australia)	Report
Clean Energy Council	2008	Australian Bioenergy Roadmap (2020+)	Report
RIRDC	2008	Future Biofuels for Australia	Report

There is a wealth of literature with a focus on bioenergy production and the vast majority of this research has examined the application of bioenergy from a purely technological or ecological perspective (Iakovou et al., 2010), which has left the area of the business of bioenergy and food supply chains relatively unexplored (Jensen & Govindan, 2014; Sam et al., 2017). There has been little research exploring the social barriers to, and drivers of, bioenergy development by Australian farming (Wilkinson, 2011).

The technical literature includes mapping feedstock locations and/or measurement of theoretical volumes of organic feedstocks available; modelling and comparisons of potential for bioenergy generation in given areas/regions/industries or from particular feedstock sources using particular bioenergy conversion technologies or processes; technical descriptions and comparisons on the effectiveness, suitability and/or feasibility of bioenergy generation processes and approaches. In Australia, this literature includes research papers, consultancy reports, discussion papers, factsheets and feasibility studies prepared for government departments, industry peak bodies and other stakeholders, exploring the potential of bioenergy to be applied in specific industry sectors.

While some of these papers discuss the broad bioenergy sector and its development in Australia, many papers are narrower in their focus on the potential application of one of two main types of bioenergy conversion approaches; direct combustion of solid/dry biomass materials, or biodigestion (also known as biogas or anaerobic digestion - AD) of liquid wastes, to produce biogas. Research exploring biogas applications in the Australian agro-food sector tends to concentrate on agribusinesses such as dairies, beef feedlots, piggeries, and meat processors. Studies on direct combustion applications are more diverse, focussing on a broader range of agribusinesses, such as sugar processors; forestry, agroforestry, and timber processors; protected cropping sector and other industries using solid biomass as fuel. In the period from 2000-2012 there was considerable research activity in Australia exploring the potential of various forms of bioenergy to contribute to Australia’s renewable energy generation mix and commitments to reduce emissions of greenhouse gases, but this activity appears to have tapered-off.

There is a substantial body of academic literature from many countries with a focus on the potential of organic waste-to-energy approaches to deliver social, environmental, and economic outcomes, while also identifying the barriers to waste-to-energy investment and development. These papers identify opportunities for organic waste-to-energy development in each location or industry, or utilising a particular feedstock or technology, but studies identifying the factors driving agribusiness investment and development of on-site waste-to-energy systems are relatively limited. For the remainder of this overview, concentration is on the drivers and barriers to organic waste-to-energy engagement in agribusiness literature.

2.9 Waste-to-energy drivers

The development of renewable energy has been promoted as a critical strategy to reduce the emissions of greenhouse gases from energy generation into Earth's atmosphere. It is expected this need for cleaner energy production will be a major driver of bioenergy development around the world (Holm-Nielsen et al., 2009; Kopetz, 2013; Li et al., 2020; Mesas & Morais, 2014; Nakada et al., 2014; O'Connell et al., 2009). Development of renewable energy generation capacity has also been attractive to governments and NGOs because of its social and economic contributions as a knowledge-based industry and driver of job creation, energy security, economic growth, competitiveness and regional and rural development (Edwards et al., 2015; ENEA Consulting and Deloitte Financial Advisory, 2021; European Commission, 2016; FAO & UNEP, 2010).

Despite the urgent requirement for renewable energy development to combat climate change and the general enthusiasm for the broader social and economic benefits that can be associated with bioenergy developments, these are only secondary motivations for agribusinesses investing in organic waste-to-energy systems (Ackrill & Abdo, 2020; Granoszewski et al., 2013). Instead, studies of agribusinesses from around the world indicate the main drivers for their interest in organic waste-to-energy development fall into two broad categories; factors relating to the cost or supply of energy, and factors relating to the management of organic waste. For agribusinesses wishing to reduce energy costs and/or improve the security of their energy supply, becoming more self-sufficient in meeting their on-site energy needs, also known as 'energy autarky' (Ehlers, 2008; Müller et al., 2011), can be an attractive option. For other agricultural operations, their interest in waste-to-energy technologies can be driven by a desire to modify their management of large or problematic volumes of organic waste materials (Ehlers, 2008; Geels & Raven, 2006; Hamawand et al., 2016; O'Connor, Ehimen, Pillai, Black, et al., 2021; Romets et al., 2015; Tranter et al., 2011; Vasco-Correa et al., 2018). The nature of these drivers is explored further in the following sections.

2.9.1 Energy autarky

There are substantial costs associated with purchasing energy for running machinery and water heating, space heating, cooling, and lighting of food manufacturing plants and intensive farming operations (such as piggeries, poultry sheds, beef feedlots, dairies, and fruit/vegetable glasshouses). These agribusinesses are often exposed to fluctuations in the prices and availability of electricity, natural gas, liquid petroleum gas (LPG) and other fuels, which can have major impacts on the financial performance of these businesses (DISER [Department of Industry Science Energy and Resources], 2022; Massé et al., 2011; Mesas & Morais, 2014). As a result, a desire for energy autarky can be a key driver for some agribusinesses' interest in organic waste-to-energy systems, as it presents an opportunity to generate their own electricity and/or heat 'behind the meter'. By generating energy on-site, some agribusinesses can substantially reduce their energy costs, their dependency on fossil fuels and their exposure to uncertain energy prices and supply issues (Ackrill & Abdo, 2020; Adams et al., 2011; Romets et al., 2015; Solomie et al., 2010; Tait et al., 2021; Wilkinson, 2011).

In the past, relatively low energy prices have been seen as a disincentive for industrial consumers to consider renewable energy options (Effendi & Courvisanos, 2012; Harkema et al., 2015). This has been the case with bioenergy in Australia, where renewable energy has been sidelined by cheap energy generation from domestic fossil fuel supplies (Edwards et al., 2015; Wilkinson, 2011). However, recent issues with the cost and security of supply of electricity, natural gas and LPG in Australia and around the world have prompted many businesses, particularly agribusinesses, to reconsider their organic waste-to-energy generation options (Gandhi, 2014; IEA Bioenergy Task 37, 2017; Scherger, 2017).

2.9.2 Waste management strategy

Another critical factor driving agribusiness investment in organic waste-to-energy has been the desire of farm and food manufacturing businesses to improve their waste management practices (Hamawand et al., 2016; Holm-Nielsen et al., 2009; Romets et al., 2015; Tait et al., 2021; Tranter et al., 2011). For some agribusinesses, their motivation to improve their waste-management practices is related to their desire for energy autarky. This is a desire to improve their farm/business's efficiency by extracting greater value from a by-product for which they receive little value (financial or otherwise) or is a cost to the business, or to more cost-effectively manage their organic waste streams (Ehlers, 2008; Krzywoszynska, 2012; Mesas & Morais, 2014).

These agribusinesses may not view the by-products of their agricultural production as being waste, but instead regard these biological materials as underutilised or undervalued resources, recognising the calorific, mineral, moisture and/or biological value contained in their agricultural by-products. For these agribusinesses, organic waste-to-energy technologies can represent opportunities to capture the value more fully in their by-products.

For other agribusinesses, the need for ecological modernisation of their organic waste management strategies has been more urgent. Updating traditional organic waste management approaches with on-site waste-to-energy technologies is an example of ecological modernisation. This a process in which existing production systems (such as energy production, agricultural production and processing, and waste management) are reconfigured to take into account environmental concerns (Bluemling et al., 2013).

The intensification of livestock production and food processing has been most effective in increasing the efficiency of food production and reducing costs to consumers, but some of the waste management practices involved in these systems have introduced major environmental challenges such as water and air pollution (Holm-Nielsen et al., 2009; Innes, 2000; Martinez et al., 2009; Massé et al., 2011; Tait et al., 2021; Vasco-Correa et al., 2018). The emergence of these challenges has prompted increased activity from agribusiness regulators and opposition to some types of agribusinesses from local communities and other stakeholders. These challenges have encouraged agribusinesses to consider their options for ecological modernisation.

Generally, jurisdictions with robust health and environmental regulations tend to better control and support development of organic waste-to-energy technologies (Vasco-Correa et al., 2018). The clearest example of this support being the strong air and water pollution policies of European Union countries that have played a major role in establishing Europe as a global leader in the development of a range of waste-to-energy technologies (Edwards et al., 2015). Countries such as the United Kingdom, Belgium and Germany have stringent limits on the amount of nitrates and phosphates that can be applied to certain soil or crop types, to reduce surface and groundwater pollution by manure-derived nitrates (Edwards et al., 2015; Vasco-Correa et al., 2018). For agribusinesses wanting to foster more positive working relationships with stakeholders, ensuring compliance with environmental regulations and avoiding contamination of the local environment are fundamental concerns, and so exploring ecological modernisation options for improved waste management becomes a priority (Edwards et al., 2015; Ehlers, 2008; Massé et al., 2011; O'Connor, Ehimen, Pillai, Black, et al., 2021; Romets et al., 2015; Vasco-Correa et al., 2018).

2.10 Barriers to agribusiness investment in waste-to-energy

Around the world, there is a range of common barriers that impede agribusiness investment in on-site waste-to-energy technologies. These barriers include financial, technical and regulatory obstacles, as well as unsupportive attitudes or a general lack of knowledge about organic waste-to-energy amongst agribusiness operators, financiers, regulators and the wider community (Ackrill & Abdo, 2020; Capodaglio et al., 2016;

Chasnyk et al., 2015; Holm-Nielsen et al., 2009; Igliński et al., 2012; McCormick, 2010; O'Connor, Ehimen, Pillai, Black, et al., 2021; Prasertsan & Sajjakulnukit, 2006; Reise et al., 2012; Stræte et al., 2022; Xu et al., 2022). Each of these barriers is discussed in the following sub-sections.

2.10.1 Financial barriers

Costs associated with access to energy markets, the transport and supply of biomass feedstocks, the conversion technologies and their efficiency, and access to finance are critical factors that can determine the financial viability of agribusiness waste-to-energy investments (Wilkinson, 2011). These critical financial factors include the relatively high capital costs and long payback periods associated with investing in waste-to-energy plants (Ackrill & Abdo, 2020; Capodaglio et al., 2016; Jensen & Govindan, 2014; Massé et al., 2011; Mesas & Morais, 2014; Mofijur et al., 2021; O'Connor, Ehimen, Pillai, Black, et al., 2021; Romets et al., 2015; Stegelin, 2010; Tranter et al., 2011; Wilkinson, 2011).

For some agribusinesses, waste-to-energy capital costs can be prohibitive. Agribusinesses adopting these technologies are required to make substantial financial investments, which may be beyond the reach of many agribusinesses, particularly smaller agribusinesses (O'Connor, Ehimen, Pillai, Black, et al., 2021). In some countries and regions, this issue can be compounded by difficulties accessing finance to invest in organic waste-to-energy plant and equipment (Mesas & Morais, 2014). In part, these difficulties can be caused by financiers' lack of knowledge, experience or awareness of these technologies and a tendency to view such investments as high risk (O'Connor, Ehimen, Pillai, Black, et al., 2021).

The business case for organic waste-to-energy can also be affected by the availability of suitably sized plants for the scale of the agribusiness operation. Smaller scale agribusinesses generally do not produce the consistent volumes of organic feedstocks needed to fully utilise the capacity of the commercial plants and equipment on offer, which can have a critical impact on the financial viability of agribusiness investment in organic waste-to-energy technologies (Mesas & Morais, 2014; O'Connor, Ehimen, Pillai, Black, et al., 2021). Also, for some agribusinesses, their production of organic feedstocks can vary substantially depending on the season, which for some parts of the year can result in a surplus of biomass material that needs to be stored safely until it can be processed; while at other times, shortages in supply can disrupt or halt energy generation.

To utilise the production capacity and economies of scale of larger bioenergy units most efficiently, smaller-scale agribusinesses may need to supplement their feedstock supply with organics sourced off-site. Such arrangements may carry additional transport, storage and supply costs, which can have a critical impact on the economic viability of these projects (Capodaglio et al., 2016; ENEA Consulting and Deloitte Financial Advisory, 2021; Hertle, 2008; O'Connor, Ehimen, Pillai, Black, et al., 2021). This is where geography and the availability of similar and/or complementary industries nearby can be critical to the feasibility of a waste-to-energy project in the agriculture sector.

The issue of high capital costs of technologies to convert organic waste into energy can be compounded by uncertain and/or modest rates of return on investment and long payback periods, which make investments in organic waste-to-energy less attractive to agribusiness decision-makers and financiers (Harkema et al., 2015; Massé et al., 2011; Mesas & Morais, 2014; Prasertsan & Sajjakulnukit, 2006; Stegelin, 2010; Tranter et al., 2011). In some countries, the high capital costs of investing in organic waste-to-energy have been acknowledged, with the governments of many European countries offering various financial incentives, but these are not usually enough to initiate a bioenergy project (Capodaglio et al., 2016).

Returns on organic waste-to-energy investment are heavily impacted by the prices agribusinesses are paid for the energy and by-products generated by these technologies. In many countries, relatively low electricity and thermal energy prices have been identified as barriers to investment not just in organic waste-to-energy systems, but also in renewable energy in general (Ackrill & Abdo, 2020; Edwards et al., 2015; IEA Bioenergy Task 37, 2017; REN21,2016).

To address this barrier, a range of economic support mechanisms such as renewable energy targets, special ‘feed-in’ tariffs, low-interest loans, grant schemes and performance-based incentives have been developed to improve the payback period of renewable energy investments and to encourage the development of renewable energy systems. While financial incentive schemes are seen as being critical to improve the business case for waste-to-energy developments, there has been substantial variation in the ways these support mechanisms have been implemented and their efficacy in supporting renewable energy developments (Sam et al., 2017).

Despite the existence of government incentives encouraging renewable energy development, organic waste-to-energy projects are rarely viable based solely on the financial returns businesses receive for the electricity, biogas and transport fuels they export to local energy markets. In some countries, energy markets may be difficult to access; or may be immature in terms of infrastructure, policy and/or critical stakeholders; or the costs of connecting to electricity and/or gas distribution networks may be prohibitive (Edwards et al., 2015; O'Connor, Ehimen, Pillai, Black, et al., 2021). As a result, for organic waste-to-energy plants to be financially viable, many agribusinesses must be able to utilise the thermal energy and other by-products produced by these technologies to reduce costs in other parts of their business, or they must find productive applications for these resources off-site (Hertle, 2008; Jensen & Govindan, 2014; Walla & Schneeberger, 2008).

With the low prices small electricity generators are paid to export electricity into regional electricity networks (relative to the price of the electricity they consume), and the high costs associated with connecting to these electricity networks or distributing heat off-site, exporting bioenergy off-site can appear less attractive financially (Bluemling et al., 2013). Thus, some agribusinesses prefer to utilise their bioenergy on-site, ‘behind the meter’, to offset the electricity and gas they need to import to run their operations (Hertle, 2008; Scherger, 2017). For an agribusiness not able to offset all or part of a major business expense by utilising most of the energy they produce, there may be little financial incentive to invest in an organic waste-to-energy plant.

Sharp rises over the last decade in the cost of electricity and natural gas in Australia and other countries, have prompted some agribusinesses to reconsider alternative sources of electrical and thermal energy, including organic waste-to-energy options (Gandhi, 2014; Scherger, 2017). For agribusinesses unable to productively utilise electricity, heat and organic by-products and/or fertilisers on-site, having cost-effective access to markets for these products can be critical in the business case for organic waste-to-energy investment. In some cases, an agribusiness's proximity to electricity transmission lines and thermal energy and fertiliser customers are key factors determining the transmission and transportation costs, which can substantially impact the viability of organic waste-to-energy technologies (Bluemling et al., 2013).

Another critical factor affecting business cases of organic waste-to-energy investments is the availability and reliability of the biomass feedstock supply, as well as the quality and cost of the organics that can be converted into thermal and electrical energy (Ackrill & Abdo, 2020; Mesas & Morais, 2014; O'Connor, Ehimen, Pillai, Black, et al., 2021). Ideally, organic waste-to-energy plant operators prefer to use feedstocks they produce on-site, or those imported from off-site for which they receive a gate fee, or can be sourced and transported for free or at very low cost (Astill & Shumway, 2016). For agribusinesses with a plentiful and/or problematic supply of organic waste materials produced and managed on-site (such as piggeries, dairies, sugar refineries, cotton gins and food manufacturers), waste-to-energy can be a viable waste management option. However, if a plant's feedstocks must be supplemented by biomass purchased from another business, that require transportation long distances or for which there is competition from other industries or applications, the risks associated with variable feedstock supply costs and availability can be critical barriers to agribusiness investment in bioenergy (Ackrill & Abdo, 2020; Jensen & Govindan, 2014; Mesas & Morais, 2014; Stucley et al., 2012).

2.10.2 Knowledge-based barriers

Bioenergy, more broadly, and organic waste-to-energy, more specifically, have both suffered because of a general lack of knowledge by all stakeholders in agribusiness of energy, organic waste-to-energy and waste management technologies and systems. Unhelpful attitudes and negative beliefs regarding the perceived economic, social and environmental impacts of biomass energy have been substantial barriers to bioenergy development (Capodaglio et al., 2016; Chasnyk et al., 2015; Holm-Nielsen et al., 2009; Igliński et al., 2012; Kulla et al., 2022; McCormick, 2010; Prasertsan & Sajjakulnukit, 2006; Reise et al., 2012).

The related issues of land use, and land use change, due to the production of bioenergy have been particularly contentious for many years and can potentially impact on the social acceptance of organic waste-to-energy developments. These issues have had a negative impact on support for the development of bioenergy and biofuels in many parts of the world, including Australia (Farine et al., 2012; Granoszewski et al., 2013; Wubben & Isakhanyan, 2013). This has been known, in part, as the ‘food versus fuel debate’, in which questions have emerged concerning the ethics and sustainability of growing energy crops on arable land on which food crops have been grown previously; diverting land, water, energy, labour and other inputs away from food production and into fuel production. Critics have been concerned about the impact this bioenergy production may have on food production, food prices and ultimately on global food security (Brown, 1980; Ehlers, 2008; Popp et al., 2014; Stucley, 2010; Tenenbaum, 2008; Wubben & Isakhanyan, 2013).

Other research has countered the ‘food versus fuel’ criticisms of biofuels, suggesting food production has been uncritically prioritised as a higher order use of land and water

(O'Connell, 2009). These arguments frame questions around food security and land use as being much broader policy and political challenges that should not be applied to bioenergy alone, and require substantial efforts in science, economics and policy to guide the most efficient and sustainable allocation and use of land and other resources (Moomaw, 2008; O'Connell et al., 2009).

The 'food versus fuel' debate once primarily involved the biofuels sector, which harvests energy crops such as oilseeds, grains, grasses and sugar (cane, beets and palms) to generate transport fuels. This debate is becoming increasingly relevant to biogas operations, with organic feedstocks from energy crops now being used to stabilise anaerobic digesters and/or maintain a year-round supply of substrate to the digester (Capodaglio et al., 2016; Wilkinson, 2011). Similar concerns have been held for the impacts that increased bioenergy production may have in accelerating deforestation and land clearing, by increasing the global demand for woodchips and for land to be cleared to make way for energy crops (Cushion et al., 2009; Moomaw, 2008). These issues are not directly relevant to organic waste-to-energy in agribusinesses, although the broader implications and negative attitudes associated with the 'food versus fuel' debate need to be countered by better understandings of the role that waste-to-energy technologies play in sustainable development (McCormick, 2010).

Organic waste-to-energy investment has also been impacted by a general lack of knowledge, awareness and understanding of these technologies in several sections of society (McCormick, 2010). This has resulted in opposition to proposed organic waste-to-energy developments from neighbouring communities often fearful, sceptical, confused and/or misinformed about the details of such developments and their social and environmental impacts (Bößner et al., 2019; Capodaglio et al., 2016; Chasnyk et al., 2015; Igliński et al., 2012; Kulla et al., 2022; McCormick, 2010; Mofijur et al., 2021; Prasertsan & Sajjakulnukit, 2006; Xu et al., 2022). In some cases, this has included a lack of trust in the motivations of developers and the information they have provided, and/or the ability of regulators to effectively monitor performance of waste-to-energy developments (McCormick, 2010). There appears to be a consensus in the literature that organic waste-to-energy projects tend to be more successful when the stakeholders are aware of, and well informed about, energy issues, waste issues, and the potential roles that can be played by organic waste-to-energy approaches.

In many countries, community opposition has been one of the most critical barriers to bioenergy development. This opposition from local communities often features genuine quality-of-life concerns including unpleasant odours, water contamination, inconvenience (such as increased road traffic, degradation of roads) and fears of the social and environmental impacts of accidents (Granoszewski et al., 2013; Mesas & Morais, 2014; Wüste & Schmuck, 2013).

Studies have also identified evidence of bioenergy developments impacted by 'NIMBY (Not In My Backyard) syndrome' (Capodaglio et al., 2016; Kulla et al., 2022; O'Connor, Ehimen, Pillai, Black, et al., 2021). This acronym characterises opposition to bioenergy projects in a group's local area, when the same group might be supportive of bioenergy development in other locations that would not affect them. Others suggest this is an over-simplification of the issues to place all community opposition to bioenergy into this category (Rohracher et al., 2004).

There has also been a view that many farms, food manufacturers and their financiers may be not be fully aware of the opportunities to generate energy from agricultural waste streams (Mesas & Morais, 2014; O'Connor, Ehimen, Pillai, Black, et al., 2021; Stegelin, 2010). A 2012 survey of German agribusinesses found that '…it may also be the case that farmers make suboptimal decisions due to incomplete information and limited cognitive abilities in processing information, a phenomenon Simon (1956) refers to as "bounded rationality" ' (Reise et al., 2012, p. 133). Such limitations create a significant knowledge deficit in decision-making for organic waste-to-energy implementation.

In locations and sectors of agribusiness with few examples of successful application of organic waste-to-energy technologies, agribusiness managers can lack confidence in the suitability of waste-to-energy options to their operations (Prasertsan & Sajjakulnukit, 2006). This lack of accurate information, awareness and understanding of bioenergy applications can also extend to financiers, policymakers and regulators, which contributes to the social, financial and regulatory barriers that can be experienced by agribusinesses interested in investing in waste-to-energy systems (Ackrill & Abdo, 2020; Igliński et al., 2012; Massé et al., 2011; Mofijur et al., 2021; O'Connor, Ehimen, Pillai, Black, et al., 2021; Ruppert et al., 2013; Stucley et al., 2012; Tranter et al., 2011; Xu et al., 2022).

2.10.3 Technical barriers

While some literature identifies technical issues as significant barriers for organic waste-to-energy development, this is not a unanimous finding. Many papers describe the organic waste-to-energy technologies as being mature and available commercially (Holm-Nielsen et al., 2009; Johnson, 2015; Kartha, 2000; Stucley, 2010; Stucley et al., 2012; Waldenström et al., 2016). Silveira (2005, p. 16) declares '…the leap towards broader utilization of bioenergy is now more psychological than technological', and McCormick and Kåberger (2007) argue 'The key barriers affecting bioenergy are non-technical challenges rather than technical issues'. However, others suggest this view over-simplifies the reality and complexity of bioenergy approaches and underestimates the challenges in applying these in different agricultural settings (Bergh, 2013; Waldenström et al., 2016).

From a knowledge management perspective, some barriers exist that relate to a lack of specialist skills and knowledge about the effective application of organic waste-to-energy technologies. These include shortages of: i) organic waste-to-energy developers (especially smaller scale) (O'Connor, Ehimen, Pillai, Black, et al., 2021; Scherger, 2017; Stegelin, 2010; Xu et al., 2022), ii) substantive consulting and technical expertise to design and build suitable organic waste-to-energy plants (Bößner et al., 2019; O'Connor, Ehimen, Pillai, Black, et al., 2021; Piwowar et al., 2016; Stucley, 2010; Uhunamure et al., 2019), and iii) skilled workforce to operate these plants (Bößner et al., 2019; Prasertsan & Sajjakulnukit, 2006; Romets et al., 2015; Stucley, 2010). This final point is critical, because the performance of organic waste-to-energy technologies such as anaerobic digesters can be highly sensitive to variations in feedstock composition and contaminants. If these technologies are not effectively managed and maintained, plant performance can be compromised, resulting in an erosion of stakeholder confidence in the safety and efficiency of the technologies, substantial costs associated with fixing the plant and disruption to waste management practices (Geels & Raven, 2006).

2.10.4 Regulatory barriers

The regulatory environment is a critical factor influencing the viability of organic waste-to-energy developments in the agribusiness sector, with farmers and food manufacturers sensitive to regulations that can be too weak or too onerous. Organic waste-to-energy developments are subject to a range of environmental, energy and financial regulations, legislation, by-laws and schemes, which can be both supportive of organic waste-to-energy development or barriers to bioenergy investment.

For some agribusinesses managing large volumes of organic wastes, effective management of these wastes can be ‘a considerable financial and bureaucratic burden’ (Krzywoszynska, 2012, p. 57) and the requirement to comply with environmental regulations can provide an incentive for managers to consider organic waste-to-energy plants as part of their waste management processes (Bößner et al., 2019; Holm-Nielsen et al., 2009; Massé et al., 2011). If these agribusinesses are operating in countries such as Germany or Belgium or some states in USA, with robust environmental regulations effectively applied by regulators, they may be encouraged to explore easier and more cost-effective waste management approaches (Astill & Shumway, 2016; Mesas &

Morais, 2014; O'Connor, Ehimen, Pillai, Black, et al., 2021; Vasco-Correa et al., 2018; Wilkinson, 2011)

Conversely, in other countries including Australia, organic waste-to-energy development can be impacted by investment uncertainty or negative consequences that can result from lack of environmental regulation, weak regulations, or the failure of regulatory authorities to effectively apply regulations that do exist in these areas (O'Connell et al., 2009; Romets et al., 2015; Uhunamure et al., 2019; Wilkinson, 2011). If environmental and other regulations and standards relevant to organic waste-to-energy systems do not exist, are weak, or not applied effectively; there may be little incentive for agribusinesses to change from their current waste management practices (Mesas & Morais, 2014; Prasertsan & Sajjakulnukit, 2006; Vasco-Correa et al., 2018).

For other farmers and food manufacturing managers, complexity of environmental regulations and planning approval processes involved with management and storage of feedstocks for organic waste-to-energy plants can also be a disincentive to investment. In such cases, compliance with these regulations is regarded as being too complicated, too burdensome, and too time-consuming (Ackrill & Abdo, 2020; Bößner et al., 2019; Chasnyk et al., 2015; Geels & Raven, 2006; Mesas & Morais, 2014; Tranter et al., 2011).

Organic waste-to-energy developments are also affected by financial regulations and market structures, which can help or hinder agribusiness investment in this area (REN21, 2016). In some countries such as Australia, Poland, Indonesia (Bali), Ukraine and Thailand, immature, inflexible or inappropriate energy regulations are substantial barriers for organic waste-to-energy development (Bößner et al., 2019; Chasnyk et al., 2015; Kopytko, 2014; Mesas & Morais, 2014; Wilkinson, 2011).

In other cases, energy structures and incentive schemes put in place to support renewable energy development, such as renewable energy targets, low interest loans, subsidies, tax incentives and feed-in tariffs, can be supportive of large-scale developments. These support schemes tend to be less beneficial to smaller, farm-scale developments related to bioenergy and organic waste-to-energy projects, with other types of renewable energy seen as more attractive to these smaller agribusinesses (Chasnyk et al., 2015; Waldenström et al., 2016).

Finally, in many parts of the world, and Australia in particular, uncertainty around environmental and energy policies is seen as being a major barrier to organic waste-to-energy investment (Chasnyk et al., 2015; Nakada et al., 2014; REN21, 2016; Wilkinson, 2011). Policy uncertainty has been a feature of the Australian energy landscape for more than two decades and remains a substantial impediment to renewable energy investment today (IEA Bioenergy, Byrnes et al., 2013; Effendi & Courvisanos, 2012; 2016b), with '…instability of current support policies that may change with whichever political party is in power, [which] causes renewable energy deployment to suffer with stop-and-go situations influencing Australian renewable energy development' (Hua et al., 2016, p. 1046). Better policies supporting renewable energy are essential for the growth of the renewable energy sector (IEA Bioenergy, Hua et al., 2016; 2016b; Vasco-Correa et al., 2018).

This lack of public policy certainty and support effects particularly seriously the development of nascent bioenergy systems and further undermines stakeholder knowledge of and attitudes to organic waste-to-energy. The resolve of policymakers to introduce or maintain policies supporting bioenergy can be further eroded by community and media opposition to bioenergy proposals, underlining the importance of effective communication and stakeholder engagement strategies to enhance social acceptance of bioenergy developments (McCormick, 2010).

2.11 Summary

This chapter has reviewed literature relevant to the adoption of organic waste-to-energy technologies by agribusinesses, with a focus on Australian enterprises, and the sustainability transitions of Australia's food and fibre farmers and processors.

This review outlines the development of innovations theory through the 20th century, and the emergence of transitions studies as an important new strand in innovations literature, to understand and describe the radical changes needed in the way our societies and economies function, in order to transition to a sustainable footing (Köhler et al., 2019). Radical transformations are also required in the agricultural systems that grow and process the world's food and fibre, and several heuristic frameworks have been developed to explain the dynamics of such transitions. One of the leading frameworks, MLP, has been applied in many contexts, including the exploration of energy (Geels et al., 2020; Sovacool et al., 2020) and agriculture transitions (Bui et al., 2016; El Bilali, 2019a), and has been particularly useful when combined with SPA to conceptualise sustainability transitions in agriculture (Hinrichs, 2014).

One of the fundamental features of MLP is the identification and analysis of the impact of drivers and barriers to innovations for sustainability transitions in a given context, and so this review has also focussed on literature exploring the drivers prompting agribusiness engagement with organic waste-to-energy systems, and the barriers to agribusiness adoption of these technologies. Studies identify a range of factors motivating agribusiness interest in exploring waste-to-energy options, but these fall into two basic categories; factors associated with the cost and/or supply of energy; and reasons surrounding the on-site management of organic waste materials. Agribusinesses around the world encountered numerous impediments to their adoption of organic waste-to-energy technologies, with the most common being financial barriers, knowledge/attitudinal barriers, technical barriers and regulatory barriers.

In the next chapter, drivers and barriers to agribusiness engagement with organic waste-to-energy systems identified in this literature review will be applied using the MLP and SPA frameworks.

3. Conceptual framework

This chapter presents the conceptual foundations to this research project's approach to explain agribusiness transitions to organic waste-to-energy technologies. This study is fundamentally based on the MLP framework, developed by Geels et al. (2017) and discussed in the previous chapter (see Section 2.5.1). MLP is applied to analyse the transition journey of organic waste-to-energy technologies (niche-innovations) seeking to replace incumbent approaches in the regime.

To represent the drivers and barriers, identified by the academic literature as influencing agribusinesses that attempt to adopt bioenergy technologies, a bioenergy drivers and barriers heuristic is introduced. This heuristic details critical factors that impact transition journeys, within MLP's socio-technical regime, as agribusinesses transition to bioenergy approaches. The focus of this heuristic is on the agribusiness itself and identifies the drivers and barriers that impact an agribusiness on its transition journey. The MLP framework identifies the same critical factors from bioenergy drivers and barriers heuristic, but in a more holistic, complex, and richer multi-level context, to provide an understanding of the transition process involved with these drivers and barriers. These drivers and barriers are then considered in the context of Social Practice Approach (SPA), to explore the role of agency and everyday practices in these agribusiness transitions (Hargreaves et al., 2013; Hinrichs, 2014; Liedtke et al., 2017; Svennevik, 2022).

3.1 MLP framework for agribusiness transitions to waste-to-energy

The main conceptual approach used in this study is a model based on the MLP framework (Geels et al., 2017) (see Figure 2.1). It has been adopted for this study to represent the dynamics of transition processes affecting agribusiness adoption of organic waste-to-energy technologies. The critical factors influencing this process are applied to the three levels of activity and interaction in socio-technical transitions identified by MLP: the niche-innovations level, the socio-technical regime level, and the socio-technical landscape level. Working through these three levels enables a new technology to become viable and enduring. Innovations emerge in Phase 1, at the niche-innovations level in the bottom left corner of Figure 2.1. As the innovation develops over time, the new technology or process progresses through Phases 2 and 3, to enter and disrupt the regime at the meso-level and ultimately replace previous approaches or contribute to a new regime that influences the landscape at the top right corner of the model.

At the niche-innovation level, radical innovations are invented in ‘safe spaces’, where they can be developed and further refined in a supportive, nurturing environment. In the case of agribusiness transitions to organic waste-to-energy, these radical innovations are the conversion routes and technologies developed to capture and/or extract the chemical energy contained in biological feedstocks (including agricultural by-products) and convert this into usable forms of electrical, thermal or transport energy.

Emerging bioenergy conversion routes involving secondary processes for gasification and pyrolysis, bio-photochemical routes (photosynthetic microorganisms such as microalgae) and other biological/chemical routes currently reside in MLP’s Phase 1, at the niche-innovation level. In Figure 2.1, these niche-innovations are represented by the shorter arrows in the bottom left corner. These conversion pathways may be proven concepts and processes, but their commercial bioenergy applications are still being developed and refined. Viable applications for these innovations may or may not eventuate, with the ones showing potential moving to test their viability and effectiveness in niche market applications and innovations that may be further developed or abandoned. The trajectory of the arrows indicates the progress of the innovations, with the more promising rising more sharply, but for others suffering setbacks or taking more time to develop, their rise may be more modest. Some innovations may fail to emerge out of Phase 1 and thus showing arrows that move downwards.

More established bioenergy technologies such as biomass combustion boilers and anaerobic digesters (biogas production) are relatively well-understood and have been available commercially for several decades in some parts of the world (see Figure . While these technologies are reasonably well known, they are still considered to be niche-innovations, but have progressed into Phase 2 of the MLP model and are represented by the slightly longer arrows. These technologies have been developed in laboratories and workshops and further refined and proven in small market niches but are now in search of ‘windows of opportunity’ for additional applications and growth in the socio-technical regime.

The socio-technical regime is the MLP’s meso-level that includes all the incumbent actors, communities, institutions, networks, infrastructures, regulations, public policies and norms at a regional or national scale. The agriculture sector’s own meso-level is one with existing technologies and production practices (including energy and organic waste management practices) and the government/environmental authorities and policy-makers regulating these practices. Agribusiness supply chains are also part of the regime, including machinery and equipment suppliers; energy suppliers (electricity, gas and liquid fuels); agricultural advisors (agronomists, agents, finance/business advisors and technical consultants); contractors; and their downstream customers. These are represented by long horizontal arrows (in the mid left-hand side) heading to the mid right-hand of the diagram in Figure 2.1, as the components of the multi-faceted structure at the mid-level of the model that extends through Phases 2 and 3 of socio-technical transitions.

The long horizontal arrows represent the existing energy and waste management approaches widely used within the agriculture sector. Incumbent organic waste management approaches currently in use may include the composting or spreading of raw effluent or animal waste on surrounding farmland; the burning of cropping residues or stubble; the incineration or burial of organic waste. Energy generation and consumption practices currently in use by farmers and processors of agricultural production may include consumption of energy from fossil sources (coal-fired electricity, natural gas, liquid petroleum gas, petrol and diesel) to fuel transportation, machinery operation, on-site power generation, space and/or water heating and cooling.

As niche innovations, bioenergy technologies such as biomass combustion boilers and anaerobic digesters are seeking opportunities for entry into this regime. They seek to move via the long, curved arrow heading upward to the top right-hand corner of the diagram through the existing practices and technologies, from its periphery into the mainstream. This will enable the innovation to compete with the established agribusiness approaches to energy and organic waste management. Making such a move would be indicative of these innovative technologies progressing into MLP’s Phase 3, but the stable nature of a regime can ‘lock-in’ the incumbent structures and approaches and present barriers for niche innovations to break into the regime. As a result, successful progressions of new entrants to Phase 3 are dependent on the existence of key drivers such as price/performance improvements and/or support from actors and organisations in the regime, supporting their transition journey (Geels et al., 2017). Agribusiness transitions to organic waste-to-energy approaches feature both requirements for progression to MLP’s Phase 3; the internal and external drivers and overcoming barriers featured in Figure 3.1, and some support from stakeholders in the regime.

The exogenous context of MLP framework is the socio-technical landscape wherein the global environment exists under which all regimes and niche-innovations sit. The most fundamental international-scale development or trend impacting agribusiness transitions to organic waste-to-energy is climate change and global commitments to reduce emissions of greenhouse gases. These commitments have resulted in the adoption of a range of policies and regulatory positions in some countries that impact the regimes in which agribusinesses function, especially those impacting energy generation and waste management. These impacts have included widespread support and encouragement for the development of renewable energy generation capacity, including bioenergy and organic waste-to-energy options, as well as the growing need for the global agriculture sector to reduce the carbon intensity of its food and fibre production.

Global energy and commodity markets form another relevant landscape factor impacting agribusiness transitions at regime and niche-innovation levels. These are international markets over which the regime and its stakeholders have little or no control, but these global behaviours can influence the way in which the regimes operate. These impact on the prices agribusinesses are paid for their produce and the prices they must pay for the energy consumption and other inputs. It is with support of global and national commitments and international markets that waste-to-energy technologies can successfully transition to Phase 4 as dominant systems in agribusiness.

3.2 Drivers and barriers impacting transitions to bioenergy

Figure 3.1 provides a heuristic, mapping drivers and barriers in agribusiness transitions from ‘business-as-usual’ waste management and energy consumption practices towards adoption of innovative approaches to organic waste-to-energy systems. The drivers and barriers featured in Figure 3.1, have been identified in bioenergy studies conducted in other countries, as being critical factors impacting agribusiness transitions to bioenergy approaches (mainly biogas and direct combustion). To answer this study’s research question, this heuristic is applied to explore the extent to which these drivers and barriers are factors for Australian agribusiness transitions to organic waste-to-energy approaches.

In making this transition, these agribusinesses engage in transformative innovation processes. The nature of these processes has been described by many evolutionary theories, such as those listed by Godin’s (2006) Taxonomies of Innovation context for decision-making by agribusiness in relation to drivers and barriers for shifting (or not) into waste-to-energy systems.

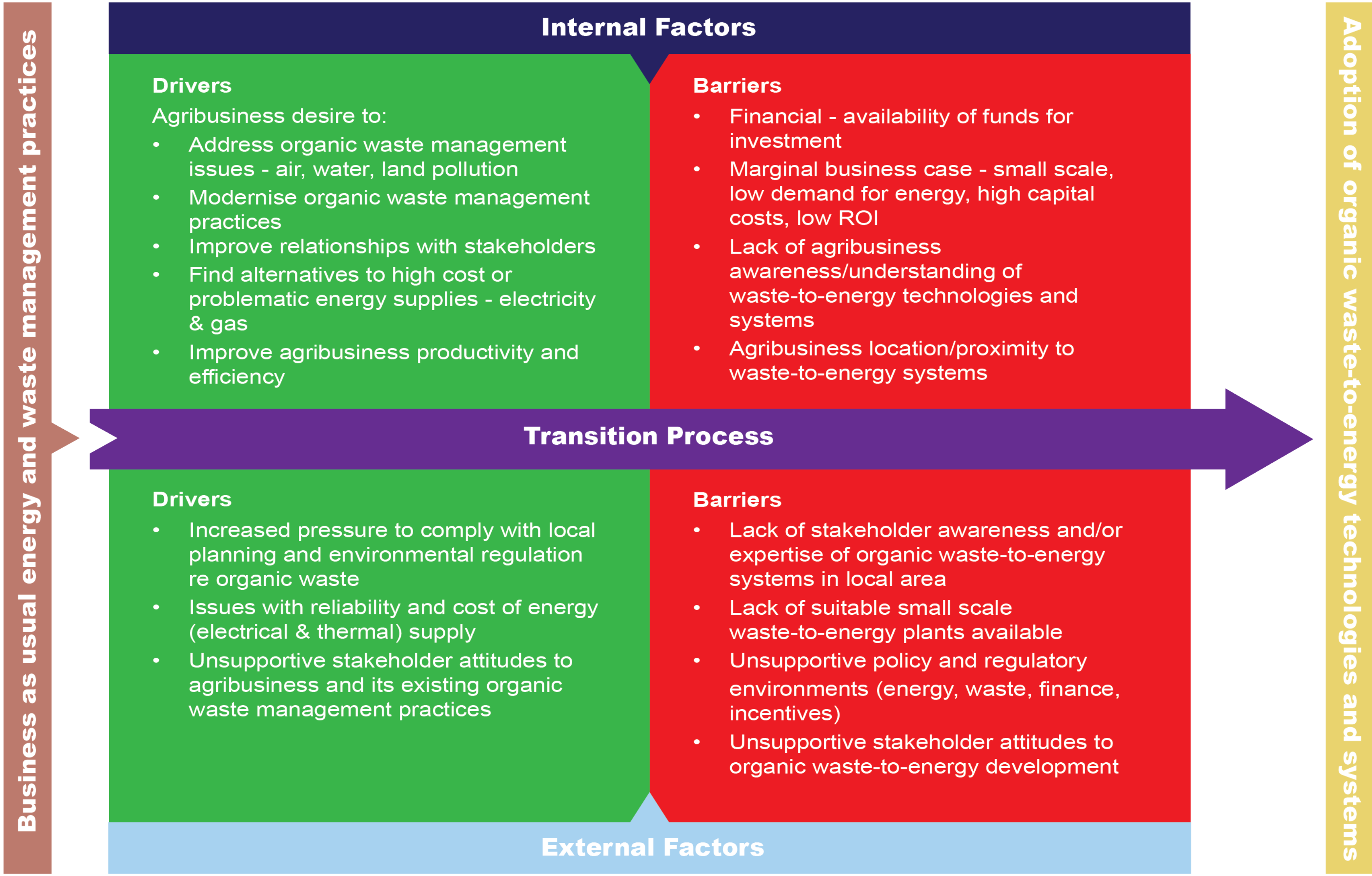


Figure 3.1 Bioenergy drivers and barriers heuristic

In this bioenergy drivers and barriers heuristic, an agribusiness transition journey begins on the left side of Figure 3.1, in the position of ‘business as usual’. The business’s waste management practices and energy consumption reflect established routines and systems already in place, and/or those commonly used at a particular location or in a particular agribusiness sector.

If agribusinesses engage with a transition process towards waste-to-management systems, then such actions are represented by the long purple arrow in the middle of the diagram. This process would move agribusinesses from their business-as-usual position to a new position, their destination, on the right side of the heuristic, where they have invested in waste-to-energy technologies and modernised their on-site organic waste management and energy practices.

The transition journey is impacted by a broad range of critical factors from inside (internal) and outside (external) the agribusiness, that can drive it through this innovation process or present obstacles and barriers that inhibit progress or halt the journey altogether. The drivers are the factors that prompt agribusiness decision-makers to engage with waste-to-energy systems; to reconsider their waste management and energy approaches and to explore their organic waste-to-energy options. These drivers also provide the impetus to move the agribusiness through a transition process and to potentially overcome the barriers it will encounter on its innovation journey.

In this representation, the light green internal drivers and dark green external drivers pull agribusinesses into the transition process and then push them through the journey, to the adoption of organic waste-to-energy technology. Internal drivers originate from within the agribusiness operation itself and include any desire to address issues with organic waste and/or energy, but these can also be influenced by factors from outside the organisation. External drivers are primarily associated with the responses of external stakeholders to the agribusiness’s waste management practices and the cost and reliability of the energy consumed by the agribusiness provided by external suppliers.

For food and fibre producers and processors for which ‘business-as-usual’ continues to meet their needs, there may be little interest (or drive) in adopting new technologies such as on-site organic waste-to-energy plants and so there may be no imperative to engage with a transition process. In such cases barriers are great and very few (if any) drivers for innovation exist. However, if the incumbent ‘business-as-usual’ waste management and energy approaches no longer meet the needs of the agribusiness or they are problematic, these agribusinesses may be driven to explore innovative waste management and/or energy options.

Barriers are the internal and external factors listed in the diagram’s red and brown quadrants that impede the transition process. These are the hurdles, obstacles and problems agribusinesses encounter on their innovation pathways and must overcome to progress through to the adoption of organic waste-to-energy technologies. The most common internal barriers include financial and/or business case considerations that can be specific to the type of agribusiness, such as its location, types of agricultural production/processing, energy needs, organic waste streams and levels of investment required.

A broad range of external barriers can present as substantial impediments to agribusiness transition to organic waste-to-energy technologies, including a lack of knowledge or awareness of organic waste-to-energy systems amongst key stakeholders, or a lack of supportive public policies, regulatory arrangements and local environments. The external barriers listed in Figure 3.1 relate to a market’s maturity or readiness to support the introduction of innovative technologies (Stræte et al., 2022). While bioenergy technologies (such as biomass combustion and anaerobic digestion) are relatively mature and commercially available (see Figure 1.1), immature markets and under-developed regulatory environments can increase the risks associated with agribusiness investment in these innovations. Such barriers, if significant, undermine the drivers so that the transition journey is not embarked on (or terminated mid-journey).

Agribusinesses complete their transition journey when they have been able to overcome the range of internal and external barriers to reach their destination. In this case, the destination is the point at which an agribusiness invests in technological modernisation, installing and beginning operation of an on-site organic waste-to-energy plant, as an integral part of its energy and waste management systems. The purple arrow of the transition process in the model indicates businesses generally move through this process sequentially from left to right, and that to reach the point of adopting these innovative technologies, barriers must be overcome. However, once an agribusiness has invested in organic waste-to-energy technologies, the barriers to this process do not necessarily go away and can be an on-going threat to the continuous viability and operation of these innovative technologies.

3.2.1 Relationships between MLP and bioenergy drivers and barriers heuristic

Figures 2.1 and 3.1 can provide insights into Australian agriculture's transitions to the adoption of organic waste-to-energy technologies. However, these models view these transitions from different perspectives, to complement each other and address this study's research question. While these figures share some common features, they are pictures with different units of analysis and other key differences in terms of scale (scope and time) and complexity.

The application of the MLP model (Geels, 2019) takes a global and holistic view of the multi-level journey of a new technology (in this study it is organic waste-to-energy technology) from its emergence as a radical niche innovation, to becoming a dominant and transformational socio-technical influence on the socio-technical regime, and further to dominate the landscape as well. This transition journey takes an innovative technology or approach through a four-phase development journey that may take a generation or more to complete. Figure 3.1, on the other hand, describes just one section of the MLP model, with the unit of analysis being the agribusiness adopting a waste-to-energy innovation, rather than the innovation itself. This heuristic has a much narrower focus than that of Figure 2.1 and occurs across a much shorter time-frame, with the Figure 3.1 drivers and barriers fitting in MLP's Phase 3 at the regime level. These drivers and barriers influence sustainability transition in the agribusiness sector that are featured in the MLP model, but Figure 3.1 has been developed to complement Figure 2.1 by detailing specific drivers and barriers relevant to organic waste-to-energy transition.

3.3 Impact of SPA in agribusiness transitions to organic waste-to-energy

Social Practice Approach (SPA) contends that changes in social practice, or routine patterns of action, play a critical role in sustainability transitions (Liedtke et al., 2017) and 'Social Practice Theories (SPT) can deepen our understanding of the key social mechanisms and dynamics underpinning transitions in everyday life' (Svennevik, 2022). As noted in Chapter 2, SPA has been identified as a useful approach to partner with MLP, to address some of MLP's perceived weaknesses in engaging with human agency. This study considers agency when applying the frameworks explored in the previous sections to agribusiness transitions to organic waste-to-energy.

In their analysis of the dynamics of social practice, Shove, Pantzar and Watson (2012, p. 21) posit 'two deceptively simple propositions'. The first is that social practices are comprised of three elements; meanings, competences and materials. The second explains that 'practices emerge, persist and disappear as links between their defining elements are made and broken'. For agribusinesses to adopt organic waste-to-energy technologies as part of their energy and waste management practices, linkages between the defining elements of these practices must be broken. Relevant meanings may include farm manager and/or worker understandings of and attitudes towards existing waste management practices, and knowledge and awareness of alternative waste management practices. Competences may include the knowledge and skills to collect, treat, store, transport and/or dispose of organic by-products of agrifood production.

Materials refers to the organic waste products themselves, as well as the agribusiness infrastructure, machinery and equipment required to manage biological wastes.

In making transitions in the form as represented by Figure 2.1, agribusinesses must make changes to operational routines related to their existing energy consumption and waste management practices. The internal and external drivers identified in academic literature represent reasons agribusinesses may seek to change their established practices. An agribusiness's existing energy and waste management practices can be significant contributors to agency issues, which can manifest as an erosion of stakeholder support for and/or the development of stakeholder opposition to existing approaches. These stakeholders are generally part of the MLP regime and include local actors such as employees, neighbours, clients/customers, suppliers and regulators. These stakeholders are affected as active participants in the incumbent agribusiness energy and waste management routines, or they may be impacted by the continuation of the status quo.

An example of a social practice issue acting as a driver for agribusiness organic waste-to-energy transitions could include a piggery's desire to change from its routine of spreading piggery wastewater/effluent (including washdown water and raw manure/urine) onto its surrounding farmland to a less problematic practice. While spreading effluent may be an established waste management strategy for many piggeries, odour issues associated with this practice can negatively impact local amenity and the ability of neighbours and local communities to enjoy their outdoor routines. This can impact the meanings attached to this practice, which may in turn contribute to poor relationships with these stakeholders and complaints from the farm's local communities and regulators.

As a social practice, this waste management routine and its odour issues can also affect the practice's meanings for employees, and be a source of discontent for those involved in the collection and spreading of the piggery's organic waste. In the face of stakeholders' discomfited attitudes towards the piggery's existing waste management routines, its managers may be prompted to explore waste management options with fewer odour issues, such as anerobic digestion.

On the other hand, social practice issues can also present as barriers impeding sustainability transitions. In the case of agribusiness transitions to organic waste-to-energy approaches in Figure 3.1, social practice issues around stakeholder awareness and understanding of waste-to-energy technologies, and/or unsupportive attitudes to these opportunities can emerge to lock in incumbent routines and resist change to new approaches.

For agribusiness managers and employees, a lack of awareness and understanding of the operation of organic waste-to-energy technologies are linked in this social practice's meanings and competences. This can result in low motivation and/or ability to explore relevant waste-to-energy options and foster negative attitudes to changing the established energy or waste management routines. Examples include employee concerns that a change in routines may result in an increase to their workload, or the new routines may be in areas in which they are unfamiliar and less comfortable, requiring additional development of knowledge and skills.

Similarly, community stakeholders can also develop negative meanings associated with bioenergy developments. These can emerge as unsupportive attitudes to local agribusiness organic waste-to-energy proposals, based on community perceptions of how personal routines might be adversely affected by changes in a primary producer/processor's energy and waste management technologies and processes. For instance, if an agribusiness proposed to supplement its organic feedstock supply (for a waste-to-energy plant) with biomass sourced off-site, neighbours could have concerns about the impact on their personal travel routines of increased truck movements required to transport the outsourced biomass to site. Such increases in truck movements could be viewed unfavourably by local communities believing their everyday lives would be negatively affected by an increase in local traffic congestion and hazards and a reduction in road conditions and amenity.

This research will apply a SPA lens to the drivers and barriers to agribusiness adoption of organic waste-to-energy approaches. The common drivers and barriers that impact these agribusiness transitions, identified in the academic literature, and summarised in Figure 3.1, include agency-related factors. These factors will be examined to explore the extent to which agribusiness energy and waste management routines enhance or inhibit transitions to the adoption of bioenergy technologies.

3.4 Summary

In this chapter, MLP is applied to agribusiness adoption of waste-to-energy technologies to provide a holistic understanding of the nature of these socio-technical transitions in the Australian context. The MLP framework focusses on the factors impacting the transition journeys of innovative technologies at three levels (niche innovation, regime and landscape) and this model is applied to explain the factors impacting the emergence of waste-to-energy technologies and their adoption by the agriculture sector. To complement MLP's application and to address this study's major research question and its sub-questions, a bioenergy drivers and barriers heuristic was presented. This heuristic features the drivers and barriers identified in academic literature as being the key factors impacting agribusiness transitions to organic waste-to-energy approaches. Finally, SPA is applied to identify the contribution of human agency within a social relations setting to the key drivers and barriers impacting waste-to-energy transitions in agriculture.

Building on the literature review in Chapter 2 and conceptual approaches set out in this chapter, the next chapter describes the research methodology for this study. This includes the philosophical approach adopted by this study and the research strategies, methods and techniques used to elicit information to respond to the major research question and its sub-questions.

4. Research methodology

This chapter describes the research methodology used in this study to explore its research question and sub-questions relating to the drivers and barriers impacting Australian agribusiness transitions to the adoption of organic waste-to-energy technologies. This description begins with outlining the overall methodological framework used in the study, followed by an explanation and justification of the philosophical paradigm and the approach adopted to theory development. The chapter then specifies the research design with research methods adopted, strategies utilised to collect and analyse data, concluding with ethics considerations and summary.

4.1 The research 'onion' framework

Research is a process of enquiry and investigation, and is systematic and methodical (Wilson, 2010). Saunders et al. (2015, p. 5) define research as '…a process that people undertake in a systematic way in order to find out things, thereby increasing their knowledge'. Research methodology refers to the systematic and methodical approach used to conduct research, but there exists a variety of different ways to find out things. The research methodology developed for this study is described using Saunders et al.'s (2015) research 'onion' framework for research methodology design.

Figure 4.1 offers a pictorial systematic representation to designing research methodology. It presents key methodological considerations as layers or rings of a research 'onion' framework. Each of the onion's rings represents an important aspect for consideration by researchers designing research projects. Within each ring sits a range of methodological options to be considered by researchers and decisions or choices to be made. The main choices concern research philosophy, research approach to theory development, methodological choice, research strategy, time horizon and data collection and analysis techniques and processes (Saunders et al., 2015).

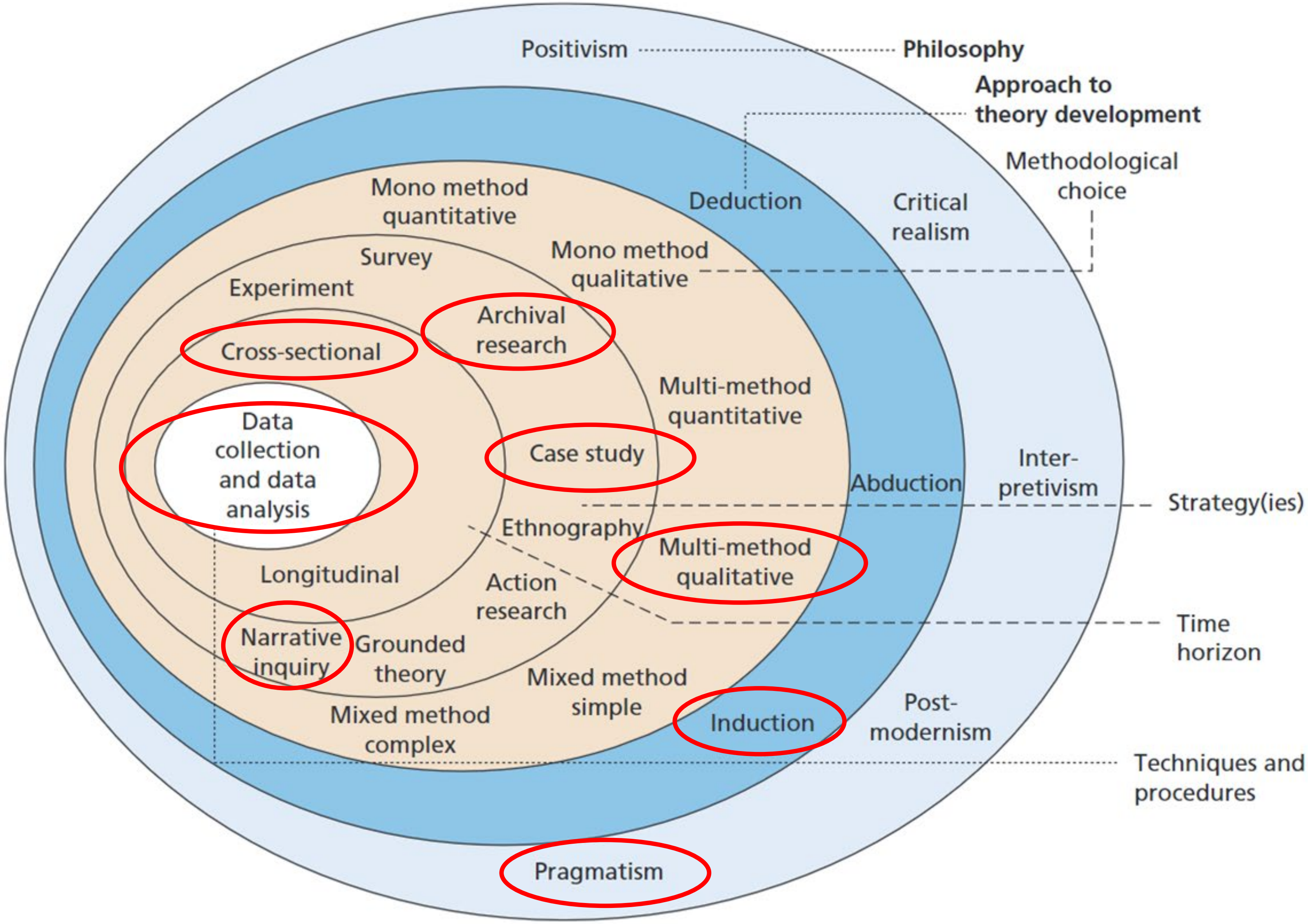


Figure 4.1 The research 'onion'

Source: Adapted from Saunders et al., (2015, p. 124)

This approach suggests that researchers begin their research design decision-making process at the outer-most ring of the onion and work through these choices sequentially into the centre of the onion. The choice made at each layer is guided by the selection made at the previous layer and will influence the choice made at the next layer. The methodological choices made for this study are circled in Figure 4.1.

4.2 Research philosophy - Pragmatism

The basic beliefs that comprise a researcher's research philosophy are related to a worldview that defines for the researcher '… the nature of the "world", the individual's place in it, and the range of possible relationships to that world and its parts' (Guba & Lincoln, 1994, p. 107). Consideration of a researcher's research philosophy is critical, as the beliefs and assumptions of the main philosophical paradigms underpin their methodological choice, research strategy, data collection techniques and analysis processes (Saunders et al., 2015).

Research theorists identify several philosophical paradigms that guide research design, and they describe several key types of differences in their assumptions about knowledge. Social scientists characterise two of these key areas of difference as ontological assumptions and epistemological assumptions (Bryman, 2016; Crotty, 1998; Saunders et al., 2015; Wilson, 2010; Guba & Lincoln, 1994). Ontological assumptions are concerned with the nature of reality, what is real and what can be known. Epistemological assumptions are about the nature of knowledge, what is acceptable knowledge and if/how this knowledge can be accessed by the researcher (Saunders et al., 2015; Wilson, 2010; Guba & Lincoln, 1994).

In considering these essential distinctions in beliefs and assumptions about knowledge, research theorists have identified a range of philosophical paradigms that guide research methodological choices and design. Traditionally, there has been a philosophical dichotomy of positivist/objectivist and interpretivist/constructionist approaches underpinning research, with positivism/objectivism valuing quantitative research and interpretivism/constructionism supporting qualitative methods (Bryman, 2008; Johnson & Onwuegbuzie, 2004; Tashakkori & Teddlie, 1998). Philosophical paradigms became more diverse as additional theoretical perspectives emerged with different ontological, epistemological, axiological and/or methodological assumptions. Saunders et al. (2015) identify five major philosophical paradigms that guide research in business and management; positivism, critical realism, interpretivism, post-modernism and pragmatism, but also acknowledge others such as subjectivism, nominalism, social constructivism, functionalist, radical humanist and radical structuralist paradigms.

This study embraces the pragmatism research philosophy to focus on the problem that Australian agribusinesses have been slow to adopt on-site organic waste-to-energy technologies, which represents lost opportunities to realise social, economic and environmental benefits associated with these innovations. Based on the scholarly and grey literature exploring these benefits, this research adopts the pragmatism position that agribusinesses transitioning to organic waste-to-energy approaches, in certain circumstances, find this preferable to traditional approaches to energy generation/consumption and management of organic waste. This study also assumes the adoption of organic waste-to-energy technologies can play a role in assisting Australia's agriculture sector to transition to more sustainable practices. The unit of analysis of this study comprises Australian agribusinesses that have experience of the transition process to the adoption of organic waste-to-energy technologies. That is, they have transitioned from business-as-usual energy and waste management approaches, to the integration of organic waste-to-energy technologies into their operation's energy and waste management processes.

Pragmatism research philosophy originated in the late-nineteenth to early-twentieth centuries with the work of American philosophers Charles Sanders Peirce, William James and John Dewey (Kelly & Cordeiro, 2020; Saunders et al., 2015), and '…has been refined in newer directions by latter-day neo-pragmatists (e.g. Davidson, Rescher, Rorty, Putnam)' (Johnson & Onwuegbuzie, 2004, p. 17). Pragmatism helps to bridge the divide between opposing philosophies. It rejects traditional dualisms (e.g. rationalism vs. empiricism, realism vs. antirealism, free will vs. determinism, Platonic appearance vs. reality, facts vs. values, subjectivism vs. objectivism) (Johnson & Onwuegbuzie, 2004; Simpson & den Hond, 2021) and the 'paradigm wars' (positivism vs. interpretivism, quantitative vs. qualitative research) (Borges & Revez, 2019; Bryman, 2008). Instead, pragmatism is centrally interested in 'what works' to deliver practical outcomes by addressing research problems and research questions in the real world (Kelly & Cordeiro, 2020; Saunders et al., 2015; Tashakkori & Teddlie, 2010; Voparil, 2021).

Pragmatism's ontological approach is one that begins with a problem or doubt and makes research methodology choices that can best produce the desired outcomes (Simpson, 2018; Tashakkori & Teddlie, 1998); practical responses to the research question, '… to make us happier by enabling us to cope more successfully with the physical environment and with each other' (Rorty, 1991, p. 27). This approach may include positivist and interpretivist beliefs and assumptions about knowledge and may consider both quantitative and qualitative research methods, depending on what will work best in addressing the specific research objectives (Borges & Revez, 2019; Saunders et al., 2015).

Pragmatism's epistemological perspective is not preoccupied in the subjectivism vs. objectivism dichotomy (both are accepted), but has a sharp focus on what is practical and can be applied (Creswell & Plano Clark, 2007). Pragmatism values both quantitative and qualitative data collection techniques and analysis procedures of the mixed-methods approach (Borges & Revez, 2019; Saunders et al., 2015). Thus, mixing and matching research tools in a method specifically designed to most effectively explore the research questions underpins pragmatism (Borges & Revez, 2019; Johnson & Onwuegbuzie, 2004; Simpson & den Hond, 2021).

Pragmatism as a philosophy is well suited to this study's objectives seeking to understand the transition processes of Australian agribusinesses adopting organic waste-to-energy technologies. The main problem this study seeks to address is that Australian agribusinesses have been slow to make this change. Aligning with the pragmatism philosophy, this study infers that the reality surrounding the problem and research questions exists primarily with the experiences of decision-makers within Australian agribusinesses that have engaged in the transition to organic waste-to-energy adoption, as well as with key stakeholders from outside these businesses. However, insights relevant to the problem and research question may also be found in existing sources of information on Australian agribusinesses and renewable energy development. As research based on the pragmatism research philosophy, this study develops a research methodology best suited to collecting data from these different sources.

4.3 Approach to theory development

The next research methodology choice to be considered is the study's approach to theory development. This choice requires researchers to nominate one of three main approaches to develop theory: a deductive approach, an inductive approach or an abductive approach. A deductive approach begins with a theory or hypothesis based on existing theory, then designs a research strategy and collects data to test or to prove or disprove that hypothesis (Wilson, 2010). This approach is usually associated with quantitative research. Alternatively, an inductive approach collects data on a particular phenomenon and analyses the data to identify patterns and build theory to describe or explain the research (Saunders et al., 2015). This approach is often associated with qualitative research. An abductive approach begins with data collection and analysis to develop new theory or to modify existing theory, and then tests the new/modified theory through subsequent data collection and analysis (Saunders et al., 2015).

This study adopts an inductive approach to theory development. This research is based on the conceptual framework described in the previous chapter and its research methodology is designed to collect data from a relatively small number of cases. Themes and patterns are identified inductively from the specific to the general (Saunders et al., 2015), to inform theory development.

4.4 Methodological choice

The methodological options considered by researchers are related to the philosophical paradigms of their research and the approaches to theory development adopted. Methodological choices require researchers to choose quantitative strategies, qualitative strategies or a combination of quantitative and qualitative strategies. Quantitative research generally uses data collection strategies and techniques such as experiments, surveys and statistical analyses to generate numerical data to test a theory or hypothesis (Saunders et al., 2015; Shan, 2022; Wilson, 2010). On the other hand, qualitative studies collect and analyse data in narrative form, with qualitative researchers typically using narrative data collection techniques such as semi-structured interview, focus group, ethnography and case study methods to explore research questions (Shan, 2022). Both quantitative studies and qualitative studies can use a mono-method strategy, which uses one data collection technique, or a multi-method strategy, which utilises multiple data collection strategies (Saunders et al., 2015).

Traditionally, a methodological divide has existed between quantitative and qualitative research, with the two approaches functioning in parallel, independent of each other, with researchers identifying with and using one approach, but not the other (Shan, 2022). For several decades, arguments about the merits of both approaches have formed part of the so called paradigm wars – debates or ‘wars’ ‘…in the social and behavioural sciences regarding the superiority of one or the other of the two major social science paradigms or models' (Tashakkori & Teddlie, 1998, p. 3). The same authors conclude the paradigm wars is essentially '…the conflict between the competing scientific worldviews of positivism (and variants, such as post-positivism) and constructivism (and variants, such as interpretivism) on philosophical and methodological issues' (Teddlie & Tashakkori, 2009, p. 20).

Pragmatism rejects the premise of the paradigm wars and asserts that '…social scientists do not have to make an either-or choice between the postpositivist position and the constructivist/interpretivist position. They are free to choose the methods, data, and procedures of research that best meet their needs and purposes' (Shan, 2022, pp. 3-4). As a result, research guided by a pragmatist philosophical worldview is often associated with research using a mix of methods. Literature on research that applies a mix of methods has increased markedly since the mid-1990s, but there is still debate about this approach (Anguera et al., 2018; Morse, 2003). The arguments revolve around the use of quantitative and/or qualitative research methods.

Mix of methods for research needs to be defined. Plano Clark and Ivankova (2015, p. 60) define multi-methods research as 'studies in which the researcher combines multiple quantitative approaches (e.g. experimental and survey research methods) or combines multiple qualitative approaches (e.g. ethnographic and narrative research methods) or combines both quantitative and qualitative approaches'. On the other hand, mixed methods research combines both quantitative and qualitative research methods (Cameron, 2011; Johnson & Onwuegbuzie, 2004; Saunders et al., 2015; Shan, 2022; Tashakkori & Teddlie, 1998).

Some researchers use the terms mixed methods and multi-methods interchangeably (e.g. Borkan, 2004; Ivanova, 2018; Mandić et al., 2009; Stange et al., 2006), with Anguera et al. noting this practice was 'particularly prevalent around the turn of the millennium' (2018, p. 2759). Other scholars acknowledge the distinctions between mixed methods and multi-methods research but combine the two methods into one; multi-method and mixed methods research, also known as MMMR (Anguera et al., 2018; Hesse-Biber & Johnson, 2015; Knappertsbusch et al., 2021).

While the debate continues about how multi-methods and mixed methods should be defined, this research project recognises the more common view. According Hesse-Biber (2015, p. xxxix), the more accepted understanding is; ‘Multi-method research differentiates itself from mixed methods in that its definitional borders do not require having at least one quantitative/qualitative method in any given research project’. This view is reflected in the methodological choices provided in the research onion (Saunders et al., 2015) (see Figure 4.1), which includes mixed methods (simple or complex), and multi-methods (quantitative or qualitative) options. From these options, this study chooses the multi-methods qualitative approach.

4.5 Multi-method qualitative research

As research with a pragmatist philosophical perspective, this study prioritises methodological choices that will work best to reveal answers to the research question. Just as pragmatism rejects the paradigm wars between quantitative and qualitative research approaches, multi-methods research rejects the ‘methodological parochialism’ (Brewer & Hunter, 2005, p. 9) affecting research methods choices. According to Brewer and Hunter (2005, p. 9):

> There is a strong tendency in all fields of social science for particular methods to be valued so highly by their users that they become ends in themselves, to be defended against rival methods and nourished by selecting only research problems for which they are well-suited.

Instead, multi-methods research recognises all research methods have strengths and weaknesses. By combining complementary strategies, multi-methods approaches can strengthen the quality of research and heighten confidence in the validity of research findings (Brewer & Hunter, 2005; Mik-Meyer, 2020). The use of more than one source of data allows for the validation of research data, analysis and interpretation, through triangulation. A key strength of multi-methods research, triangulation uses ‘two or more independent sources of data-collection methods within one study in order to help ensure that the data are telling you what you think they are telling you’ (Saunders et al., 2015, p. 730).

This study adopts a multi-methods qualitative research design (see Figure 4.2), featuring three different qualitative methods, conducted sequentially, in three stages.

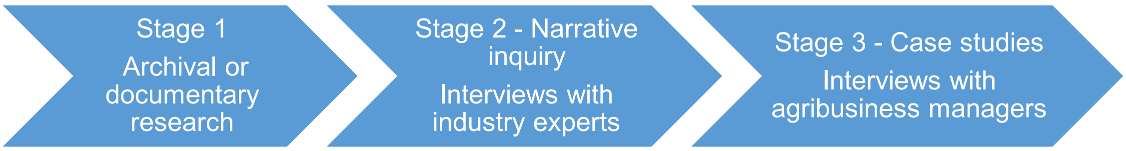


Figure 4.2 Multi-methods qualitative research design

According to Creswell and Plano Clark (2018, p. 614), sequential research designs can be effective approaches, as ‘results from the first type of data can then inform what is collected in the second type of data, usually by making decisions about sampling, research questions, and instruments’. One of the primary reasons for this study’s sequential multi-methods design is initiation. This is where the initial use of a qualitative method provides background information to better understand the research subject, and to assist with the refinement of subsequent qualitative methods for use later in the study (Saunders et al., 2015).

The purpose of this study’s first stage is to introduce the reality of agriculture applications of organic waste-to-energy technologies in Australia and to support the latter stages in this research design. The data collected in this initial stage provides insights into the ‘who, what, where and how many’ of organic waste-to-energy installations in Australian agribusiness. This stage collects data, from secondary sources, exploring the number of organic waste-to-energy plants in operation in

Australian agribusinesses, the geographic locations and types of agribusinesses, the size/capacity of waste-to-energy plants installed, and the bioenergy conversion pathways/technologies used. These data help to define the scope of organic waste-to-energy in Australian agriculture, identify what can be known and provide criteria for the later purposive selection of data sources.

Creswell and Plano Clark (2018, p. 614) also posit, 'Sequential designs also implicitly weight one type of data as more important than the other as the first data collected informs design and content decisions for the second data collection', and this is the case in this study, with an emphasis on data collected in Stages 2 and 3. Figure 4.2 shows Stages 2 and 3 use different qualitative research methods (from that used in Stage 1), and focus on data from different sources.

The latter two stages are similar, in that they both focus on collecting data from sources with knowledge, experience, expertise and/or relevant insights to Australian agribusiness engagement with organic waste-to-energy systems. Stage 2 has a focus on collecting relevant narrative data from stakeholders (industry experts) external to Australian agribusinesses that have adopted waste-to-energy technologies. However, Stage 3 has a focus the agribusiness's internal stakeholders. In terms of answering this study's research question, the data collected in Stages 2 and 3 add depth and understanding to the descriptive data collected in Stage 1, but the Stage 1 data plays a critical initiation role to inform participant selection for the subsequent stages and contextualise the choices that emerge from the pragmatism approach.

This study's multi-methods qualitative research design is a suitable methodology to apply the MLP and SPA frameworks to Australian agribusiness energy and waste management approaches. Narrative explanation and the comparison of multiple cases have been identified as viable approaches for analyses of sustainability transitions (Köhler et al., 2019), with data collection from stakeholder interviews and/or focus group discussions featuring in several MLP studies in the agrifood sector

(Bremmer & Bos, 2017; Bui et al., 2016; Deviney et al., 2023; Hassink et al., 2013; Moritz et al., 2023; Polita & Madureira, 2021; To et al., 2018).

There is some debate, however, concerning the value of interview-based research of social practices. This debate centres on differences between what practitioners may say about their practice in an interview, and what they might actually do in practice (Asmare et al., 2022; Schatzki, 1996). As a result, the method frequently identified as the ‘gold standard’ of social practice research, involves the collection of data through observation of the performance of the practice being studied, in the field (Nicolini, 2017; Schmidt, 2017; Sedlačko, 2017). There has also been enthusiasm for multi-methods approaches that combine social practice observations with interview-based methods and/or other data collection approaches (Asmare et al., 2022; Balázs et al., 2016; Crivits & Paredis, 2013; Littig & Leitner, 2017; Minas, 2019; Poulsen, 2017).

When it is not practical or possible for the researcher to witness performance of practices in the field, the use of interviews as the primary research method is viewed as the next best data collection approach (Nicolini, 2017). This was the case with this research project, as it was not possible for the researcher to travel to relevant agribusiness sites. Observations of relevant on-site energy and waste management practices could not be conducted, due to COVID-19-related travel restrictions imposed in Australia during the data collection stages of this study.

In social practice research, a review of 118 academic papers combining SPA and MLP approaches found the use of interviews to be the most common data collection method used, with 27% of studies utilising this strategy (Keller et al., 2022). The other main data collection methods used in these papers were case studies (17%), desk research (15%), document analysis (12%) and observations (10%) (Keller et al., 2022, p. 20). Interviews also feature prominently in qualitative multi-methods research designs exploring the social practices in agriculture (Blättel-Mink et al., 2017; Jansma & Wertheim-Heck, 2021; Kaiser & Burger, 2022; Kontothanasis, 2017). The next section explores the strategies adopted in this study’s multi-method qualitative research design.

4.6 Research strategies

A research strategy is a plan for how a researcher will go about answering research questions (Saunders et al., 2015) and provides a link between a study’s philosophy and choices of methods for data collection and analysis (Denzin & Lincoln, 2011). A range of strategies exist and have been widely used to conduct research in a range of discipline areas. Strategies commonly used in business and management research include experiment, survey, archival and documentary research, case study, ethnography, action research, grounded theory and narrative inquiry (Saunders et al., 2015). The three qualitative research strategies adopted in this study are documentary research in Stage 1, narrative inquiry in Stage 2, and case study analysis in Stage 3. These strategies are explored in the following sections.

4.6.1 Documentary research

Documentary inquiry is a research strategy that collects primary or secondary data recorded in textual, visual or audio forms. Buckler, Dolowitz and Sweeney (2008, p. 39) define documents as ‘…any written, printed, photographed, painted or recorded material that can be used to provide information or evidence’, but in its simplest form, documents are records of something and exist in many different forms. According to Tight (2019), documentary research is an often overlooked aspect of social research, but it has much to offer. For research in the business and management discipline, the most common strategy for the application of documents, is to combine documentary data collection and analysis with another method (Tight, 2019).

From a practical perspective, documentary research can provide social researchers with vast amounts of relevant data that already exists and is readily accessible for little or no cost. The emergence of the Internet and the digitisation of documents has substantially increased the documentary data available to researchers (Saunders et al., 2015; Tight, 2019). Some documents, whether in digital formats stored online or hard copy resources, may be beyond the reach of researchers for a range of reasons, including the location and/or accessibility of the documents, or the researcher's permission to access these materials. However, there are also many digitalised documents available on the Internet that can be valuable sources of data and are able to be accessed efficiently and relatively easily.

Tight (2019, p. 62) identifies five main types of documentary research: literature reviews, systematic reviews and meta-analyses, secondary data analysis, archival and historical research, and policy research. The type of documentary research used in this study is secondary data analysis; that is, analysis of data collected by someone else. For Tight (2019, p. 64):

> The key advantage of secondary data, rather obviously, is that you don't have to collect it yourself. Not only does this save a great deal of time, cost and trouble, but, for most social researchers, working on their own or in a small team, it would simply be unfeasible to collect such a substantial data set. If it relates to a topic of interest to you, and you can get access to it, its analysis is, therefore, likely to be very useful; either instead of collecting more data yourself, or as a supplement, comparator or context to this.

The time, cost and trouble saved by accessing secondary data was an important consideration for this research project. Stage 1 of this study collects data from documents available online. Documents relevant to this study's research question include digital databases and lists of some of Australia's renewable energy generators and maps identifying the approximate location of Australian bioenergy generation sites. Other relevant online documents include case studies, reports, news articles and webpages.

4.6.2 Narrative inquiry

In Stage 2 of this study, narrative inquiry is used to explore the narratives of stakeholders (external to agribusinesses), with substantial expertise in and experience of agribusiness engagement with organic waste-to-energy plants and systems in Australia. Narrative inquiry is a research strategy to record the lived experiences and/or perspectives of an individual or small group of people, relating to a particular phenomenon being studied (Clandinin, 2006; Kutsyuruba & Stasel, 2023). According to Connelly and Clandinin (2006, p. 375):

> People shape their daily lives by stories of who they and others are and as they interpret their past in terms of these stories. Story, in the current idiom, is a portal through which a person enters the world and by which their experience of the world is interpreted and made personally meaningful. Narrative inquiry, the study of experience as story, then, is first and foremost a way of thinking about experience. Narrative inquiry as a methodology entails a view of the phenomenon.

Narrative inquiry is an ‘event-driven’ research tool that focusses on the stories told by humans of their experience (Mertova & Webster, 2019, p. 58). Human perceptions and interpretations of their experiences of critical events have ‘a unique, illustrative and confirmatory nature in relation to an investigated phenomenon’ (Mertova & Webster, 2019, p. 103), and can be explored through narrative inquiry. A narrative is a story or an account of an individual’s experience, which features a sequence and flow of critical events, that convey meaning to the researcher about the narrators’ perspective of a phenomenon (Connelly & Clandinin, 2006; Saunders et al., 2015).

The use of narrative inquiry is common in studies in the fields of education, social sciences, humanities, business and management research (Kutsyuruba & Stasel, 2023; Saunders et al., 2015). This strategy is particularly well suited to this research’s pragmatism philosophy (Clandinin, 2006), and the human-centred focus of narrative inquiry (Mertova & Webster, 2019) aligns with this study's emphasis on human agency (see Section 3.3).

Narrative inquiry can use a range of research methods, including autobiography, autoethnography, biography, case study, ethnography, life history, and portraiture (Kutsyuruba & Stasel, 2023). This strategy is often associated with qualitative research interviews, in which participants are 'inevitably' involved in story-telling (Saunders et al., 2015, p. 197). A useful application of narrative inquiry collects and contrasts the narratives of a small group of participants (one, two, or three) that focus on the same specific event or phenomenon.

Conversely, the narrative inquiry approach used in this research features a slightly larger, purposively selected sample of eight participants. In this sample, 'those selected are judged as being critical cases or extreme cases, from whom much may be learnt' (Saunders et al., 2015, p. 198). The stakeholders interviewed in Stage 2 are identified as external agribusiness stakeholders with expertise and experience in Australian agribusiness adoption of organic waste-to-energy technologies.

Instead of participants focussing on the same event, this study's approach has a broader focus on each participant's interpretation of the critical events they have experienced, that are related to Australian agriculture's transition to organic waste-to-energy approaches. To analyse the narratives, the researcher identifies and selects strands and themes that emerge from the narrative accounts, to construct an overall story of the phenomenon being researched (Saunders et al., 2015).

4.6.3 Case study research

Stage 3 of this study adopts the case study strategy to collect data relevant to its research question. Sage Research Methods (2023, p. 1) acknowledges case study research has various meanings, '… but today usually refers to the intensive study of a small number of cases, or a single case'. As the third qualitative component of this study's multi-methods methodological choice, the case study research strategy 'is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and context are not clearly evident' (Yin, 2014, p. 16). This strategy can collect data from intensive and in-depth research, supporting rich, empirical descriptions and theory development (Eisenhardt, 1989; Eisenhardt & Graebner, 2007; Saunders et al., 2015; Yin, 2014). Case studies are concerned with what has happened in the real-world and try to illuminate decisions made in a particular context: why these decisions were taken, how they were implemented, and with what result (Schramm, 1971).

The subject of case study research, or the case, can be a person, a group of people, an organisation, an event or many other types of case subject (Saunders et al., 2015). This study explores multiple cases relevant to the impact of drivers and barriers on the decision-making of Australian agribusiness managers that have engaged in the transition from business-as-usual waste management practices towards the adoption of on-site waste-to-energy technologies. This multiple case study approach has been chosen to allow for replication (Yin, 2014), from cases that are similar, in that they are all Australian agribusiness managers that have experienced a transition to organic waste-to-energy technologies. However, these cases also have important differences, in terms of the types of agribusinesses they manage, and the locations, size, waste feedstocks used, and technologies adopted by their operations.

The cases are stakeholders from inside agribusinesses with substantial expertise and experience in agribusiness transitions to organic waste-to-energy technologies in Australia. These cases primarily feature agribusiness owners, managers and key employees involved in decision-making processes and/or the on-going operation of organic waste-to-energy technologies, as an integral part of their on-site energy and waste management processes. The focus of these case studies is on interviews identifying drivers and barriers and exploring how and why these factors impact on the decision-making of the agribusiness owner/managers in their transition processes.

4.6.4 Time horizon

When determining the time horizon for research projects, researchers must consider two main types of time frames; cross-sectional research or longitudinal studies. Saunders et al. (2015, p. 200) call these time horizon choices the ‘snapshot’ and ‘diary’ approaches, with cross-sectional research taking a ‘snapshot’ of the phenomena at a particular point in time. Conversely, the ‘diary’ approach is longitudinal research that studies the change or development of phenomena over a particular period of time. This research study takes a cross-sectional approach, focussing on the period 2010 to 2021 as one decision-making period affected by similar circumstances.

4.7 Data collection

As described in Section 4.5, this study adopts a multi-methods research design that utilises three different qualitative research strategies and data collection techniques. The most common combinations of data collection strategies used in multi-methods qualitative research, are interviews combined with observations and/or documents (Mik-Meyer, 2020). This study’s multi-methods research design also uses this combination; documentary research and semi-structured interviews, which are described in the following sections.

4.7.1 Stage 1 – Documentary research

The first stage of this study comprises searches for and collection of documentary data from secondary sources, relating to the installation and operation of organic waste-to-energy technologies by Australian food and fibre producers and processors.

This stage is an important first step in this research, as it creates a picture that measures the contemporary reality (2010-2021) of the application of waste-to-energy technologies at Australian agribusinesses and identifies the descriptive and contextual characteristics of the businesses that have engaged with this transition. These characteristics include the business's location, agribusiness sector, scale/size, waste-to-energy technology installed, volumes and types of organic waste produced, volumes and forms of energy produced and the names of key contacts. The main purpose of this stage is initiation; to better understand the research problem on the current state of waste-to-energy systems, to help with redrafting of the Stage 2 and 3 interview questions, to assist with the formulation of the criteria for selection of cases and to identify industry experts and potential interview participants (Saunders et al., 2015).

Stage 1 data collection utilises three main Internet search strategies to source relevant documents and data from online sources. The first strategy was to review existing online databases of bioenergy installations in Australia. The key data sources for this strategy were the Biomass Producer website, hosted by the Australian Government's Rural Industries Research & Development Corporation (RIRDC, 2013), and the Clean Energy Council's Renewable Energy Map (2014b), which both included Google maps embedded. The Google maps featured dropped pins marking the locations of bioenergy installations and resources in Australia and when a pin was selected, information about the bioenergy resource at that location would open in a pop-up window. Information provided included details about the bioenergy installations, technology providers/consultants, industry experts, and/or biomass feedstock suppliers in Australia.

The dropped pins provide varying levels of detail about the bioenergy installation or resource at each location – some references are very brief and provide basic details such as the name of the company/organisation and the technology type installed, while others are more informative, providing additional descriptive data about the organisation and/or the technology used and links to company websites, published case studies, news articles and contacts details and procedures for requesting further information. In many cases, the data provided on the websites and online documents did not provide all data required for this research stage, but they did provide an excellent starting point by providing key information to identify potential subjects for Stages 2 and 3, as well as the names, locations and other keywords for additional online searches.

Documentary data collected in Stage 1 of this study was collected in 2016-2018, with most of the data sourced from two Australian websites; Biomass Producer (RIRDC, 2013) and Renewable Energy Map (Clean Energy Council). However, these websites are no longer available, as much of the data from these sources is now captured by the Australian Government's Australian Renewable Energy Mapping Infrastructure Project (AREMI), which was completed in 2021 (ARENA, 2023). The AREMI platform features more than 1,000 searchable datasets 'ranging from renewables, electricity, infrastructure to environment, boundaries, population, research and weather' (ARENA, 2023, para 2) and presents these datasets on the Australian Government's NationalMap (Geoscience Australia and CSIRO, 2023). The Biomass Producer website (www.biomassproducer.com.au) is no longer managed by RIRDC. An archived version of the content on the Biomass Producer website in 2017 is available (see Appendix F), but this does not include the Google map and the key bioenergy data it contained. The URL for the Renewable Energy Map is still active, but links to the Clean Energy Council's Technologies webpage (Clean Energy Council, 2014b), not the Google map used in this research.

The second online search strategy used in Stage 1 was to search for a range of relevant keywords in online search engines such as Google, Google Scholar and Ecosia. The terms used in these searches included various combinations of the following keywords: bioenergy, waste-to-energy, energy-from-waste, biogas, biomethane, woodchip, boiler, sawdust boiler, heat, energy, electricity, combined heat and power, agriculture, agribusiness, farm, farmer, producer, processor, grower, piggery, dairy, feedlot, winery, viticulture, sugar, bagasse, grain, manure, waste, energy, abattoir, food processor, protected cropping, glasshouse, greenhouse, straw, pellets, heater, generation, renewable energy, olives, nuts and cannery. These general searches were particularly effective in identifying news reports, media releases, industry case studies and web pages relevant to organic waste-to-energy installations at Australian agribusinesses.

The third online search strategy used in this study was to search websites of key organisations, industry peak bodies, companies and stakeholders, for data relating to agribusiness organic waste-to-energy applications in Australia. These searches included keyword searches using the website search functions and site maps, scanning for relevant webpages, reports, case studies, newsletter articles, video/audio clips and media releases.

The relevant data from the Stage 1 searches was recorded and organised in an Excel spreadsheet with two main pages of data; the first page listed agribusinesses with bioenergy installations, the second listed relevant industry experts. The first page recorded descriptive data concerning agribusinesses in Australia that have installed organic waste-to-energy technologies. This data included the business name, name of contact, contact position, email address, telephone number, location, state, agribusiness type, energy generation capacity (MW), waste-to-energy technology, feedstock type, date of installation, data source/weblink, plant status (under construction, operating or decommissioned), other comments. The second spreadsheet page recorded the details of bioenergy stakeholders with expertise/experience with agribusiness adoption of organic waste-to-energy technologies in Australia. This spreadsheet page recorded information under the following headings; name, organisation, position, location and state, email address, telephone number, role in the bioenergy and/or agribusiness sector, area of expertise/experience, data source and other comments.

The primary objective for Stage 1 was to provide initiation; to provide a picture of the reality of the application of bioenergy technologies by Australian agribusiness, to generate energy from organic waste. A critical part of compiling this snapshot was to collect descriptive data about these applications, to support a purposive interviewee selection approach in the next stages of this study. These stages, Stages 2 and 3, are explored in the following sections.

4.7.2 Stage 2: Narrative inquiry - Interviews with industry experts

Stage 2 features the second of the qualitative components of this research design; narrative inquiry. This strategy collects relevant data using inductive, semi-structured in-depth interviews with eight external stakeholders who have substantial experience and expertise in Australian agribusiness engagement with organic waste-to-energy systems. In semi-structured interviews, the researcher has a general structure prepared for the interview, in the form of identified themes to cover and prepared questions for the interviewee. However, the researcher also retains some flexibility to adjust the interview structure from one interview to the next; to omit questions or to ask follow-up questions to probe responses from the interview participant, depending on what happens in the interview (Saunders et al., 2015; Wilson, 2010).

Semi-structured interviews are a commonly used data collection strategy in qualitative research and narrative inquiry, with a key strength of this technique being 'its attention to lived experience while also addressing theoretically driven variables of interest' (Galletta, 2013). The interviews with agribusiness and bioenergy industry experts provide narrative accounts and high-level insights into their lived experience of critical events in the development and performance of organic waste-to-energy systems in Australian agribusinesses. See Appendix D (Stage 2) for the prepared questions for the interviews with experts.

A purposive approach was adopted for the selection of stakeholder participants for the Stage 2 interviews. Purposive sampling is an interview participant selection method where '…researchers intentionally select (or recruit) participants who have experienced the central phenomenon or key concept being explored in the study' (Creswell & Plano Clark, 2018, p. 176). This approach is often used to ensure variety in the key characteristics (relevant to the research question) of the sample members participating in the research (Bryman, 2012). A purposive participant selection approach was used in Stage 2 of this study, to ensure the diversity of participants selected was broadly reflective of the variety of perspectives and experiences of agribusiness applications of organic waste-to-energy technologies in Australia.

To provide this diversity, this study selected participants with expertise/experience working with range of organic waste-to-energy technologies; from a variety of organisation/business types; playing a range of different roles in the organic waste-to-energy sector. Table 4.1 lists the bioenergy experts interviewed in Stage 2. The interview participants represented a range of different types of organisations, including Local and State Government agencies; technology providers, consultancies and agencies; universities and other research organisations; and bioenergy advocacy bodies. The roles of these participants included bioenergy policy experts; technology experts and consultants; and bioenergy researchers. The bioenergy technologies in which these participants had expertise and experience included biomass combustion boilers, anaerobic digestion, gasification and/or pyrolysis.

Selected experts were invited to participate in an interview via email. The invitation email (see Appendix A) introduced the researcher and the study, with additional information about the project provided in the study's Plain Language Information Statement (see Appendix B) and an Informed Consent form attached (see Appendix C).

Experts invited to participate in the Stage 2 interviews generally accepted or declined to participate by return email. Experts accepting the invitation were then contacted via telephone to discuss the interview further, ask/answer any questions and schedule a time and place to conduct the interview. A total of 11 experts identified in Stage 1 were invited to participate in an interview in Stage 2; seven accepted the invitation, two did not respond to invitation emails and voicemail messages, one politely declined and one declined but arranged for a replacement interviewee.

The Stage 2 interviews with bioenergy experts located in Victoria were conducted in-person and recorded using a digital voice recorder. Interviews with participants from interstate were conducted via Microsoft Teams and recorded using this platform's meeting record function. Recordings of the interviews were saved as MP4 video files or MP3 audio files stored on the Federation University intranet.

As semi-structured interviews, Stage 2 participants were asked a series of questions relevant to the research question and sub-questions – see Appendix D (Stage 2). In drafting the questions for Stage 2 interviews, this study was initially guided by the key drivers and barriers identified as impacting agribusiness transitions to bioenergy in other countries (see Sections 2.9 and 2.10, and Figure 3.1). The questions were designed to probe interview participants' stories of their experiences, observations and engagement with Australian agribusinesses that have explored their organic waste-to-energy options and the insights. In particular, these interviews focused on the participants' insights gained about the drivers and barriers impacting agribusiness investment in waste-to-energy technologies.

The Stage 2 interviews were conducted from May 2019 to July 2020. Questions were generally open questions that asked participants to reflect and expand on their relevant experiences and to describe their perceptions of the reality of agribusiness engagement with organic waste-to-energy systems in Australia.

Table 4.1 Stage 2 Interview Participants			
Interview participant	**Organisation type**	**Role**	**Technology type**
IE-01	State Govt. agency	Bioenergy policy	Biomass boilers and anaerobic digestion
IE-02	Technology provider - company	Technology developer and consultant	Anaerobic digestion
IE-03	Bioenergy body and farmer	Bioenergy policy expert and advocate	Biomass boilers and anaerobic digestion
IE-04	Technology provider - agent	Technology consultant and installer	Biomass boilers
IE-05	Research body & bioenergy body	Researcher	Gasification
IE-06	University	Researcher	Anaerobic digestion
IE-07	Local Govt.	Consultant/Project Manager	Biomass boilers
IE-08	Technology provider – company and farmer	Technology developer and consultant	Pyrolysis

Participants provided verbal responses to the questions in interviews that generally ranged between 40 minutes and 70 minutes in length, although the shortest interview was completed in 34 minutes and the longest interview took 1 hour and 34 minutes.

4.7.3 Stage 3: Case studies – Interviews with agribusiness managers

The final stage in this multi-methods qualitative research design, featured the analysis of cases relevant to this study's research question. The cases selected for analysis were managers/decision-makers of 14 Australian agribusinesses that have engaged in the organic waste-to-energy transition process (see Table 4.2 and Appendix G). Each of the cases analysed in Stage 3 were managers at agribusinesses growing, producing and/or processing Australian food and fibre products. Australian farmers/growers participating in this study included broadacre cropping (grain) farmers, dairy farmers, vegetable and flower growers, and pork producers. The food and fibre processors interviewed included a sugar mill/refinery, an abattoir, organic waste processors, a cheese factory, and a grain processor (flour mill).

The purpose of the Stage 3 case studies was to provide insights at the business level, detailing the experiences of agribusinesses engaging with organic waste-to-energy systems and the transition process. To collect relevant data on the selected cases, inductive, semi-structured in-depth interviews were conducted with key decision-makers from these agribusinesses.

As with the selection of interview participants in the Stage 2 interviews with industry experts, the Stage 3 interviews with agribusiness managers also used a purposive selection approach to select agribusinesses, or cases, for this study. This selection process aimed to identify a sample of agribusinesses that featured a range of agribusiness types from across Australia and included examples of the two main bioenergy technologies; biomass boilers (direct combustion) and anaerobic digestion (biogas).

While the 14 agribusiness managers participating in this study form a broadly representative sample of Australian agribusinesses that have engaged with organic waste-to-energy technologies since 2010, this is nevertheless a small sample. Another important selection criterion was the date of the installation of the bioenergy plants, with this study preferring to interview managers of agribusinesses that had plants installed after 2010. Agribusinesses that had installed their organic waste-to-energy plants more recently were preferred for this study, as they were more likely to have insights relevant to the research questions.

Table 4.2 Stage 3 Interview Participants			
Interview participant	**Agribusiness type**	**Technology type (and feedstock)**	**Location**
AM-01	Broadacre cropping & straw pellet supplier	Biomass boiler (Straw pellets)	Victoria
AM-02	Dairy and cheese factory	Biomass boiler (Wood chip)	Victoria
AM-03	Organics composter and fertiliser supplier	Anaerobic digestion (Green wastes)	South Australia
AM-04	Abattoir (lamb)	Biomass boiler (Saw dust)	Victoria
AM-05	Commercial flower grower (Protected cropping)	Biomass boiler (Wood chip)	Victoria
AM-06	Piggery	Anaerobic digestion (Pig manure)	New South Wales
AM-07	Piggery	Anaerobic digestion (Pig manure)	Victoria
AM-08	Piggery	Anaerobic digestion (Pig manure)	New South Wales
AM-09	Organic waste processor	Biomass boiler (Viticulture waste)	Victoria
AM-10	Vegetable grower (Protected cropping)	Biomass boiler (Wood chip)	New South Wales
AM-11	Vegetable grower (Protected cropping)	Anaerobic digestion (vegetable waste)	Queensland
AM-12	Sugar refinery	Biomass boiler (Bagasse)	Queensland
AM-13	Dairy	Anaerobic digestion (cow manure)	Victoria
AM-14	Grain processor (Mill)	Biomass boiler (Grain husks)	Western Australia

Also, the experiences of the more recent agribusiness installations were more likely (than pre-2010 installations) to be reflective of the current state of organic waste-to-energy applications and systems in the Australian agribusiness sector. All but one of the agribusinesses interviewed had installed their technologies after 2010. One agribusiness was interviewed that had installed its original plant before 2010 but had invested in a substantial modification/expansion to its technology and systems in the time period being studied, and so had recent experience and insights relevant to the research question.

A total of 23 agribusinesses were contacted by telephone and/or email and invited to participate in an interview. Of the agribusinesses contacted, 14 managers from across Australia agreed to an interview, with half of the agribusinesses interviewed located in Victoria (see Table 4.3 and Appendix G). The prominence of Victorian agribusinesses in these interviews was driven by two main factors; a relatively high level of bioenergy activity in this state, and a high acceptance rate (88%) from Victorian agribusinesses.

Table 4.3 Stage 3 interview participants by location

	VIC	NSW	QLD	WA	SA	TAS	NT	TOTAL
Invited to interview	8	7	3	2	1	2	0	**23**
Participated in interview	7	3	2	1	1	0	0	**14**

Other states such as New South Wales and Queensland also have relatively high levels of bioenergy activity, but the response rate from New South Wales agribusinesses contacted (43%) was lower than in Victoria. While Queensland has been a leader in bioenergy development in Australia, most of this state’s sugar refineries were not considered for this study, as the installation of the organic waste-to-energy plants operating at these agribusinesses pre-dated the time horizon of this research.

Most agribusiness types that have recently invested in organic waste-to-energy technologies in Australia were invited to participate in an interview and at least one agribusiness from each agriculture sector agreed to an interview, with one exception. Interviews were conducted with managers of piggeries, dairies, meat processors, broadacre cropping farmers, protected cropping (vegetable and flower) growers, sugar processors, viticulture/wineries, composters, and grain processors/millers, with six of these agribusinesses operating biogas (anaerobic digestion) technologies and eight agribusinesses investing in direct combustion boilers (see Table 4.4).

Table 4.4 Stage 3 interview participants by agribusiness type

	Piggery	Dairy	Poultry	Meat processor	Broadacre cropping	Protected cropping	Sugar processor	Viticulture/winery	Composter	Grain processor	TOTAL
Invited to interview	4	3	1	4	1	4	2	2	1	1	**23**
Participated in interview	3	2	0	1	1	3	1	1	1	1	**14**

However, no managers of egg and poultry production businesses were interviewed. While there are examples of organic waste-to-energy applications at Australian poultry farms, there was limited information available online about these operations, or the information available on company websites or bioenergy or renewable energy databases excluded current company contact details. Several attempts were made to contact a poultry producer in NSW, but no response was received.

The Stage 3 interviews with decision-makers from agribusinesses with recent experience in investment in organic waste-to-energy technologies commenced in

September 2020 and were completed in May 2021. All interviews were conducted via Microsoft Teams and recorded using the Teams record function. Interview recordings were saved as MP4 video files stored on the Federation University network.

In the Stage 3 interviews, agribusiness owners/managers were asked questions relevant to the research question and sub-questions. Interview questions focussed primarily on the agribusiness's engagement and experiences with the exploration, investment, installation and operation of specific organic waste-to-energy technologies as an integral part of their agribusiness's energy and waste management approaches (see Appendix D Stage 3). Interview participants were asked to reflect on their experiences and to describe the nature of the internal and external drivers and barriers that impacted their agribusiness's transition, in order to analyse the overall engagement of the agribusiness sector with organic waste-to-energy systems. The Stage 3 interview questions considered not only the drivers and barriers identified in academic literature as impacting agribusiness adoption of bioenergy technologies, but also insights from the Stage 2 interviews. Interview participants provided verbal responses to questions in interviews generally around 45 minutes in length, with the shortest interview being 22 minutes in length and the longest interview 1 hour and 18 minutes.

4.8 Data analysis

As a study adopting a multi-methods research design, three different qualitative data collection techniques have been utilised to collect two different types of data relevant to the research question and sub-questions. The following sections identify the types of data collected and the data analysis procedures used in this study.

4.8.1 Stage 1 data

Data collected in Stage 1 comprises data to describe the reality of organic waste-to-energy technologies being used by Australian food and fibre producers and processors. The data serves two main purposes; to provide a snapshot of agribusiness applications of organic waste-to-energy technologies in Australia; and to identify a pool of relevant individuals and agribusinesses from which to select potential interview participants for Stages 2 and 3 of this research.

Data describing individual agribusinesses and the technologies they had invested in was recorded in a Microsoft Excel spreadsheet with critical data including the name of the agribusiness, location/state of operation, agribusiness type, energy generation capacity (MW), waste-to-energy technology installed/operating, feedstock type, date of installation and plant status (see Appendix E). This database was examined to identify generalised trends and patterns, compare groups and detect relationships in the characteristics of agribusinesses that have invested in organic waste-to-energy technologies in Australia (Creswell & Plano Clark, 2018). Analysis of the Stage 1 database also included preparation of visual representations (graphs and tables) of key data.

4.8.2 Stages 2 and 3 data

Stages 2 and 3 of this study's research design collected data using narrative inquiry and case study approaches. Both stages used similar strategies (semi-structured interviews) to collect similar forms of data (narrative data recorded on audio/video file) from purposively selected interview participants. Similar strategies were also used to analyse data collected in Stages 2 and 3, but these analyses were conducted in sequence and independently of each other.

Qualitative research develops meanings through the words (spoken and textual) in social interactions (Saunders et al., 2015). When conducting qualitative data collection via interviews, it is important the researcher has a record of the interview, so the words featured in these social interactions can be analysed. Choices about how interviews are recorded can vary according to the types of data collected and how the data is analysed (Cassell et al., 2018). This study chose to analyse its qualitative data, collected in the Stage 2 and 3 interviews, using NVivo (Lumivero, 2023a), a Computer Assisted Qualitative Data Analysis Software (CAQDAS) tool commonly used in qualitative data analysis (Creswell & Plano Clark, 2018).

CAQDAS programs do not analyse data for the researcher – the researcher still needs to do the analytical thinking (Yin, 2015), but they are tools that researchers can use to help identify and develop meanings, theories and relationships that may be evident in the data (Leech & Onwuegbuzie, 2011). Key functions performed by CAQDAS programs include the storing and management of text documents; the coding and organisation of sections of text for easy retrieval; sorting codes and other text into visual representations (Creswell & Plano Clark, 2018).

NVivo is a code-and-retrieve CAQDAS tool that can assist a researcher to analyse qualitative data in textual records (Lee & Fielding, 2004). To create qualitative documents for analysis, the social interactions from the Stage 2 and 3 interviews were recorded as video/audio files (mp3 or mp4 files) and transcribed into verbatim transcripts (PDF files) compatible with the NVivo software.

This project accessed an online transcription service, Happy Scribe, to use automatic, web-based, transcription software to convert the audio/video files to full verbatim transcripts (Happy Scribe, 2022). To access the Happy Scribe transcription services, the researcher created a password-protected account/login on the transcription service website, purchased minutes/hours of transcription services and customised the transcription settings (language and vocabulary) of the tool. Shortly after each interview was conducted, the recording (video/audio file) was uploaded to the researcher's Happy Scribe account for transcription. The transcription of these files generally took a period half the length of the audio file to transcribe; for example, an interview file 1 hour in length would usually take about half an hour to transcribe.

When the video/audio file had been successfully transcribed, the researcher opened the video/audio file and the transcript text in the Happy Scribe website/platform and proof-read the transcript for accuracy. Happy Scribe claims to produce transcripts with an accuracy rate of 85% fidelity to the recordings (Happy Scribe, 2022), so the text in each transcript still needs to be edited manually by the researcher. The editing process checks the transcribed text for accuracy, to correct mistakes or fill in gaps that may have appeared in the transcript as a result of quality or clarity issues with the video/audio file.

Some interview recordings were affected by muffled or unclear speech, background noise, telephone or Internet issues, and/or glitches in the video/audio file itself. While editing, the researcher added the initials of the speakers to the transcripts and activated the platform’s timestamp feature, to identify who said what in the interview and at what time it was said. This editing process initiated the preparation and analysis of the data, with the researcher also highlighting sections of text and adding notes/comments to the transcripts. When the editing of each transcript was completed, the files were downloaded as PDF text documents, which were saved to the Federation University network.

While Lumivero (2023b) describes the analysis of qualitative data as an iterative process that does not follow a set procedure, Figure 4.3 outlines the type of path that may be taken to analyse qualitative data using NVivo. This broadly represents the CAQDAS approach to data analysis conducted by this research project. The process began with the importing of the interview transcripts into the NVivo software, and the exploration of the text.

The next step involved the coding of textual data; identified by Creswell and Plano Clark (2018) as one of the key processes of qualitative data analysis:

> Coding is the process of grouping evidence and labelling ideas so that they reflect increasingly broader perspectives. In coding the researcher divides the text into small units (phrases, sentences, or paragraphs),

> assigns a code label to each unit, and then groups the codes into themes. The coding label can come from the exact words of the participants (in vivo coding), phrases composed by the researcher, or concepts used in the social or human sciences. (Creswell & Plano Clark, 2018, pp. 212-213)

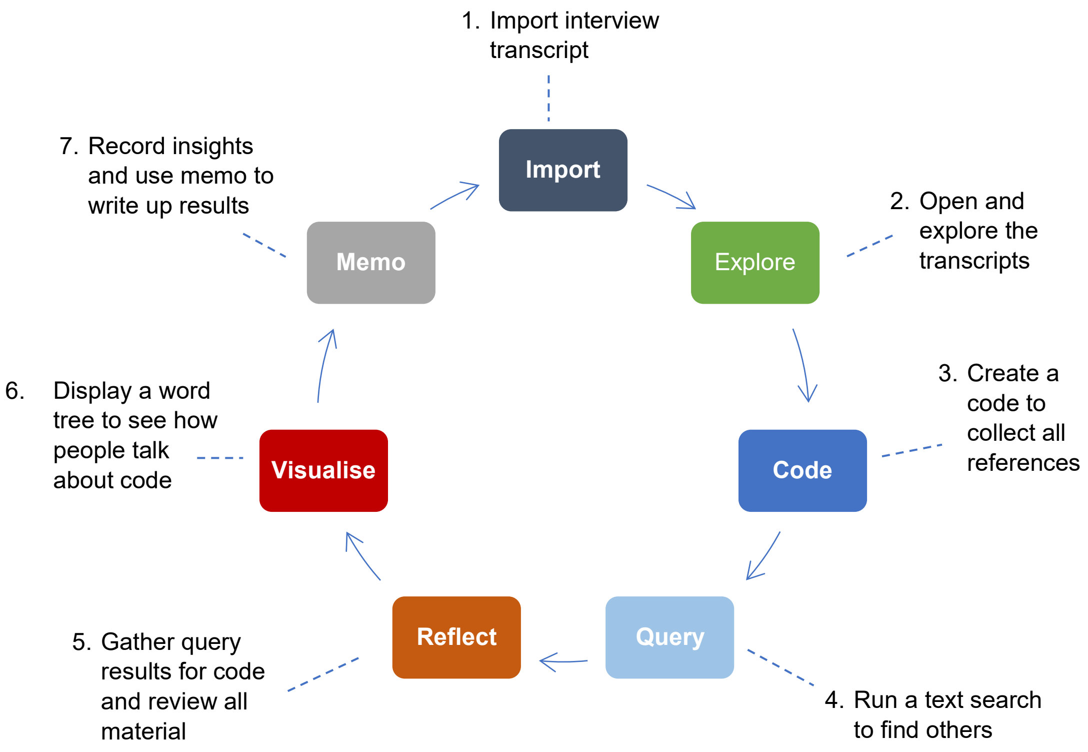


Figure 4.3 Example of possible NVivo investigation pathway

Source: Adapted from (Lumivero, 2023b)

Coding qualitative data manually can be 'a formidable, tedious task' (Bazeley & Richards, 2000, p. 23), but CAQDAS tools can enable the efficient analysis of large volumes of data (Waller, 2016). When coding with NVivo, this study used program functions such as codes, notes, nodes, cases and sets to classify and organise sections of text, as the researcher read the interview transcript. The text search function enabled text in the interview transcripts to be searched for key words and phrases, to quickly find additional sections of text that may have been relevant to the codes. In the coding of this research project's Stage 2 and 3 qualitative data, the labels used to classify the interview themes generally aligned with the key drivers and barriers to agribusiness adoption of organic waste-to-energy approaches, as identified in sections 2.9, 2.10, and Figure 3.1. When Stage 2 interview transcripts had been coded, the researcher used NVivo tools such as queries, visualisations and reports to explore the coded data, and for meaning and insights to emerge from the interview data. Nvivo's query function allowed codes from multiple interviews to be grouped for analysis, and visualisation tools were also applied to generate charts, maps, diagrams, matrices, word clouds and word frequency trees to present data visually. These exploratory tools assisted the researcher to interpret the meaning of the results; to identify insights, patterns and themes in the interview data:

> Basically, an interpretation of results involves stepping back from the detailed results and advancing their larger meaning in view of the research problems, the questions or hypotheses in a study, the existing literature, and perhaps author related experiences (in qualitative research). (Creswell & Plano Clark, 2018, p. 216)

Key findings that emerge for the researcher in the interpretation of results can be documented in NVivo as memos, for further development in the study's discussion of the research findings. The same data analysis procedures used to explore the Stage 2 data were then applied to analyse data collected in the Stage 3 interviews.

While the coding of the themes from the Stage 2 and 3 interviews was structured to support this study's application of the MLP framework, this analysis also included a SPA component. A social practice lens was applied to the analysis of the interview transcripts, with notes and codes made in NVivo to identify themes relevant to the social practices associated with agribusiness adoption of organic waste-to-energy technologies. This included the identification of participant comments about their energy and waste management practices, that provided insights to the meanings, competences and materials of those practices.

4.9 Ethics considerations

Research ethics is an important consideration for all researchers. Saunders et al. (2015, p. 726) define research ethics as 'The standards of the researcher's behaviour in relation to the rights of those who become the subject of a research project, or who are affected by it', and numerous professional associations have established codes of ethics, ethical standards and guiding principles to be applied by researchers in particular professions and/or discipline areas (Bryman, 2016; Yin, 2015). A wide range of issues can be addressed in research ethics frameworks, including integrity and objectivity of the researcher; respect for others; avoidance of harm; privacy of those taking part; voluntary nature of participation and the right to withdraw; informed consent of those taking part; ensuring confidentiality of data and maintenance of anonymity of those taking part; responsibility in the analysis of data and reporting of findings; compliance in the management of data; and ensuring the safety of the researcher (Saunders et al., 2015).

As research conducted at Federation University Australia, this study is bound by research ethics requirements detailed in the Australian Code for Responsible Conduct of Research (Universities Australia, 2018) and Federation University's Ethical Conduct of Research Policy (Federation University Australia, 2015). Of particular importance in this study was the requirement to ensure the ethical treatment of people participating in the Stage 2 and 3 interviews, and the security of the data collected. To address these research ethics considerations, this study's research methodology and data collection processes were approved by the University Human research ethics committee (HREC). All interviewees were provided with Plain Language Information Statements prior to their participation in interviews (see Appendix B), and their agreement to be interviewed was recorded in the study's Informed Consent Form (see Appendix C).

4.10 Summary

The research methodology described in this chapter is a systematic plan of research processes to address this study's research question and sub-questions. The processes explored follow the key methodological considerations identified in Saunders et al.'s (2015) research 'onion'. The choices made in the development of this methodology are guided by the pragmatism research philosophy, with a focus on choosing practical approaches and strategies to explore the fundamental problem this study seeks to explore; Australian agriculture's slow transitions to the adoption of organic waste-to-energy approaches. Chapter 4 describes this study's multi-method qualitative design, as well as its the data collection and analysis procedures, and ethical considerations.

The key themes and insights to emerge from this study's research methodology are identified in the next chapter, where the research findings are explored in terms of their relevance to the major research question and sub-questions.

5. Research findings

This chapter presents details of the key research findings from the three stages of this study's data collection, to provide a snapshot of the state of organic waste-to-energy adoption by Australian agribusinesses, and to identify the major drivers and barriers impacting agribusinesses that explore organic waste-to-energy approaches. The first section presents published documentary data to create an overall picture of the state of bioenergy and organic waste-to-energy adoption in Australia. This also provides context for where bioenergy and organic waste-to-energy approaches fit in the Australian agribusiness and energy landscape. The descriptive data presented in this section are complemented by findings from the Stage 2 interviews conducted with industry experts, exploring narrative accounts of their experiences relevant to the adoption of organic waste-to-energy approaches by Australian agribusinesses.

The second section presents research findings that identify and describe the major drivers prompting Australian agribusiness to consider investments in organic waste-to-energy technologies, as an integral part of their on-site energy and waste management strategies. These findings are based on the major themes that emerged from analysis of the narrative inquiry data collected in the Stage 2 interviews with industry experts, and the Stage 3 case studies of Australian agribusiness managers with relevant experience of the transition processes to organic waste-to-energy adoption. The drivers identified in this section describe the main reasons why Australian agribusinesses consider changing from their business-as-usual energy and waste management approaches, to adopt organic waste-to-energy technologies in their business.

This chapter's third section also draws on the analysis of data collected in the Stage 2 and 3 interviews but focusses on the barriers encountered by Australian agribusinesses investing in organic waste-to-energy approaches. These barriers describe the significant themes identified by the industry experts and agribusiness managers interviewed. Key topics centred on what they saw as the important barriers that interrupt agribusiness waste-to-energy transition processes and/or discourage agribusinesses from investment in these technologies. This section also identifies the critical factors that contribute to these barriers and strategies that help agribusinesses to avoid or overcome these blockages.

5.1 Organic waste-to-energy in Australian agribusiness

This section describes the current reality or state of organic waste-to-energy deployment at Australian food and fibre producers and processors. Organic waste-to-energy is still an emerging component in the Australian energy landscape and various industry websites, online databases and case studies have been developed providing descriptive data on bioenergy installations around Australia. Descriptions of organic waste-to-energy are usually included in bioenergy data that generally do not separate the types of organisations producing the energy. Bioenergy data is often presented using other descriptors, including by technology type (e.g. biogas or anaerobic digestion; biomass/combustion boilers; gasification; pyrolysis), by feedstock type (bagasse; wood chip/sawdust; straw; manure; sewage/wastewater; municipal solid waste etc.), by energy type (thermal, electricity or transport), or by generation capacity.

To understand the current role played by organic waste-to-energy technologies at Australian agribusinesses, it is important to understand where it, and bioenergy more broadly, sit in the Australian context. The next section explains the role played by bioenergy and the other renewable energy contributors to the Australian energy landscape.

5.1.1 Bioenergy in Australia

The application of modern bioenergy technologies is an emerging approach to energy generation and waste management around the world. While some forms of modern bioenergy have existed in Australia for more than a century (Clean Energy Regulator, 2023), it makes only a modest contribution to Australia's overall energy mix – about 4% of Australia's total energy consumption (McCabe, 2020) and 1.4% of Australia's total electricity generation (KPMG, 2018). The relatively small space occupied by bioenergy in Australia is recognised by the industry experts interviewed in this study. They generally agreed that Australia's embrace of bioenergy and organic waste-to-energy has been slow (IE-03; IE-04); that the Australian bioenergy industry is immature (IE-07), nascent (IE-01) and still in its infancy (IE-02, IE-04), and that the development of this industry is behind that of other comparable countries (IE-01; IE-03; IE-05; IE-07).

With bioenergy contributing 4.3% of Australia's renewable energy generation, it suffers by comparison to the current leaders of the renewables sector; solar PV (photo-voltaic) and wind energy, which have both grown substantially in recent years (Clean Energy Council, 2022). According to the Clean Energy Council's reporting on renewable energy generation in Australia (see Figure 5.1), in the period from 2013-2021, bioenergy generation generally hovered around 3,000-3,500 GWh annually, increasing from 2,400 GWh in 2013/14, to a peak of 3,713 GWh in 2017. However, over the same period, the annual generation from wind energy almost trebled and solar generation saw a seven-fold increase.

As shown in Figure 5.1, the rapid increase in wind and solar energy development has positioned these technologies as the dominant players in the renewable energy space. Figure 5.2 shows wind and solar energy overtaking hydro energy as the sector leader and reducing the proportion of bioenergy's contribution to Australia's renewable energy generation, which has fallen from 9.7% in 2017, to 4.3% in 2021. The failure of bioenergy to match the strong growth of energy generation from solar and wind has been a source of frustration for some stakeholders in the renewable energy industries, with one Stage 2 interviewee characterising bioenergy as 'the poor cousin' of the renewable energy technologies (IE-08).

Another industry expert viewed bioenergy development in Australia as having 'stagnated' (IE-06) and this is supported by the bioenergy data in Figures 5.1 and 5.2.

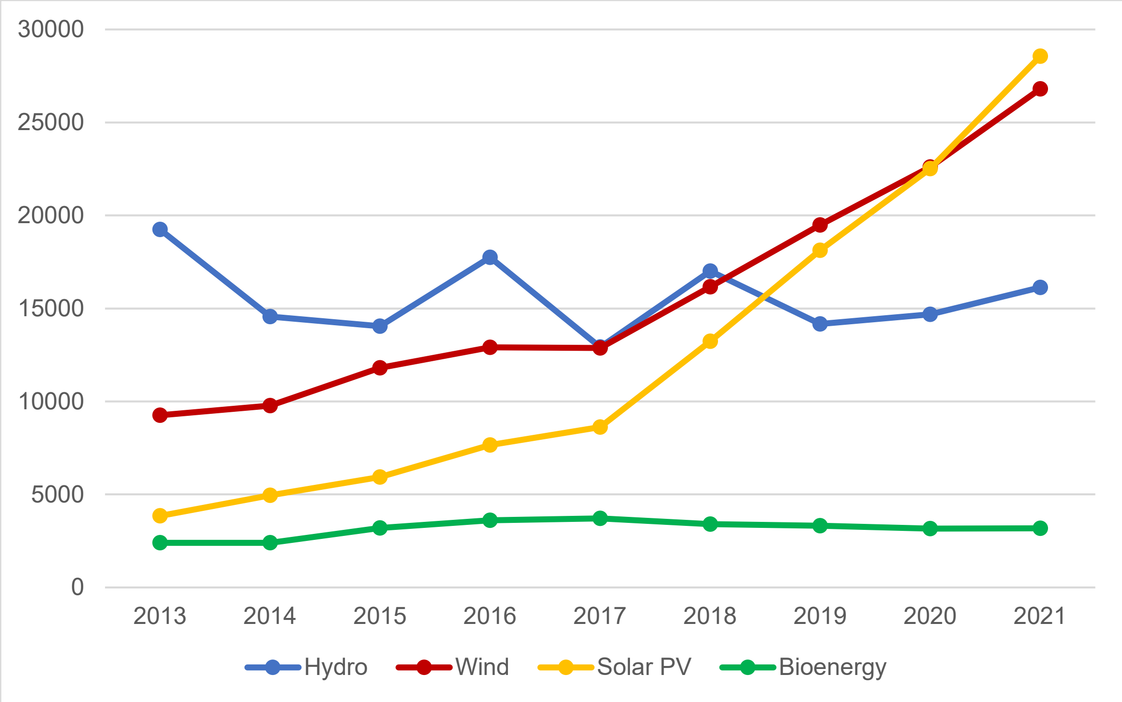


Figure 5.1 Annual renewable energy generation (GWh) in Australia - by type

Source: Adapted from Clean Energy Council (2013, 2014a, 2015, 2016, 2018, 2019, 2020, 2021, 2022).

However, most of the other interviewees agreed bioenergy was building, but doing so very slowly (IE-01, IE-03, IE-04, IE-05, IE-07). While some of the experts interviewed expressed frustration and exasperation at what they saw as 'missed opportunities' caused by Australia's slow rate of progress in this space, others were more sanguine in acknowledging this reality. These experts suggested the bioenergy industry's development trajectory was reasonable and to be expected 'given the circumstances' (IE-06), such as Australia's geography and population densities, waste and energy structures and processes, the maturity of the bioenergy market and State and Commonwealth Government policies. These circumstances will be explored later in this chapter. This sanguine perspective takes a pragmatic and holistic view of the bioenergy industry's development, accepting that bioenergy development in Australia may not mirror the patterns experienced in other countries, and that its growth trajectory and development pathways will be different to those of other renewable energy technologies.

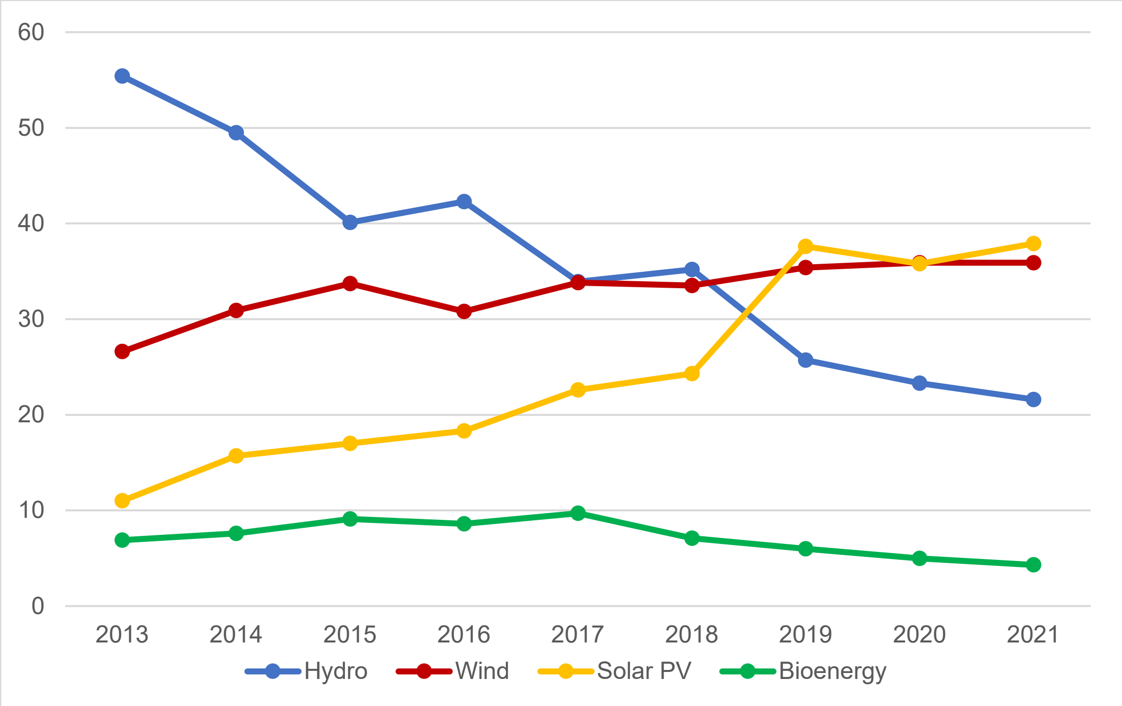


Figure 5.2 Contribution (%) to renewable energy generation in Australia - by type

Source: Adapted from Clean Energy Council (2013, 2014a, 2015, 2016, 2018, 2019, 2020, 2021, 2022).

Despite the minor role currently played by bioenergy in Australia and the slow uptake of bioenergy technologies, most experts interviewed were positive about the future of organic waste-to-energy in Australia and most, but not all, suggested there was a gathering of momentum around bioenergy and waste-to-energy. One of the reasons for this optimism was a perceived 'increase in interest' in organic waste-to-energy technologies in Australia. This interest included increased engagement of agriculture industry peak bodies with bioenergy researchers and experts (IE-06), strong attendance numbers of prospective stakeholders at bioenergy information events such as workshops, field trips and webinars (IE-01); and an increase in enquiries about bioenergy options (IE-03; IE-04; IE-05).

Most experts interviewed were optimistic about bioenergy's imminent growth and development, but some were more cautious about the inevitability or desirability of such industry expansion. One interviewee noted that while the bioenergy industry in Australia has matured over the last five years and there has been an increase in interest in bioenergy options, this was yet to translate into an increase in the number of bioenergy plants being commissioned (IE-06). Another expert, while seeing ‘a bright future for the bioenergy industry, for sure’, also warned that current and future advances in battery storage technologies would position solar energy as a ‘significant competitor’ that could ‘push out’ bioenergy as a provider of baseload power (IE-08).

The same expert also cautioned, ‘[the] validity of bioenergy’ in a drying climate may be questioned ‘… in 10-20 years, if we see a greater impact of climate change’ (IE-08). These issues are relevant factors impacting organic waste-to-energy development in Australia and are explored later in this chapter, with other drivers and barriers impacting this sustainability transition.

5.1.2 Organic waste-to-energy feedstocks

Understanding the composition of Australia’s bioenergy feedstocks is relevant to this study, as it provides context and puts into perspective the contribution of agribusinesses generating energy from organic waste materials to Australia’s mix of energy and bioenergy. Australian food and fibre producers generating electrical and thermal energy from their organic by-products are minor contributors to the Australian bioenergy mix; which is then a small contributor to the Australian renewable energy mix; which is a small contributor to the overall mix of energy generated in Australia. However, for more than a decade, the agribusiness sector has been identified as an area that could and should make a greater contribution to Australia’s bioenergy, renewable energy and overall energy generation (Clean Energy Council, 2008).

For much of the 20th Century, bioenergy generation in Australia was led by the combustion of bagasse; the organic waste material produced in the processing of sugar cane. While this form of organic waste-to-energy remains a significant contributor to Australia’s bioenergy mix, it has been overtaken as the dominant player in Australian bioenergy, with almost two-thirds (64%) of Australia's bioenergy generation now fuelled by the conversion of municipal and industrial waste into useful forms of energy (see Figure 5.3). The remainder of Australia's bioenergy is generated from the agroforestry sector, with agricultural wastes fuelling 19%, animal residues 8% and wood waste 9% (KPMG, 2018).

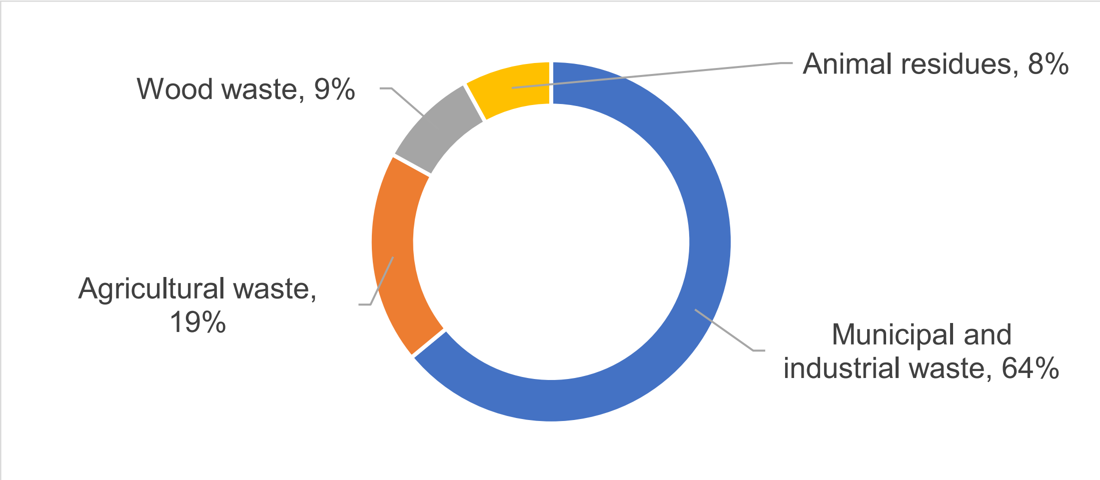


Figure 5.3 Feedstocks used in Australian bioenergy generation, 2018

Source: adapted from KPMG (2018)

In KPMG's 'Bioenergy state of the nation report' (2018), the authors recorded 222 bioenergy plants operating across all sectors in Australia, with an additional 55 projects either under construction or in the feasibility phase of development. In Stage 1 of the research design in this study, 65 bioenergy plants were identified as operating in Australian agribusinesses using organic wastes from agricultural and forestry production to fuel waste-to-energy (WtE) plants (see Figure 5.4). An additional four organic waste-to-energy plants were under construction or still being trialled, while the operational status of another four plants could not be confirmed.

Figure 5.4 shows the geographic distribution of bioenergy and organic waste-to-energy plants across Australia's states and territories.

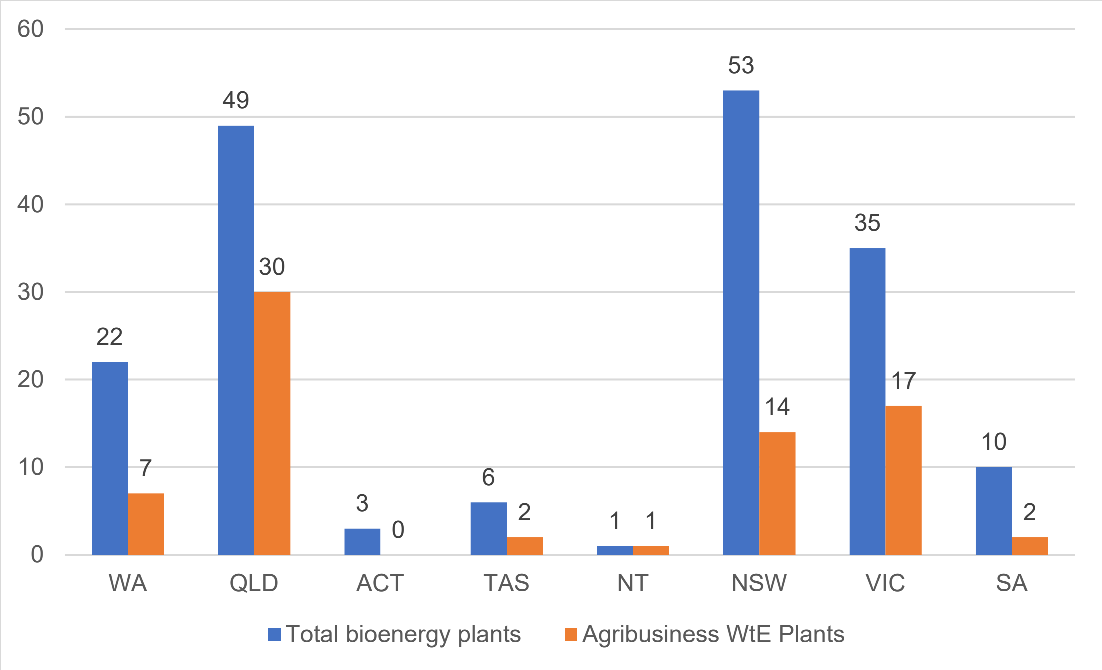


Figure 5.4 Australian bioenergy and agribusiness waste-to-energy plants, 2018

Source: Total bioenergy plant data (KPMG, 2018); and agribusiness organic waste-to-energy plant data (see Appendix E).

Each state or territory has at least one bioenergy plant, and at least one organic waste-to-energy plant in an agribusiness operation, except for the Australian Capital Territory (ACT) which has very limited agribusiness activity. Most of Australia's bioenergy plants operate in NSW and Queensland, with 53 and 49 plants respectively.

Australia's more populous states (Western Australia, Queensland, New South Wales, Victoria and South Australia) have the majority of the country's bioenergy plants and, in these states, agribusiness applications of organic waste-to-energy generally make up between one-fifth and one-third of that state's bioenergy plants. The exception is Queensland, where organic waste-to-energy from agribusiness represents more than 60% of the state's bioenergy plants, with more than 20 sugar mills utilising bagasse to produce thermal and electrical energy (Australian Cane Farmers Association, 2020).

The two main technologies used to convert Australia's biomass feedstocks into usable forms of energy are direct combustion technologies (56%) and anaerobic digestion

(29%), with other conversion processes comprising the remaining 15% (KPMG, 2018). The bioenergy technologies adopted by Australian agribusinesses reflect similar usage trends, although the adoption of emerging bioenergy technologies is lower at 5%, which contributes to a slightly increased proportion of agribusinesses using direct combustion technologies (63%) and anaerobic digestion plants (32%). Figure 5.5 shows combustion technologies are favoured by agribusinesses in Western Australia, Queensland, Tasmania and Northern Territory, but there is a more even split between anaerobic digestion and direct combustion plants in use at agribusinesses in New South Wales, Victoria and South Australia.

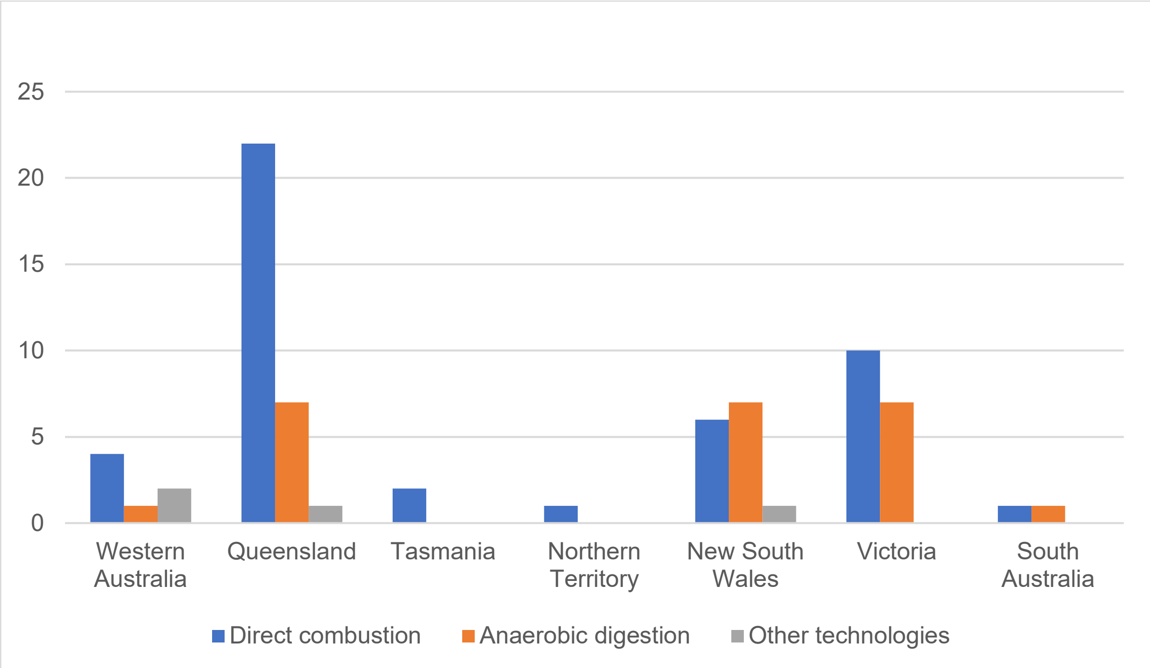


Figure 5.5 Number of organic waste-to-energy plants in Australian agribusiness - by technology type and by state

Source: Appendix E

The choices made by agribusinesses when selecting technologies for organic waste-to-energy generation are generally dictated by the types, characteristics and availability of the biomass feedstocks used to fuel these plants. As a rule, agribusinesses with mainly wet wastes adopt biogas/anaerobic digestion technologies, and agribusinesses with mainly dry feedstocks (note especially QLD with bagasse) apply direct combustion technologies.

Figure 5.6 shows the organic waste-to-energy technologies used by different Australian agribusiness types. More than half of Australian agribusiness' 48 direct combustion organic waste-to-energy plants are employed in Australia's sugar mills, which produce large volumes of bagasse (sugar cane trash) that is a suitable feedstock for direct combustion. A small number of Australian grain processors and flour mills are also operating direct combustion plants, utilising their milling by-products (husks, seed casings) to fuel energy generation.

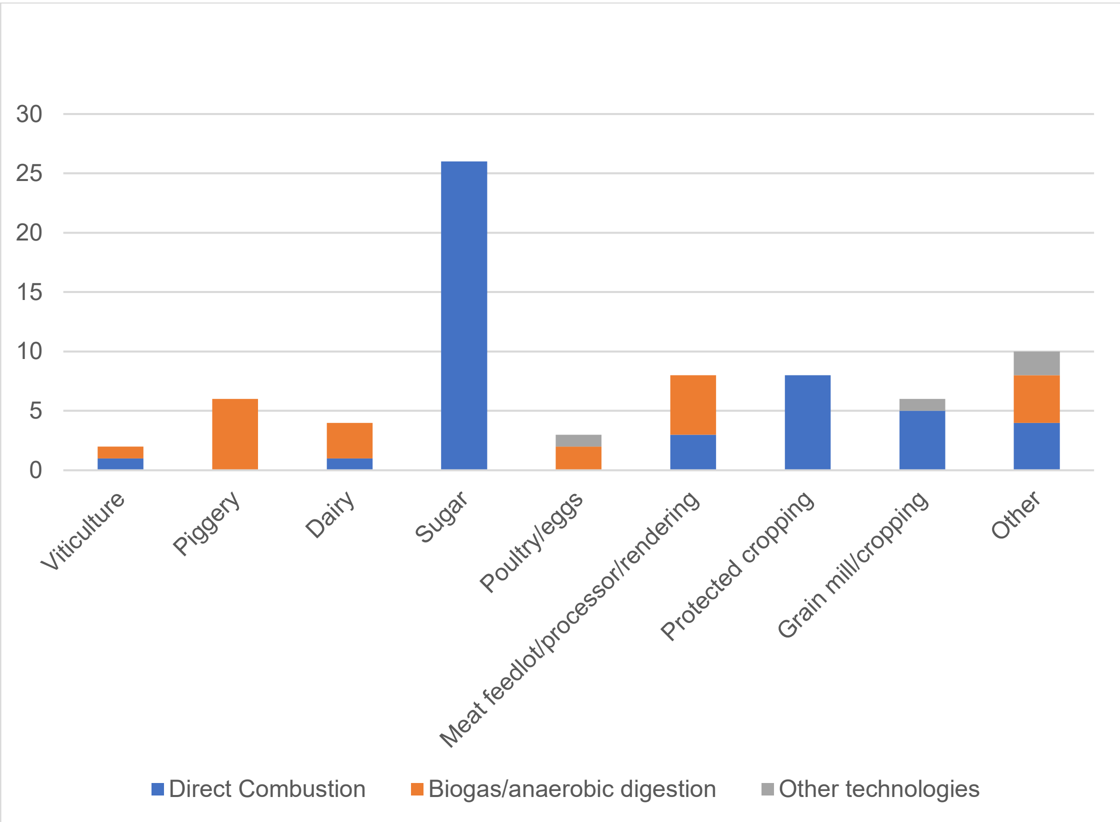


Figure 5.6 Number of organic waste-to-energy plants in Australian agribusiness – by technology type and by industry sub-sector

Source: Appendix E

In the last ten years, the protected cropping sector has increasingly utilised direct combustion technologies to heat the 'protected' growing environments, in their glasshouses and plastic hothouses, for year-round production of a variety of fruit, vegetable, flower, and seedling crops. The meat processing sector also uses biomass boiler technologies, but these two agribusiness sub-sectors generally fuel their direct combustion plants with forestry/sawmill waste (woodchips and sawdust), rather than using organic by-products from their own production processes (see Appendix E).

The use of biogas technologies by Australian food and fibre producers and processors has mainly been in the dairy and meat production (pork, lamb and beef) sectors, all of which produce relatively large volumes of wet wastes (see Appendix E). Australian agribusinesses such as piggeries, dairies (sheep and cattle), beef feedlots and abattoirs all produce wet by-products such manures and urine, offal and animal parts and/or washdown water, which are suitable feedstocks for anaerobic digestion. Other examples of Australian agribusiness applications of biogas technologies include waste management, composting and energy companies utilising organic by-products from the production and processing of the agriculture sector as feedstocks for anaerobic digestion and energy generation. A small number of other bioenergy technologies, such as pyrolysis, have been applied at Australian agribusinesses, but the commercial applications of these approaches are still in the early stages of their development.

The agribusiness sectors featured in Figure 5.6 have at least one of two characteristics in common; they either produce a large volume of organic waste, or they have a large demand for heat and/or electricity to utilise organic waste-to-energy technologies. Sugar refineries have both characteristics and this is one of the key reasons for their substantial contribution to bioenergy in Australia (AM-12). Farming and food processing operations with both characteristics can maximise the benefits of organic waste-to-energy approaches by reducing both energy and waste management costs, which can provide for a more compelling business case for the adoption of these technologies (IE-03; IE-04). Most of the Australian agribusiness interviewed in this research are using organic waste-to-energy technologies to generate thermal and/or electrical energy to utilise this energy 'behind the meter', off-setting their requirement to purchase energy from the national energy networks or from external energy suppliers (AM-02; AM-03; AM-04; AM-05; AM-09; AM-13; AM-14).

Notably, some of Australia's major agribusiness sectors, such as broadacre farming, do not feature prominently in Australia's bioenergy generation. Broadacre cropping accounts for more than a third (34%) of Australia's agricultural production by value (ABARES, 2022) and cropping residues suitable for bioenergy generation are considered to be abundant and underutilised (Clean Energy Council, 2008). Yet, this form of agriculture makes a negligible contribution to Australia's bioenergy generation (see Appendix E). Similarly, broadacre livestock farmers do not have any bioenergy plants operating on-site in Australia for which organic wastes from their livestock grazing operations are the primary fuel source (see Appendix E).

5.2 Organic waste-to-energy drivers in Australian agribusinesses

The drivers identified by the industry experts and agribusiness managers as impacting Australian agribusiness engagement with organic waste-to-energy systems generally align with those identified in other countries, as found in this study's review of the literature. However, there exist some critical conditions in the Australian context that influence the dynamics of how these drivers impact Australian agribusiness decision making when considering organic waste-to-energy options for their operations. The main drivers prompting Australian food and fibre producers and processors to consider changing to organic waste-to-energy approaches are generally related to the emergence of problems in two broad areas; problems with the incumbent energy supply, and problems with existing waste management approaches and strategies.

5.2.1 Problems with cost or security of energy supply

The energy problems that motivate Australian agribusinesses to consider investment in organic waste-to-energy technologies usually centre around two main issues; problems with the price of the energy, or problems with its supply. The industry experts and agribusiness managers interviewed in this study identified sharp increases in Australian energy costs (mainly LPG & natural gas) over the last ten years as being a key driver prompting agribusinesses to explore alternative technologies, in attempts to reduce their energy costs (IE-01; IE-03; IE-04; IE-06; IE-07; AM-02; AM-03; AM-04; AM-05; AM-10).

Energy costs are critical for agribusinesses interviewed from the protected cropping and food processing sub-sectors, which have a high demand for thermal energy (AM-02; AM-04; AM-05; AM-10; AM-11; AM-14). Protected cropping operations produce fruit, vegetables, flowers, seedlings and other plants, in 'protected' growing environments such as glasshouses and plastic greenhouses. Most of Australia's commercial glasshouses require heating during the cooler months to maintain an optimal temperature for year-round plant growth (AM-10).

Food processors such as fruit and vegetable canneries, abattoirs and meat processors, dairies and cheese factories, wineries and olive processors also have a large requirement for thermal energy in the form of steam and hot water. These agribusinesses have typically used fossil fuels such as natural gas, LPG and briquettes (blocks of compressed coal dust) to meet their thermal energy requirements, but substantial increases in the price and/or availability of these fuels over the last decade have threatened the profitability of these agribusinesses and prompted them to explore cheaper fuels and alternative boiler technologies.

For some, the rising cost of their thermal energy was becoming an existential threat to the profitability of their business, with one glasshouse operator reporting:

> And when we had issues with the natural gas price, we started looking for alternative heat sources. … we're heating a five-hectare glasshouse here with natural gas. And back in 2014, 2015, our gas contract with the local retailer was sitting at about \$6.50 per gigajoule. And then when we renewed our three-year contract, it went to about \$8.00 a gigajoule and that was due to expire late 2018. And the price was … the new contract was double. So

> they wanted to go to $15.50, right? And yeah, we said we cannot heat our glasshouses at that price. … it [changing to organic waste-to-energy] was purely economic on gas prices, I think. (AM-05)

This was a common theme with other agribusiness managers describing almost identical experiences of being confronted by substantial jumps in the costs associated with the thermal energy fuels that are an essential and unavoidable input for their business, and with limited abilities to absorb or pass on these cost increases to customers. These managers spoke about feeling trapped and having few options and so were forced to explore what they might have considered to be alternative thermal energy generation technologies – or to make other fundamental changes to their business model.

One agribusiness manager of a large glasshouse using a biomass boiler, described an experience with a previous business growing cut-flowers in a polythene greenhouse heated by bottled gas (AM-10). When the price of LPG rose sharply, this business tried to change its business model to limit their production to the warmer months so they would not need to heat their greenhouse at all:

> We used to use LPG fired heaters. … We used to pay 19, zero one nine, cents a litre and within five years that had gone up to about 89 cents a litre. So it became cost prohibitive to keep running those heating units. So, again, you know, that literally played us out of the market in the winter. We struggled and we were just not able to produce, you know, good numbers in that period, given the cost of that fuel source. (AM-10)

The strategy of cutting winter production was successful in reducing the business' energy costs, but it also resulted in a reduction in flower production and an interruption to their supply to their customers over winter and to their income, which ultimately caused the demise of that business activity.

While these shifts in the costs of natural gas and LPG made these fuels unviable for these agribusinesses, they also shifted agribusiness manager perceptions of the viability of the organic waste-to-energy business case for their operations:

> [We were] pretty much forced into it actually. … about six years ago now, gas electricity prices went through the roof, they doubled. … So all of a sudden the investment [in a waste-to-energy plant] become more viable and the return on investment was going to be a lot quicker. …And so that's the main reason we went down those lines to try and take control of some of our costs. (AM-04)

For these agribusinesses, the rising cost of their existing energy management processes was the trigger to explore other energy generation options, or as one agribusiness manager (AM-04) summarised; 'So I suppose once it's costing you a lot of money, you then go and have a look outside to see what else is possible'.

For other agribusinesses, their energy problems were less to do with the cost of their energy supply and more to do with the quality and reliability of this supply, as many of Australia's agribusinesses have been established on sites with limited or variable access to reliable energy infrastructure. Food processing businesses such as sugar refineries, cheese factories and dairy processors, abattoirs and flour mills are often situated in rural and/or relatively remote parts of Australia and have been established in these locations to be near or on the farms supplying the food and fibre they process. Situating processing operations close to farms can have a range of benefits in terms of minimising the costs and time associated with transporting raw produce/product from the farms to be processed, but these farms can also be on the fringes or beyond the reach of Australia's energy networks. As AM-11 explained;

> A lot of them [food processing operations] are in places that I guess get left behind and that the planning and infrastructure is just not kept up to standard. And a lot of businesses evolve over the years. So when they first

> get put somewhere, it may not be the ideal location [in terms of access to energy], but it's just where they are, because they probably own the land. They're already there, they're farming there. So, say they put a processing factory there and then that just grows and grows and grows. But the [energy] infrastructure doesn't keep up with it, even though they're probably a big provider of jobs for the region. So it's a … that's poor planning. (AM-11)

For the managers of these agribusinesses, a need to provide greater security and consistency for their energy supplies was one of the main drivers for their agribusinesses to invest in organic waste-to-energy plants (AM-02, AM-03, AM-04, AM-11). These agribusinesses were either completely off the national electricity grid and had been previously generating their own electricity from diesel-fuelled generators (AM-02, AM-03), or they had access to gas and electricity, but these energy supplies needed to be supplemented by generation from diesel, bottled gas or solar energy to avoid disruptions to their processing operations.

For Australian agribusinesses that do not have access to reticulated natural gas pipelines but have a high demand for thermal energy, they must rely on deliveries of bottled gas (LPG) or have on-site gas tanks refilled by supplier gas tanker trucks to meet their thermal energy needs (AM-02; AM-09; AM-10). Both options are generally more expensive than the purchase of reticulated gas supplies. For farmers using gas for their thermal energy requirements, they were impacted by the same steep increases in energy prices that prompted some in the protected cropping sector to consider organic waste-to-energy options.

Agribusinesses completely off the national electricity network found connecting to the grid can be very expensive, which can then present investing in organic waste-to-energy as a viable alternative. This was the case for one agribusiness manager interviewed:

> … on our site, where we haven't got any power. We do everything on generators and to bring the power in was one and a half million dollars, and

> the amount of power that we wanted to use in the next one-two years, was going to be about $300,000 a year in power usage. And I went, 'Piss off, I'm not ...'. - I'm sick of these bloody corrupt, bloody energy mobs - 'I'm going to build my [own biogas] power station'. (AM-03)

This agribusiness manager (AM-03) was operating off-grid and had been running large diesel-fuelled generators to meet his company's on-site electricity needs. He had previously dismissed large-scale bioenergy plants as being too expensive and beyond the financial reach of his company; 'I knew about anaerobic digesters, but of course, what I'd seen was 50, 100, 200, 300-million-dollar plants' (AM-03), but he renewed his interest in bioenergy technologies on a visit to India, where he saw several smaller-scale anaerobic digestors operating successfully. As a result of this experience, this manager reconsidered his views about the viability of biogas: 'I didn't realise that you could do [anaerobic digestion] so simply!' (AM-03) and began to see the development of on-site organic waste-to-energy technologies as a simpler and cheaper energy option than connecting to the national electricity grid.

Many farms and food processors do have access to the national electricity grid, but the condition and/or capacity of the electricity infrastructure servicing many rural and remote areas are not always sufficient to meet the electricity needs of industrial-scale food processing operations. In Australia, most residential homes are connected to standard single-phase power supplies delivering up to 240V and this is the electricity connection supplied to many farms, but industries with substantially greater voltage demands are usually connected to three-phase power supplies delivering up to 415V (Kruger Power, 2019). Single-phase power delivers electricity with less consistency than three phase-power, as it is subject to dips and peaks in voltage, whereas three-phase power delivers a steady and constant rate of electrical power (Fluke, 2022). Three-phase power is favoured in many industrial applications, as it better accommodates higher loads and is delivered at a more consistent rate, that allows for smoother and more efficient operation of large electric motors (Fluke, 2022).

Some agribusiness processors participating in this study did not have access to consistent and reliable power, or the costs of upgrading electricity infrastructure to access improved power quality were prohibitive, and so the primary driver for them to invest in organic waste-to-energy technologies was to ensure the stability and quality of their energy supplies. As two agribusiness managers explained:

> Well, look, a lot of the reason for how it came about was actually around electricity reliability. So we're at the end of what they call a rural feeder [electricity transmission line] and we have very unreliable power. And so we were just exploring ways of how you can stabilise that. (AM-11)

> In fact, we were off the grid completely at one stage because the grid was so unreliable. … And when you're trying to … you've got, you know, 50 or 80 people employed waiting for the electricity to come on. That was very frustrating! (AM-02)

AM-12 also expressed frustration with the lack of reliability of the electricity grid, commenting that '…there's system strength issues' and that '... the network's in a mess right now.' These agribusiness managers reported the poor quality and inconsistency of their electricity supply as being major problems for their operations due to the disruptions they caused to their production. Such disruptions have produced sub-optimal performance of their electrical machinery and the financial costs of lost productivity and increased plant maintenance. Investing in an organic waste-to-energy plant was seen as a cost-effective option to supplement and stabilise their electricity supply. The business cases for these bioenergy options were enhanced by the fact the processors were utilising organic by-products from their own operations which meant the feedstocks were essentially free, required no transportation and were off-setting the operations' waste management costs.

5.2.2 Waste management issues

For other agribusinesses, a significant driver prompting investment in organic waste-to-energy technologies was their need or desire to do something different with their waste, in response to a range of perceived problems with their incumbent waste management strategies. The motivations for changing existing waste management practices and exploring organic waste-to-energy options varied substantially. This variation was dependent on the extent to which existing waste management practices were seen as being problematic. This was generally determined by a combination of factors; the agribusiness type, the types and volumes of organic waste the operation produced/managed, the location of the business and where these issues sat in terms of the agribusiness manager's priorities.

One of the waste management problems prompting some agribusiness managers to explore organic waste to energy options was related to odour issues associated with manure management. Manure management is an important consideration for agribusinesses with relatively large numbers of animals concentrated in relatively small areas. These include agricultural operations such as piggeries; sheep, cattle, and goat dairies; livestock feedlots and abattoirs; and poultry sheds. This was especially the case for some agribusinesses interviewed, whose operations were located on sites relatively close to neighbours' homes or worksites, towns, cities, recreation sites (parks, lakes/rivers, sporting grounds/venues etc.) and other stakeholders (AM-02; AM-04; AM-07; AM-08). For these agribusinesses, unpleasant odours emanating from traditional manure management processes such as the use of effluent ponds or spreading of raw manure onto nearby farmland, were seen to be affecting the quality of life or amenity of their neighbours. Negatively impacting the amenity of nearby stakeholders resulted in complaints and/or unsupportive attitudes towards their business, and these complaints were communicated directly to their businesses and/or to regulators (local government or state-based statutory authorities). Dealing with these complaints and the impacts of negative attitudes from stakeholders (i.e. neighbours) was a significant motivator for these agribusiness managers to consider changes to their existing manure management practices. As one manager explained:

> So the rationale [for investing in a biogas plant] really was about reducing odour in the first place … as well as giving the company something to hang their hat on with the local community; saying, 'look, we've spent some money trying to reduce odour'. (AM-08)

This was a cause of some frustration for several managers, who identified the issue of odour management becoming a more significant priority for them, as their businesses continued to be affected by encroachment. For these agribusinesses, encroachment occurs when their production sites experience an increase in stakeholders moving into areas around their operations that could be impacted by the agribusiness' activities. AM-08 described the growth of the agribusiness' nearest town, with its expansion bringing urban development closer to his business; 'The whole town is expanding out and we unfortunately have some neighbours who've moved into very small acreages in the airstream that flows from [our business]. So there's a lot of odour issues and a lot of complaints'.

Other managers echoed this experience:

> But there was also the driver … There was a lot of sort of small acreage allotments getting cut up and subdivided around our area. And all of a sudden we had quite a lot of neighbours and, you know, running a traditional pond system or irrigating effluent directly out to the paddocks was probably not going to be an option. (AM-07)

> And the other thing is we're being encroached by hobby farmers. And even though we're zoned farming here, you only ... if you have 100 hectares, you can build a house. And that is what sort of happening around us. So it [waste-to-energy] is something that we've invested in just as a precaution [for what regulation may be applied] down the track. (AM-02)

While odour management was a driver for some of the agribusiness managers to invest in biogas plants, it was not a significant factor for all agribusinesses managing large volumes of manure and other wet wastes. These other managers acknowledged this was an issue for their industry, or for other similar agribusinesses, but it was not an issue for them, because they had substantial buffer zones around their sites or were in areas not experiencing substantial encroachment (AM-03; AM-04; AM-06).

Another motivation for agribusiness managers to change their waste management strategies was to reduce the fire risks for their businesses and their neighbours. Managers of two agribusinesses managing large volumes of 'dry' plant matter reported concerns with their traditional waste management approaches and saw the combustion of this material to produce thermal energy as a strategy for their businesses to reduce their volumes of combustible waste material on-site. One manager was nervous about his company stockpiling too much organic waste for too long, as he saw this material as a fire hazard that could combust spontaneously, in certain conditions (AM-12). This manager saw the investment in a biomass boiler as a strategy to consume more of these waste materials, to better control his operation's volumes of organic wastes and reduce the risk of spontaneous combustion.

A broadacre cropping farmer also had concerns with his traditional waste management practice of burning his cropping residues, known as stubble (plant stalks, straw, and chaff), that remain in the paddock after a crop has been harvested. While many croppers have adopted stubble retention practices to conserve soil moisture and organic matter, and protect their soils from erosion (Agriculture Victoria, 2022), some farmers in high rainfall zones prefer to remove their stubble by burning it in the paddock. However, a distressing personal stubble-burning experience provided a strong motivation for one interviewee farmer to explore alternative approaches to his stubble management:

> Yeah, well, it [exploring waste-to-energy technologies] started out as trying to solve a problem. One of the big ones was a fire, a burning off ... A stubble fire got away on me and it burnt out … it burnt about 30 or 40 hectares into the neighbour’s farm. And after that I said, ‘I never want to burn again’, because it's a pretty horrifying, not horrifying ... yes horrifying experience. And I didn't want to be in that position again. So that drove me a bit harder to try and find a use for the straw. I always thought that would be great to have a use for the straw, but I always thought it was going to be too hard to come up with a decent idea. (AM-01)

Other croppers have taken similar stances on stubble burning and are looking for alternative ways to remove stubble from their paddocks, but for environmental and climate change reasons. Stubble burning releases substantial volumes of pollution and greenhouse gases into the atmosphere and some farmers wish to avoid these emissions altogether to reduce the carbon footprint of their operations, and/or to modernise their waste management practices in preparation for regulation that may place restrictions or bans on stubble burning in the future (IE-3; IE-7). While stubble can easily be cut, baled and removed from a paddock, some farmers are looking for approaches to do so in a cost-effective way that recoups some of these waste management costs, and these approaches include the development of a market for using straw as a feedstock for bioenergy generation (IE-3; IE-7; AM-01).

For two agribusinesses interviewed, a dairy (AM-02) and a piggery (AM-06), part of their interest in organic waste-to-energy technologies was their desire to improve the efficiency of their operations by modernising their waste disposal approaches. These managers, like many agribusinesses dealing with large volumes of manure and/or wastewater, were managing their manure and wash-down water using effluent ponds that are covered to capture the methane gas from the ponds. The captured methane was then flared (burnt) to prevent the methane, one of the main greenhouse gases contributing to climate change, from escaping to the atmosphere. As a waste management strategy, this practice is regarded as best practice and an environmentally responsible effluent management approach. However, the thermal energy produced by the flaring process is not captured and is wasted, as it does not deliver any benefit to the agribusiness, other than disposing of its methane. For these agribusinesses, investing in an organic waste-to-energy plant was a way to capture the energy from the organic wastes, deliver a benefit to the business, modernise their waste management approaches, and to improve the overall efficiency of their operations (AM-02; AM-06; AM-08).

The desire to modernise agribusiness waste management approaches was also a consistent driver for other agribusiness sub-sectors to invest in organic waste-to-energy technologies. For these managers, there may have been more pressing primary motivations for modernising their waste management systems, but they also viewed the adoption of organic waste-to-energy approaches as opportunities to improve the efficiency of their businesses, by generating greater value from their organic waste materials (AM-02; AM-03; AM-06; AM-07; AM-11; AM-12).

5.3 Barriers to organic waste-to-energy adoption

The agribusiness managers identified several critical barriers that substantially impacted their transitions to the adoption of waste-to-energy technologies as integral parts of their companies' on-site waste and/or energy management approaches. These barriers were major obstacles that impeded the progress of their agribusiness transition journeys and needed to be overcome for these businesses to continue these processes through to the successful installation and operation of organic waste-to-energy plants. For most of the agribusiness managers interviewed, their companies had overcome the barriers they encountered, or were still in the process of finding solutions to these challenges. The industry experts interviewed identified a similar set of barriers that impacted agribusiness transitions to organic waste-to-energy technologies.

The most fundamental barrier impacting these transitions is the development of a reliable business case justifying their agribusiness' adoption of an organic waste-to-energy technology. Other internal and external barriers exist, such as finance, social factors, technological challenges and information issues, but in most cases, the impacts of these barriers were compounded by impacts they had on the overall business case.

5.3.1 Business case barriers

As with most business investment decision-making, a critical factor for Australian agribusiness managers considering investment in organic waste-to-energy technologies was the strength of the business case and return-on-investment (ROI). All industry experts interviewed in Stage 2 of this study identified weak business cases as being one of the main barriers to agribusiness investment in organic waste-to-energy plants in Australia .

Financial business cases for agribusiness investment in organic waste-to-energy technologies can be complex and must be customised to meet the specific needs of the agricultural operation. When considering the expenditure requirements for investment in bioenergy approaches, the business cases include costs for key elements such as technology, plant and equipment; installation and construction; project management/ consultancies and advice; purchase, transport and storage of organic waste feedstocks; operation and maintenance; energy connection and reporting fees; regulatory and compliance fees. Critical factors on the revenue side of the ledger are related to the income raised through the sale of the energy generated, carbon credits and/or gate fees received for organic waste accepted from other sources external to the agribusiness. Revenue raised may also include the energy and waste management costs saved/avoided in other parts of the business.

The fundamental issue for many agribusinesses considering organic waste-to-energy options can be marginal ROIs. The cost of installing bioenergy technologies can be high, but the energy they generate and/or the return they get for this energy, in the form of feed-in tariffs or energy savings, can be low. For most, but not all managers interviewed, their business cases did support their company's investment in an organic waste-to-energy plant. For some, the business case was strong; 'a no brainer' (AM-01; AM-04;) and clearly supported their decisions for bioenergy investment. These businesses typically had access to a large and consistent supply of a low-cost or free waste stream (feedstock) and a high demand for thermal and/or electrical energy. However, for agribusinesses with high waste supply but low energy demand, or low feedstock supply and high energy demand, the business cases were more marginal.

For agribusinesses with marginal business cases, the high capital costs for some organic waste-to-energy installations were a substantial barrier. The costs for organic waste-to-energy plants suitable for Australian agribusinesses start at $20,000 - $40,000 and increase to hundreds of millions of dollars as the size, capacity and complexity of the technologies of the plants increase. Most of the agribusinesses interviewed for this study had invested more than $100,000 for their plants, some had invested more than $1M. One agribusiness had invested more than $80M for a new bioenergy plant that had not begun to return on the company's investment (AM-12). Agribusinesses required to make substantial financial outlays for organic waste-to-energy proposals with only marginal business cases, that would take 5-10 years to provide a ROI, often struggled to secure support for these initiatives (IE-03; IE-06; IE-07). The industry experts interviewed gave some useful examples of agribusinesses unwilling to entertain marginal business cases. One expert referred to an opportunity for a green waste facility to invest in gasification technology to replace their use of LPG;

> [It was] Technically feasible, not very hard to do, [using] off the shelf components, but it was just a bit too much to have to fork out the cash to

> build it and potentially have the risk of it not having the returns that they'd hoped. (IE-05)

Several expert interviewees identified the relatively high cost of bioenergy technologies as a substantial factor restricting the viability of organic waste-to-energy applications in the agriculture sector:

> I think usually it gets to the point where it just costs too much ... either they [agribusiness owners] can't afford the upfront capital investment or they're not willing to wait however long it takes for them to have a return on that investment. (IE-05)

Another expert described experiences where the ROIs demanded by some managers interested in organic waste-to-energy were unrealistic and unachievable:

> But I think even though they [a bioenergy plant] can offer them, I guess, energy at a lower price than they currently have, it's that unknown. They just see it as being too difficult. And the sort of payback that they want from investing in these systems …! So, in other words, if they're going to stop using natural gas and use straw, they have to invest in some pretty expensive plant. And most businesses require a return on investment that's not possible with bioenergy, because it's expensive, long-life equipment. One large company said they need [the ROI to be] less than 12 months, which is just not ... it just can't be done. Certainly most businesses will want it in less than five years and preferably only, sort of, three or four. (IE-07)

Based on such expert opinions, it is clear that some bioenergy proponents view this requirement for very strong business cases and short ROIs as evidence of an aversion to business risk, thus limiting Australian agribusiness investment in organic waste-to-energy technologies (IE-02; IE-07).

IE-05 identified one of the fundamental barriers to the adoption of organic waste-to-energy technologies by Australian farmers being their prevailing mindset of ‘Why would you do anything that costs more when you don't have to?’. This statement reflects the view that unless there is a problem with an agribusiness’ energy consumption or waste management practices, then they should not take a risk on an expensive change in plant and equipment that might have a marginal business case or lengthy ROI (IE-05; IE-06; IE-07). For many agribusinesses, there is little urgency to change their current energy and/or waste management practices, and if the business case does not present a compelling rationale to change their current practices, there can be little enthusiasm for entertaining their bioenergy options.

A critical requirement for agribusinesses to build a strong business case for bioenergy is to have a productive application for the thermal energy generated by waste-to-energy plants;

> Heat is the key, because if someone's got a huge electricity bill and that's all they want, you're going to produce a lot of heat. No matter what system you put in, you're going to produce heat and to make the economics work, you've got to do something with that heat. Something productive … (IE-04)

About two-thirds of the energy produced by bioenergy generation technologies is thermal energy (IE-03), so the strongest business cases supporting agribusiness investment in organic waste-to-energy were for agribusinesses with a large requirement for thermal energy. This included agribusinesses whose thermal energy needs had previously been met by fossil fuels such as natural gas and LPG. Given the price rises for these fuels discussed earlier in this chapter, the business cases to replace these fossil fuels with biomass were for some agribusinesses, ‘no-brainers’ (AM-04).

Most of the agribusinesses interviewed used most or all the energy they generated on-site, ‘behind the meter’ and did not generate enough energy to justify selling excess (or exporting) electricity to the grid and/or qualify for payments for carbon credits (AM-02;

AM-03; AM-04; AM-05; AM-06; AM-07; AM-09; AM-10; AM-14). For agribusinesses that did receive income for electricity exported to the grid and for carbon credits, these were important contributions to their bioenergy business cases, but these options included financial and regulatory barriers and could not be justified for most of the managers interviewed. As AM-08 explained:

> So for a lot of piggeries, they don't need that much electricity and they don't need that much heat. So without the carbon credits, the whole thing just doesn't stack up. But if you've got an industry next door that can use that electricity and use that heat, and then there's some regulatory issues about exporting electricity across the fence at the moment - that's not allowed. So you've got to send it out through the network and they charge heaps and heaps of money just to transport the electricity, even if it's only going right next door. (AM-08)

For agribusinesses with more marginal business cases, they needed to have multiple factors in their favour to support their investment in bioenergy; 'a perfect storm' (IE-01) or as one manager described it, 'all your stars aligning' (AM-09). There were some examples where the stars did indeed align, and an agribusiness serendipitously found everything worked to support their investment in organic waste-to-energy (AM-04; AM-06). However, for most of the agribusiness managers interviewed, they had to work hard to explore more creative and holistic solutions to overcome the barriers and to build stronger business cases; to get the business case to support a change to bioenergy approaches.

An example of a unique circumstance that had a positive impact on the business case supporting change to bioenergy was AM-04's agribusiness, which was able to substantially reduce its feedstock delivery costs by back-loading one of its own trucks that was delivering a different waste material to a waste treatment facility operating in the same general area as the feedstock supplier (AM-04). This had a significant impact on improving the business case for the adoption of its bioenergy technology, because this agribusiness was located more than 200 km away from its feedstock supplier; a distance that can be considered too far for the viable transport of bioenergy feedstocks.

Another agribusiness was also able to reduce its feedstock delivery costs by negotiating a cheaper delivery rate with its supplier by providing a secure storage space at the agribusiness for its supplier to park its truck overnight and on weekends (AM-10). Several agribusinesses had their business cases enhanced by having a complimentary business nearby that was willing to pay a gate fee for disposal of a suitable organic waste material, or to deliver this feedstock to the agribusiness at no or minimal cost (AM-02, AM-09, AM-11).

A key factor impacting the business case for agribusiness investment in organic waste-to-energy technologies is the location of the agribusiness, in terms of its proximity to key stakeholders. As mentioned previously in this chapter, the location of an agribusiness relatively close to its key stakeholders could be both a driver or a barrier for its bioenergy business case, just as being relatively isolated from its key stakeholders could also support or undermine the rationale for an agribusiness to change to a waste-to-energy technology. Whether the location was a significant driver or barrier depended on the stakeholders and varied substantially across the agribusinesses participating in this study.

Agribusinesses being relatively close to key stakeholders was advantageous for operations requiring delivery of feedstocks to fuel their organic waste-to-energy plants (AM-02; AM-04; AM-05; AM-10; AM-11). The relevant stakeholders for these agribusinesses were their feedstock suppliers, that were generally complimentary businesses producing organic by-products suitable for their bioenergy technologies, such as vegetable growers, sawmills, and a timber truss manufacturer. One agribusiness manager (AM-11) identified having a local and reliable source of suitable waste feedstocks as being a key prerequisite for agribusiness adoption of bioenergy technologies:

> The business that does it [adopts a waste-to-energy approach] needs … to be relatively close to where the waste comes from. That would probably rule a lot of people out, but you've just got to make it work for yourself.

Transportation costs are a significant component of the overall costs of supplying feedstocks for bioenergy plants and a significant factor in a bioenergy business case. For agribusinesses needing to fuel their bioenergy plants with feedstocks from off-site, they generally prefer to source their feedstocks from suppliers located as close as possible to their waste-to-energy plants, to minimise the feedstock delivery costs and for convenience. Most of this study's agribusinesses purchasing organic feedstocks from off-site received deliveries from suppliers situated less than 50 km away, but some agribusinesses sourced their feedstocks from as far away as 200 km (AM-04; AM-10). To make the business case for bioenergy adoption 'work' financially, when the agribusinesses managed by AM-04 and AM-10 needed to source their feedstocks from suppliers 200 km away, they needed to explore creative 'bespoke' solutions to help bring their 'stars into alignment'. However, for agribusinesses located in areas that do not have complimentary businesses producing suitable organic feedstocks, the transport costs associated with purchasing these feedstocks from further afield can make organic waste-to-energy options less viable financially (AM-11).

The location of the food and fibre production or processing operation was also an important factor in terms of the business' access to technical expertise to support the operation and maintenance of organic waste-to-energy plants. Most of the bioenergy plants adopted by agribusinesses participating in this study, were imported from manufacturers in Europe, Asia or North America, and installed by contractors generally based in Australia's capital cities or regional centres (AM-02; AM-04; AM-05; AM-06; AM-07; AM-08; AM-09; AM-10; AM-11; AM-12; AM-14). In some cases, the manufacturers and contractors provided some level of periodic servicing of the installed plants, but specialist technicians were sometimes required to fix problems with the waste-to-energy plant operations. Agribusinesses relatively close to the capital cities or regional centres generally had reasonable access to the technical expertise to service their bioenergy technologies, but for agribusinesses in rural or remote parts of Australia, accessing technical expertise was more difficult and more expensive (AM-09; AM10; AM-15).

The lack of access to technical expertise was a major problem for an agribusiness manager (AM-15) who had all but given up on ever getting his food processing company's biomass combustion boiler operating at full capacity. This manager described having an organic waste-to-energy plant that while operational, was delivering only a fraction of the energy the company believed it would generate, and despite having an underperforming plant, the manager was reluctant to invest any additional funds into improving the plant's performance. Over several months, AM-15 had already paid specialist consultants and technical experts from a capital city to travel to his food processing site to optimise the performance of his waste-to-energy plant. Despite this investment, they had not been able to find a long-term solution to the technical issues affecting the performance of the plant, and AM-15 had reluctantly decided his business could no longer sustain the high costs associated with trying to fix its bioenergy plant, would 'cut his losses' and accept the sub-optimal performance of the plant (AM-15).

Another agribusiness, located in the NSW Central Coast region several hours travel away from the technical expertise needed to service its bioenergy plant, experienced similar issues with the difficulty and cost of accessing contractors to support the operation of their waste-to-energy plant:

> But, you know, certainly one of the biggest issues of investment is, one, the back-up, because we are lacking in critical mass [of businesses in the area using similar technologies].

> So in terms of [servicing] this actual boiler unit, it is quite expensive for us, because if we need this guy [bioenergy technical contractor] to come out, we've got to rely on other guys [from], say, let's point down to the Victoria area. We need them and require the services of the manufacturer to come and do some maintenance there. And then obviously we've got to pay their air ticket, the hourly rate, da da da da. You know what I mean, to get the guy up here. (AM-10)

The difficulties and expense associated with the servicing and maintenance of bioenergy technologies can impact businesses at any location, but these issues are amplified by distance, which was the case for several agribusiness managers in this study (AM-09; AM-10; AM-12; AM-15).

While the location of agribusinesses relatively close to stakeholders such as feedstock suppliers and technical experts/contractors can be beneficial to these businesses, being near to other stakeholders can also be problematic for some agribusinesses. This was particularly the case for some dairies and piggeries that were relatively close to stakeholders such as neighbours and their local communities and experiencing odour issues from their manure management approaches (AM-02; AM-07; AM-08; AM-13). As discussed earlier in this chapter (Section 5.2.2), the extent to which odour/manure management issues were a driver for these types of agribusinesses to explore organic waste-to-energy options was influenced by the location of the agribusiness and its proximity to specific stakeholders.

5.3.2 Lack of awareness and unsupportive attitudes to bioenergy

The extent to which agribusiness stakeholders are aware of the opportunities for bioenergy and/or have opinions and attitudes supportive of such developments, are significant factors impacting the investment by Australian agribusinesses in organic waste-to-energy technologies. Several interviewees identified that bioenergy is not well understood in Australia (IE-02; IE-04; IE-05; AM-03), and this lack of understanding begins with the general population:

> So I think fundamentally what's stopping Australia from taking up these technologies from my view is a combination of, ‘why would you do anything that costs more when you don't have to’, combined with a fairly low level of awareness of what's possible [with bioenergy]. (IE-05)

> The worst [barrier] ... probably the worst one was the lack of knowledge [of bioenergy] that's out there in general public ... (AM-03)

The industry experts interviewed generally agreed this lack of familiarity extends to Australian agribusinesses and their stakeholders, which contributes to a lack of awareness of organic waste-to-energy opportunities and/or unsupportive attitudes towards on-site bioenergy developments (IE-02; IE-03; IE-04; IE-05; IE-07).

As a result, agribusiness stakeholders with low levels of awareness of bioenergy options and unsupportive attitudes towards its implementation are substantial barriers to its development in Australian agribusinesses. Conversely, stakeholders having an awareness of bioenergy’s potential and supportive attitudes towards its development are seen as being important enablers in the transition of the Australian agriculture sector to organic waste-to-energy approaches (AM-02; AM-04; AM-07).

According to the industry experts interviewed in this study, one of the key reasons more Australian agribusinesses do not explore their organic waste-to-energy options is that many of these agribusinesses are not aware of or understand the opportunities these technologies could offer their operations (IE-02; IE-03; IE-04; IE-05; IE-07). The following experts felt agribusiness managers have limited understandings of bioenergy approaches, and while they may have heard of bioenergy and its broad applications, they might not have a strong appreciation of how it could apply to their operations:

> My gut feel is they don't have a great awareness. But of course, the people [agribusiness stakeholders] I speak to are probably people I've met at forums or conferences, so they've already got some sort of awareness before they get there. But my gut feel is that the general population of people working in agribusiness wouldn't have a strong awareness of it. (IE-04)

> But I think generally it's [agribusiness manager understandings of bioenergy approaches] reasonably low. I think people understand that you can get methane off piles of pig crap, for example, but they don't really understand how you can go along the technology chain to an anaerobic digestion system that makes quite high-quality biogas. I think that extension is perhaps not particularly well understood. (IE-05)

Some agribusiness managers have a basic understanding of their organic waste-to-energy options, but express little interest in engaging further:

> First and foremost, they [agribusiness managers] [say], ‘Yes’, that they've heard about it and they've read about it. They've nodded their heads about it, but ‘don't worry me about it’. There's that sort of thing there. That's the main stumbling block. (IE-02)

> Very, very little [farmer awareness of bioenergy opportunities]. Yes, surprisingly little. … And so to a degree, it's ... people aren't getting outside the box. And so that's why it [greater adoption of bioenergy in agribusiness] isn't happening. (IE-03)

The lack of awareness of bioenergy options (in all its forms, as noted in the quotations above) is a barrier that extends beyond agribusiness managers to a range of other Australian agribusiness stakeholders. Several key stakeholders from outside an agribusiness can have a substantial impact on the decision-making of agribusinesses on bioenergy adoption; stakeholders such as farm advisors (IE-08), bankers and financial advisors (IE-07), industry organisations (IE-02; IE-03; IE-06; IE-07) and local communities (IE-01; IE-02; IE-03; IE-04). Where these stakeholders have limited understandings of bioenergy or views that do not support agribusiness investment in organic waste-to-energy developments, this can present agribusinesses with barriers to organic waste-to-energy adoption (IE-01; IE-07; IE-08; AM-02; AM-04; AM-07; AM-11). On the other hand, stakeholders aware of and supportive of bioenergy opportunities can be important enablers for agribusiness investment in bioenergy technologies (AM-02; AM-04; AM-07).

Critical to this awareness is the role of leading advocates of waste-to-energy technologies. Agronomists and farm consultants play important roles as trusted advisors to Australian agribusinesses. IE-08 described the difficulties he has experienced in trying to engage with these advisors, to raise the awareness of bioenergy and how it could be applied to the Australian agriculture sector:

> We've found it very difficult to gain traction … very difficult to find traction, simply because we had a lot of difficulty getting through to the farm consultants and the farm advisors. And we really … you know, sometimes I've been talking to farm advisors about bioenergy, you just see their eyes glaze over and they lose interest. And I think farmers are very... they basically do what farm advisors tell them largely. So I think that's been very difficult ... so it's been a bit of a constraint to the work that we've been doing. You almost have to convince the farm advisors, before you convince the farmers. (IE-08)

IE-07 had a similar view of farm advisors' awareness of bioenergy opportunities; 'Certainly, there wouldn't be too many agricultural advisors that are familiar with waste-to-energy technologies and the sorts of markets that may be available'.

Some experts saw similar situations with other key agribusiness advisors, such as accountants and financiers (IE-01; IE-07):

> It's [bioenergy] just simply too new, too unfamiliar. You know, people like accountants just don't understand it. You know financially, you ask a bank about it - they have no idea! They'll back wind and solar projects, no problem. You'll get finance easy. But bioenergy? No, they don't... it's simply unknown in the Australian context. (IE-07)

The impact of this awareness barrier was confirmed by agribusiness managers, who described the lack of understanding of bioenergy in the banking sector as contributing to an abundance of caution for banks and financial advisors considering agribusiness bioenergy proposals:

> Ahhh look … your traditional banks, I don't think they really understand it. And they are very … that would be “caution”! Er, we actually haven't really spoken to them [our bank], to be honest, because I don't think they're gonna get their head around it. (AM-11)

Three agribusiness managers (AM-02; AM-04; AM-07) could see that this was a barrier for other agribusinesses banking with ‘traditional banks’, but this was not their experience when their businesses were seeking finance for their bioenergy investments. Instead, these managers stressed the positive role their bank managers played in supporting their business’s investment in organic waste-to-energy plants; that their banks had a greater awareness, understanding and interest in supporting organic waste-to-energy developments;

> We've been dealing with the [same] bank now for 30 years and we've got a really good track record with them and they really trust us. So getting some investment to set one of these up [without a good relationship with their bank] would be a barrier for most people. (AM-02)

> We had a good bank manager and then that's probably helped as well. Who knew our business backwards, and we dealt with them for 20 odd years. … So we were lucky to have that synergy with the bank manager. … Being a European bank, they've seen these systems all over the world. So, yeah, they knew the system. So when I sat down and spoke with some of their people, they knew how many of these systems had been installed all around the world. ... They'd obviously lent a lot of money to these projects around the world. So it was it wasn't difficult to get their approvals… (AM-04)

AM-02 and AM-04 indicate that the banks servicing their agribusinesses were different to the typical banks servicing others in the agribusiness sector. Such agribusiness-based financiers had a greater awareness of and interest in bioenergy technologies and opportunities for agribusiness, and so were better placed than ‘traditional’ banks to support their agribusiness’s investment in bioenergy. AM-04 went on to explain that if an agribusiness were to approach ‘his’ bank with a bioenergy proposal;

> … they [the bank] would probably tick the box straight away, with those guys, because they actually understand the industry and understand the farming side of things as well. So ... [they] just like lending money to projects which are in this nature … they do love investing in that sort of stuff [renewable energy]. (AM-04)

A lack of awareness of and/or unsupportive attitudes towards bioenergy in various government authorities and regulatory bodies also manifest as barriers for agribusiness adoption of organic waste-to-energy technologies. As with the banking sector, the extent to which stakeholders with regulatory oversight of areas relevant to bioenergy developments, are aware of and have supportive attitudes towards agribusiness investment in these technologies, can be a critical factor impacting the adoption of these approaches. Several industry experts and agribusiness managers interviewed identified regulatory stakeholders, such as the State-based Environment Protection Authorities (EPA) and Local Government Authorities (LGAs), whose understandings of bioenergy approaches could help or hinder agribusiness developments of these technologies (IE-02; IE-03; IE-07; AM-02; AM-05; AM-06; AM-10). These stakeholders provide regulatory advice to agribusinesses and their contractors/consultants and issue the approvals and permits required for the construction and operation of bioenergy plants. Regulators familiar and/or experienced with organic waste-to-energy applications can enable a relatively smooth process for the adoption of these technologies (AM-05; AM-06; AM-07), but regulators with limited bioenergy experience and/or unsupportive attitudes to bioenergy development can present barriers (AM-03; AM-10).

For some of the industry experts and agribusiness managers interviewed, regulatory bodies such as LGAs (local councils) and EPA were important supporters of their bioenergy development and operation processes:

> When I think back about the whole project, it went pretty smoothly. And all parties involved really stepped up to the plate and helped us, including the council and the EPA, buying the boiler overseas and getting it shipped into Australia.
> I've got to give the Dandenong Council a bit of credit, because we needed to get a planning permit for the building and they vetoed [sic - approved?] the plans within four weeks for us. They wanted the project to be a success for obvious reasons. (AM-05)
> And there was a lot of common sense shown by the EPA at the time. Just to say, ‘Well, this is a this is going to be a great outcome. So let's try and help it, not stop it’. (AM-07)

For these agribusinesses, the experience and competence of their local councils and EPAs was an important factor enabling a smooth approvals process for their organic waste-to-energy plants. However, for other agribusinesses, a lack of Local Government and/or EPA experience with organic waste-to-energy technologies was a significant barrier to the development of bioenergy projects:

> … the local council were, you know, almost subscribing to the precautionary principle -"Oh we don't know enough about it, so therefore we can't have it". And so there was quite a lot of, you know, quite an arm wrestle to get this biomass boiler approved because it's the biggest in our area and it's one of the few.
>
> You know, they hadn't sort of seen movement of woodchip [like this], it was all the other bits and pieces, you know, what is the transport going to do to the roads? Is going to create congestion? Is it going to damage the roads? There were lots of other things that were the key criterion that they were looking at rather than the actual sort of boiler itself. So council were certainly quite hesitant about the whole thing. And once again, you know, being a fairly new sort of development and high tech and so on, they didn't have ...I'm not actually sure what you call them, you know, the representatives who were fully knowledgeable about this whole thing. (AM-10)

Other interviewees were critical of the government regulators and found them to be difficult to work with:

> I think we've got so bureaucratic with EPAs and governments … we've become so bureaucratic and so locked into procedure and process that sometimes that you get so worried that you're not doing a good job. … [But] if you go up to China and see how many anaerobic digesters are working up there - mate, mate ... we are so far behind in Australia! They had to teach the EPA … what an anaerobic digester was. They didn't understand what it was. I mean, here we are ... in China, you can drive around the whole of bloody China and there's hardly a city that hasn't got one, you know. So, again, in these areas, you look at some of the things that we are so advanced on, but

> on other areas, we are just so, so, so, so backward. I mean, I'm talking backward! (AM-03)
>
> I've found them [my council] really difficult and secretive and [they] dig for information and don't give anything back and all they're trying to do is get their face in the paper or make a good story of it and it never goes anywhere. (AM-01)

The main criticisms interviewees had of their council and/or EPA regulators were related to the length of time taken in these approval processes and the detail they needed to provide in their bioenergy applications/proposals. For AM-01, AM-03 and AM-10, the processes were overly bureaucratic and/or overly cautious, due to the regulator's lack of familiarity and understanding of organic waste-to-energy applications in agribusiness settings. AM-02, AM-06, AM-09, AM-11 found these processes were lengthy and sometimes costly, but they felt this was to be expected and/or no different than any other approval processes with these regulators.

While there was criticism of the EPA approval processes in some states (AM-03), IE-01 acknowledged improvement in the EPA approach to bioenergy regulation, but indicated further development was needed to better support the transition to bioenergy approaches. Other interviewees found the regulators played a positive role in supporting the development of their organic waste-to-energy developments. AM-05, AM-06 and AM-07 found government authorities provided sound advice and support for their projects, and approval procedures were handled expeditiously, which contributed to a smooth transition process for their companies.

The industry experts interviewed generally agree there is limited awareness of bioenergy opportunities amongst some stakeholders in the agriculture sector, but these experts do not agree on the extent to which agribusiness peak bodies are aware of or interested in bioenergy options for Australian agribusiness. Some interviewees identified pockets of interest and awareness within agriculture peak bodies such as Meat & Livestock

Australia (MLA), Australian Pork, Dairy Australia and Australian Eggs (IE-05; IE-06; IE-07;) and reported a growing awareness of bioenergy opportunities for larger scale agribusinesses (IE-01; IE-06), but IE-03 was more critical of what he saw as a lack of interest and leadership from some industry sectors:

> … VECCI [Victorian Chamber of Commerce and Industry] … those peak bodies, NFF [National Farmers' Federation], VFF [Victorian Farmers' Federation] … [they] cover all of those interest sectors, [but] are not interested and not informed. They don't have anybody who is dealing with the energy or maybe even the energy efficiency side of running those intensive businesses or the processing. That's a real worry because there is no leadership that they're getting. They're [agribusinesses] not getting it from the Weekly Times, they're not getting it from the ABC [Australian Broadcasting Corporation]. They're not getting it from anyone. So, they're not aware of it [bioenergy]. (IE-03)

While there was a range of views on the engagement of agriculture peak bodies and other industry organisations in supporting agribusinesses to adopt bioenergy technologies, all industry experts interviewed agreed Bioenergy Australia (BA) was playing a positive role supporting the bioenergy industry in Australia (IE-01; IE-02; IE-03; IE-04; IE-05; IE-06; IE-07; IE-08). There was also recognition of BA's growth from having what was characterised as a pure technology development focus to a more strategic approach to engaging with key stakeholders in Australia, including the media, politicians, business and industry leaders, and international experts (IE-03). IE-08 said 'Bioenergy Australia is doing a great job promoting the benefits of bioenergy, especially in the roles of biofuels and an anaerobic digestion and biogas'. IE-02 was also optimistic about BA's direction, '… they're starting to think in more of a business-like manner about it [bioenergy] and what it should be, and I think they ultimately will do some good'.

Low levels of understanding of organic waste-to-energy opportunities can be substantial barriers to organic waste-to-energy adoption, as they can contribute to unsupportive attitudes and misconceptions related to organic waste-to-energy approaches. One technology provider (IE-04) identified three main issues that contribute to unfavourable perceptions of bioenergy amongst a range of stakeholders. The first two issues question the environmental sustainability of biomass boilers, and the third relates to the physical requirements of staff operating these technologies. These questions were what IE-04 described as the common themes or concerns he had to address when discussing biomass combustion boilers fuelled by woodchips. The first issue relates specifically to the use of woodchips. IE-04 describes being challenged on this feedstock being categorised as a waste material and the perceived impacts of woodchip consumption on environmental problems such as deforestation and loss of biodiversity:

> Oh, I think it [attitude to bioenergy] is really significant, because whenever I initiate a conversation with someone who hasn't really much awareness to start with, I get the same questions every time. First one is exactly that, they say, 'Well you're burning wood, so you must be cutting down trees. That can't be good. That's not environmentally friendly. You shouldn't be doing that’. And I explain that 'No, we're targeting waste biomass'. They might still have the question saying, 'Well, you know, what if the waste runs out, then you're gonna have to cut down trees, aren't you?' You know that is there for sure. (AM-04)

The second query also questions the environmental sustainability of biomass boiler technologies, focussing on the air pollution and greenhouse gas emissions from the combustion processes:

> [People say] 'Well you're burning wood, so there's smoke, so you're polluting’. So, then you explain how efficient they [biomass combustion boilers] are, and [that] the particulate emissions are minimal, and we have

> flue gas filters and all this sort of stuff, explain that as well. … But they don't believe in the benefits of biomass. They say, ‘Well, there's still emissions, even if your particulates are low, you're still emitting carbon dioxide. So it's not a good thing to do.' And I'm saying, 'well, yeah, but it's carbon neutral.' If you consider that that tree has already removed the carbon from the atmosphere and then you burn it, it releases it, So it's one in, one out. They're saying, 'Yeah, but it should be just left in the tree'. I'm saying, 'Yeah but these trees are being cut down anyway.' It's a long argument, but it's a perception that people really struggle to get around. (IE-04)

Another agribusiness manager burning woodchips in a biomass boiler (AM-05), has had similar discussions with his stakeholders; ‘Look, I do understand that to a certain extent when people think, “Well, hang on, you're still burning trees. So how can that be for the environment? Right?”’.

The third issue commonly raised by stakeholders talking with IE-04 relates to misconceptions about the operation of a biomass boiler:

> [This is about] the work involved, [people] saying, 'well, you know, I'm going to have to shovel these bloody wood chips!' . [This is] the other thing that might put people off, … uncertainty around the management of the system because ... a gas boiler's quite easy. You light it, turn a switch on, it goes. There is a little bit more management associated with a biomass boiler. You've got to produce the fuel, get it to a certain size and quality first, load it into the hopper and make sure it keeps burning, empty the ash. There's some maintenance around it and a little bit more of an impost in terms of maybe half to one person day per week to do that. (IE-04)

While IE-04 describes these questions as coming from the point of view of an agribusiness manager, these misunderstandings are representative of a general lack of familiarity with and understanding of the operation of bioenergy technologies in Australia (IE-01; IE-02; IE-03; IE-04, IE-05; IE-06; IE-08).

5.3.3 Lack of technical expertise in Australia

A critical factor limiting the adoption of organic waste-to-energy approaches in Australian agribusinesses is the lack of technical expertise in the design, installation, maintenance, and operation of bioenergy technologies in Australia. This factor has been touched on in this chapter's previous section discussing the lack of awareness of bioenergy opportunities in Australia (section 5.4.2) and the difficulties agribusinesses in rural and remote locations can experience in accessing bioenergy expertise (section 5.4.1). However, this barrier refers specifically to a general shortage of skills and technical expertise in Australia's bioenergy industry. Half of the industry experts interviewed identified the lack of expertise in bioenergy technologies as a major issue for the bioenergy industry (IE-01; IE-03; IE-05; IE-07). IE-01 suggested Australia had enough technical expertise for small-scale, behind-the-meter installations, but there were fewer consultants with expertise at the medium scale (1-5 MW), and there was a clear skills shortage on the policy and regulatory side:

> … without a doubt. Now, EPA is getting way better at it. They've actually done their due diligence on existing facilities globally. And so they actually can bring a bit of technical expertise to bear, but I'm not entirely comfortable with our policy and regulatory capacity to deliver the needed policies to drive change. (IE-01)

According to IE-03, 'an enormous gap' exists in Australia; a shortage of people with 'good expertise and knowledge about the economics and available suppliers [of biomass feedstocks and technologies]', who can provide independent advice on bioenergy.

It was evident in the Stage 3 interviews with agribusiness managers that the experience and expertise of the consultants/contractors was a critical factor in the success or failure of the organic waste-to-energy installations at Australian agribusinesses (AM-02; AM-04;

AM-05; AM-08; AM-09; AM-10; AM-11; AM-12; AM-15). For AM-02, AM-04; AM-05, AM-08 and AM-11, their organic waste-to-energy plant was installed with few issues and was operating as expected, and they generally credited the success of these installations to the expertise of the company/contractor/consultant engaged to complete their project. These agribusiness managers were relatively ‘hands-off’ during the installation of their plants, developing excellent relationships with their contractors and trusting them implicitly to do their jobs:

> [Our contractors] … have become a very trusted partner of ours. We trust them implicitly with anything that's to do with the digester itself. They've operated that one down there [in Victoria] ...They designed it. They built it. They're pretty upfront with us about the issues that can be involved. But that's good, because at least you know. They've got the runs on the board. (AM-11)
>
> And then once we had [our contractor] on-side … we actually hired him as an advocate for us to help us with the project. He answered all the questions and gave us complete confidence, and we took it from there.
>
> He was the one that really got it going for us. … he was definitely what made the project a success for us. I think without [our contractor’s] help, I don't think it would have been a success. I wouldn't have got as far as I did. (AM-05)

Other agribusinesses were more involved in their bioenergy journey, doing much of the project management themselves and bringing in technical expertise when needed (AM-06; AM-07; AM-10). However, for AM-03, AM-08, AM-09, AM-12 and AM-14, the lack of expertise in the Australian bioenergy industry has been a major barrier for their agribusiness’ adoption of organic waste-to-energy technologies.

5.4 Summary

This chapter focussed on presenting a snapshot of the current state of organic waste-to-energy adoption by Australian agribusinesses. It identified the drivers prompting Australian agribusiness investment in organic waste-to-energy technologies as an integral part of their on-site energy and waste management strategies, and pinpointed the critical barriers that impact the transition process.

The research findings identified that bioenergy makes only a small contribution to Australia's overall energy mix and the agribusiness contribution to Australia's organic waste-to-energy installations is also small, with less than 70 Australian agribusinesses investing in these technologies. This finding aligns with Australia's position in the bottom quartile of OECD countries (in terms of bioenergy development) and the under-developed state of Australia's bioenergy industry (KPMG, 2018; Li et al., 2020; McCabe, 2020). It is important to acknowledge the relative immaturity of the Australian bioenergy market, as this may be a contributing factor to some of the barriers impacting agribusiness investment in these technologies.

However, for agribusinesses that have invested in these approaches, their main motivations for doing so were borne from a need to address one of two main types of problems with their incumbent practices. The first type of problems involves the cost and/or security of the agribusiness's energy supply; and the second type are problems with their existing waste management approaches. Sharp increases in local gas prices have created urgent challenges to the viability of some Australian agribusinesses, prompting agriculture sub-sectors with a large demand for heat to explore alternative thermal energy sources, such as bioenergy technologies. Similarly, agribusinesses with a requirement for stable and consistent supply of electricity, have been prompted to explore their on-site electricity generation options, if their current electricity supply is unreliable and/or inadequate for their operation's needs.

For other agribusinesses, problems with their incumbent waste management approaches can be the main drivers for their interest in organic waste-to-energy systems. Waste management practices such as the burning of cropping residues (stubble) or the spreading of raw manure on farmland, may no longer be as acceptable (environmentally or socially) as they once were, prompting agribusinesses managing large volumes of organic waste to consider their ecological modernisation options. These prominent drivers generally align with those identified in academic literature exploring agribusiness adoption of bioenergy technologies in Chapter 2.

The main impediments impacting agribusiness transitions to organic waste-to-energy approaches are also consistent with the obstacles identified in other studies, with the main types being financial barriers and knowledge-based barriers. Financial factors are a common barrier; including high capital costs, uncertain returns on investment and difficulties securing finance. Other barriers include the immaturity of the bioenergy market and Australia's general lack of familiarity with bioenergy technologies and their possible applications in the food and fibre production and processing sector. This general issue also contributes to more specific barriers involving Australian agribusiness managers and their key stakeholders exhibiting a lack of awareness of and/or unsupportive attitudes towards organic waste-to-energy development, and a lack of skills and expertise in the bioenergy industry to support organic waste-to-energy development in Australia's agriculture sector.

The next chapter discusses these findings in terms of their relevance to this study's research question and sub-questions. This discussion includes the application of Multi-Level Perspective (MLP) and Social Practice Approach (SPA) theoretical approaches, to develop understandings of the transitions of Australian agribusinesses to the adoption of organic waste-to-energy options.

6. Discussion

This chapter presents analysis of the adoption of organic waste-to-energy technologies by the Australian agriculture sector, based on the findings set out in the previous chapter. As a study adhering to the pragmatist research philosophy, this analysis is primarily concerned with establishing the current reality of the state of agribusiness use of organic waste-to-energy technologies in Australia and the factors impacting their investment in these technologies. A key part of the analysis of sustainability transitions is the identification and classification of critical factors identified in Figure 3.1 that affect these transformations; the drivers and barriers that enhance or hinder a transition process and the dynamics of how these factors interact (Barquete et al., 2022; Gottinger et al., 2020). The drivers and barriers impacting Australian agribusiness transitions to organic waste-to-energy technologies, as outlined in the previous chapter, are applied to the MLP and SPA theories described in Chapter 3. This evaluation then considers these findings and theoretical analyses in terms of this study's research question and sub-questions.

The first of the theoretical approaches detailed in Chapter 3, MLP provides a framework describing sustainability transitions that deliver the disruptive and transformative adoption of radical new technologies and approaches required for a sustainable world (Geels, 2005a; Geels et al., 2020; Geels & Schot, 2007; Geels et al., 2017). With organic waste-to-energy technologies and approaches having the potential to contribute sustainable energy and waste management improvements to the Australian agriculture sector, MLP is a suitable framework on which to base this analysis.

The MLP framework maps the transformation pathway of new technologies and approaches from their emergence as niche innovations, to their widespread acceptance and adoption in a society; the MLP's socio-technical regime (Geels et al., 2017). Both socio-technical regime and niche-innovation levels are influenced by the socio-technical landscape, which is MLP's global environment within which Australian agribusiness functions. The transition journey of a new technology or approach can be impacted by a range of drivers and barriers (Barquete et al., 2022; Gottinger et al., 2020); the drivers and barriers relevant to organic waste-to-energy transitions in the agribusiness sector are identified in Figure 3.1, and their impacts in the Australian context are explored in Chapter 5.

The next section (6.1) evaluates the drivers and barriers impacting this sustainability transition. Such transition is viable and enduring only if social practices are adopted that ensure long-term evolution. SPA theory identifies key social mechanisms and dynamics (Hargreaves et al., 2013; Hinrichs, 2014; Miremadi, 2021) that apply in this study to the role of human agency and social structures in Australian agribusiness and its adoption of organic waste-to-energy. Section 6.2 evaluates the findings from this SPA perspective. Section 6.3 provides responses to the four sub-research questions based on the prior analyses. Section 6.4 addresses the major research question and summarises the chapter.

6.1 Organic waste-to-energy adoption and MLP

This section presents an analysis of the impacts of key drivers and barriers to organic waste-to-energy adoption by Australian agribusinesses and explores these drivers and barriers in the context of MLP. As shown in Figure 2.1, MLP considers the transition journey of a radical technology or approach, as it progresses through four developmental phases and engages with MLP's three levels; niche-innovations, socio-technical regime, and socio-technical landscape (Geels et al., 2017).

This discussion applies the MLP framework to analyse factors impacting the journey of organic waste-to-energy technologies emerging from the niche-innovation level, to be adopted by Australian agribusinesses operating in the MLP's socio-technical regime. Much of this analysis focusses on agribusiness engagement with organic waste-to-energy systems, as these emergent niche-innovations begin to compete with the incumbent energy and waste management technologies. In the following sections, MLP is applied to the research findings, detailed in the previous chapter, and discussed in terms of Australian agribusiness transitions to the adoption of organic waste-to-energy approaches.

6.1.1 Niche-innovations

The penetration of organic waste-to-energy technologies by Australian agribusinesses varies according to the agriculture sub-sectors and bioenergy technologies. In the Australian agribusiness context, organic waste-to-energy technologies, such as anaerobic digestion, are generally niche-innovations in the early stages of their development (Edwards et al., 2015).

However, one significant exception to this characterisation, the Australian sugar industry, leads the country in terms of organic waste-to-energy technology installations (see Figure 5.6). Biomass combustion technologies have been an integral part of the sugar industry's energy and waste management approaches for more than a century (Clean Energy Regulator, 2023), where these technologies have moved beyond the niche level and become established in the regime.

Biomass boilers are common features in Australian sugar refineries, with 27 plants installed in this sub-sector around Australia, with most installations in Australia's main sugar-growing state, Queensland (see Figures 5.5 and 5.6; Appendix E). Sugar processing is an obvious fit for organic waste-to-energy technologies, given its requirement to manage large volumes of organic by-products (sugar cane trash/bagasse) and their substantial demands for both thermal (steam) and electrical energy (AM-12). But for other agriculture sub-sectors, modern bioenergy applications are far more recent innovations still emerging from the niche level, seeking to become established in the Australian agriculture regime.

The primary modern bioenergy technologies adopted by Australian agribusinesses for organic waste-to-energy applications are anaerobic digestion plants and biomass combustion boilers (Appendix E; KPMG, 2018). Other forms of bioenergy are at earlier stages of their development, with conversion routes such as gasification, pyrolysis and microalgae in the MLP experimental stages of Phase 1 or Phase 2 (see Figure 2.1), in terms of their commercial applications in the agriculture sector. Biogas/anaerobic digestion and direct biomass combustion are more advanced, but these are still emerging technologies, in MLP Phases 2 and 3 respectively. These organic waste-to-energy plants are by and large proven technologies that have been imported from Europe, Asia or North America by Australian contractors (IE-3). These plants are not experimental prototypes but established technologies with many installations in agriculture settings in other countries.

Direct combustion technologies, used in biomass boilers deployed by Australian sugar processors, are in Phase 4 of their transition journey, where they are well-established in the sugar industry regime. For other Australian agriculture sub-sectors, direct combustion technologies are in Phase 3, where they are becoming a more common generator of thermal energy for the protected cropping and meat processing sub-sectors (Appendix E). For other food and fibre producers and processors, biomass combustion boiler applications are relatively new and still in their early stages of development in terms of their applicability to Australian agriculture.

Biogas/anaerobic digestion technologies are in Phase 2 of MLP and behind combustion technologies in terms of commercialisation and deployment in Australian agribusinesses. Half of Australian agribusiness's biogas installations are at piggeries or meat processers, with the remainder mainly at dairies and poultry farms (see Figure 5.6). Biogas technologies are relatively mature, but with fewer than 25 plants operating in Australian agriculture, it is still an emerging approach to this industry's on-site energy and waste management strategies (Appendix E).

6.1.2 Socio-technical regime - drivers

MLP's meso-level, socio-technical regime, refers to technologies and incumbent approaches that engage with all actors, businesses, industries, institutions, regulators, communities and other stakeholders on a regional or national scale (Geels & Schot, 2007; Geels et al., 2017). The socio-technical regime relevant to this analysis is the Australian regime in which the Australian agriculture sector operates. This section analyses factors impacting emerging organic waste-to-energy technologies attempting to gain a foothold in the Australian regime.

As niche-innovations in MLP Phases 2 and 3, organic waste-to-energy technologies are the new approaches trying to disturb the order of this established regime, by competing with and/or replacing the incumbent approaches. To meet their transport, thermal and electrical energy needs, Australian agribusinesses currently engage with a range of energy systems that are 'locked in' and well established in the socio-technical regime (Bui et al., 2016; El Bilali, 2019a). The existing regime features a wide range of systems for the generation/manufacture, transmission/distribution, and storage of fossil energy, such as petrol, diesel, LPG, reticulated gas, and electricity generated from coal and gas. All these systems are based on fossil fuels and are thus ecologically unsustainable (El Bilali, 2019b). For organic waste-to-energy technology providers looking to expand the adoption of their technologies in the Australian agribusiness sector, these are the incumbent fossil fuel-based technologies and systems with which they are competing.

In managing the organic by-products of their food and fibre production and processing, Australian agribusinesses engage with a range of established approaches to waste management that are also part of the Australian regime. These approaches include burning of crop residues (cereal stubble, sugar cane) in the field (Agriculture Victoria, 2022; AM-01); composting of organic waste materials (AM-03); spreading manure and other organic liquid and solid wastes onto surrounding farmland as fertiliser (AM-06; AM-07; AM-13); and treating wastewater, effluent and/or manure in wastewater treatment ponds/lagoons (AM-02; AM08). These approaches are standard practices in several Australian agriculture sub-sectors and have impacts on a range of stakeholders. Consultants, industry peak bodies and researchers provide advice on technical aspects of management of agriculture wastes; Government departments and authorities provide guidance and oversight of the environmental requirements and approvals processes regulating these waste management practices. These agribusiness stakeholders are part of the Australian regime that are impacted, and can influence, the waste management approaches of Australian agribusinesses.

One of the primary reasons for the slow take-up of organic waste-to-energy technologies by Australian agribusiness is the relative stability of the Australian socio-technical regime; particularly in terms of agribusiness engagement with the regime’s energy and waste management systems. This stability was raised in Section 5.4.1, with IE-05 questioning why an agribusiness would invest in a different and/or expensive energy and waste management approach, unless they were forced to do so. The inference is that if the existing strategies are meeting the needs of these agribusinesses, they are not impelled to change from their business-as-usual practices.

However, while the Australian regime is relatively stable, this stability has been disrupted for some agribusinesses by changes which potentially threaten the established regime. These disruptions have created what Geels et al. (2017) call ‘windows of opportunity’, for niche-innovations (organic waste-to-energy approaches) to move from Phase 2 to Phase 3 in the transition journey, and into the regime. These changes to the regime, which are discussed below, became drivers for some agribusinesses to explore alternatives to their business-as-usual energy and waste management approaches.

The two main drivers prompting Australian agribusiness to invest in organic waste-to-energy technologies are related to i) energy consumption and ii) waste management strategies. Disruptions to the regime have affected the cost and reliability of energy supplies for some agribusinesses, while other changes within the regime have created problems for agribusinesses whose management of their organic by-products is impacting various stakeholders in the regime.

For agribusinesses with a large requirement for thermal energy, this disruption manifests as a series of sharp increases in the cost of the fuels from which they generate their heat; mainly natural gas and LPG (see Section 5.2.1). These price rises create existential crises for the financial viability of these agriculture operations, creating an urgent need for them to explore other heat-generation options and to change to a new technology and energy management approach. This disruption has created a 'window of opportunity' (Geels et al., 2017) for organic waste-to-energy technologies to become established in the regime.

Another energy-related problem in the regime that has disrupted some agribusinesses are issues with the quality and reliability of their electricity supply (see Section 5.2.1). These issues generally centred on the ability of the national electricity grid to reach these agribusinesses and/or consistently supply them with the electrical voltage needed to power their electricity needs. For both cases, organic waste-to-energy offers agribusinesses the ability to be more self-sufficient in terms of their energy management, and less exposed to disruptions over which they have little control.

Managing large volumes of organic by-products and any unpleasant odours from these wastes can be a problem for some agribusinesses (Holm-Nielsen et al., 2009; Romets et al., 2015; Stegelin, 2010; Vasco-Correa et al., 2018). Traditional approaches to effluent and manure management – approaches that may have served Australian agriculture well for many years – are no longer acceptable in some areas, due to the impacts of agribusiness odours on stakeholders. The disruptions impacting these agribusinesses are related to Australia's changing demographics, population growth and urbanisation, which have changed the regime.

These changes have seen the encroachment of agricultural operations by expanding cities and towns, which bring new neighbours and other stakeholders into areas surrounding agribusinesses (AM-02; AM-04; AM-07; AM-08). This disruption of the regime can also disrupt agribusiness operations and prompt their interest in alternative energy and waste management approaches. As organic waste-to-energy approaches, such as anaerobic digestion, have the capacity to reduce odour issues associated with effluent and manure management, this has created another avenue of opportunity for these technologies (Holm-Nielsen et al., 2009; Stegelin, 2010).

The main drivers prompting agribusiness transitions to organic waste-to-energy approaches, have appeared because of relatively small disruptions to the Australian regime. One factor disrupting the regime, sudden spikes in energy prices, has been influenced by pressures from the global landscape level. Whereas other important disrupting factors, quality/reliability issues with electricity supply and encroachment of agricultural areas by urban/local development, have emerged due to changes to the regime that have occurred over time.

6.1.3 Socio-technical regime – barriers

For niche-innovations attempting to break into the socio-technical regime, substantial barriers can exist to frustrate their transitions to become established. This has been the case for the transition of organic waste-to-energy technologies seeking opportunities in the Australian agriculture sector. This section analyses the barriers impacting this transition.

The previous section identified the relative stability of the Australian regime as being one of the fundamental reasons for the agriculture sector's slow uptake of organic waste-to-energy technologies. While this may be the case, the Australian energy sector, an important actor for Australian agribusinesses, is experiencing a major disruption to the established order of electricity generation in this country. For most of the 20th Century, Australia's electricity was generated from burning fossil fuels, but over the last 10 years, renewable energy approaches have substantially increased their share of Australia's energy mix (DISER, 2022).

One of the fundamental barriers restricting the adoption of organic waste-to-energy technologies by the Australian agriculture sector relates to the lack of awareness of bioenergy technologies by actors within the existing regime; what they are, the way they work, and the viable applications for these approaches in Australian agriculture. The previous chapter identified that a general lack of knowledge and understanding about bioenergy technologies exists amongst actors in the Australian regime (see Section 5.3.2). On the other hand, this study also identifies that when actors are well-informed and familiar with organic waste-to-energy systems, they are important drivers to support the successful adoption of these niche-innovations and thus affecting regime change in Australian agribusiness.

The key actors relevant to this study include agribusiness owners and managers; agronomists and other technical advisors and consultants; energy and waste management regulatory authorities; suppliers, neighbours and other stakeholders. This finding is consistent with research in other countries highlighting the critical role played by timely and accurate information being available to support bioenergy developments (Capodaglio et al., 2016; Wüste & Schmuck, 2013).

The lack of awareness, knowledge and understanding of bioenergy approaches is a factor for agribusiness managers and advisors, as this forms a barrier that excludes organic waste-to-energy options from agribusiness decision making processes (Prasertsan & Sajjakulnukit, 2006). In addition, this lack of awareness can also contribute to unsupportive stakeholder attitudes towards organic waste-to-energy technologies (Ackrill & Abdo, 2020; Chasnyk et al., 2015; Igliński et al., 2012; Kulla et al., 2022; McCormick & Kåberger, 2007); overly-cautious approaches to adoption of these systems, or outright opposition to anything to do with the concept of bioenergy.

Negative attitudes towards bioenergy and organic waste-to-energy are social practice factors that lock out these approaches, slowing or preventing the major adoption of these niche-innovations through into Phases 2, 3 and 4 of the MLP levels, while also protecting the incumbent approaches. In the MLP model, these negative attitudes exist in the regime and can be represented as the arrows pointing downwards, resisting the progression of bioenergy technologies into the regime.

Another substantial barrier to the adoption of organic waste-to-energy approaches by Australian agribusinesses is a range of financial and business case issues that can heighten the risk and threaten the viability of investing in these technologies (see Section 5.4.1). Financial issues can present as a combination of relatively high capital costs of investing in and maintaining these technologies, and difficulties agribusinesses can experience in securing finance to fund bioenergy projects. Also, marginal returns-on-investment and a lack of confidence in business case projections weaken proposals for organic waste-to-energy developments (IE-03; IE-05; IE-06). Some of the factors impacting the business case for organic waste-to-energy investment are internal factors that may be unique to a particular agribusiness, agribusiness type, industry or location; but others exist as a result of structures 'locked-in' to the existing regime.

There is a broad range of internal factors that contribute to the financial business case for agribusiness investment in organic waste-to-energy technologies. The size and location of the business; its financial position and/or ability to secure finance; the types and volumes of organic waste it produces and the energy that can be generated from this waste; its ability to fully utilise the electrical and thermal energy it can generate – or export/sell to another stakeholder. These factors are some of the important variables that can impact the financial viability of an agribusiness investment in an organic waste-to-energy plant.

The location of an agribusiness is a critical factor that can act both as a driver or a barrier to organic waste-to-energy development, depending on the specific circumstances of the agribusiness. For an agribusinesses in a rural or remote location, there may be few pressures associated with the waste management side of its business. In these more isolated areas, an agribusiness may have few stakeholders near its operation and few complaints about its existing waste management practices (e.g.

spreading manure on surrounding pastures, or burning stubble) (AM-06), and so have little motivation to change from its existing waste management strategies.

However, relatively isolated agribusinesses can also be on the fringes of the national electricity grid and have limited and/or expensive access to natural and/or bottled gas supplies. For these agribusinesses, the quality, reliability, and cost of energy supplies can be a significant driver for them to explore alternative energy options (AM-02; AM-03; AM-09).

Conversely, agri-food businesses located in a regional or peri-urban area, can have much better access to energy networks and suppliers, and so quality and security of energy supplies are not a major driver for change. Closer proximity to energy networks can also mean closer proximity to neighbours and stakeholders. When existing organic waste management approaches adversely affect the amenity of agribusinesses stakeholders, this can prompt them to consider organic waste-to-energy approaches (AM-01; AM-07; AM-08; AM-13).

When internal barriers combine with other factors in the regime that are outside the control of agribusinesses, they can create an even greater barrier to the financial business case for these new ecologically sustainable investments. For example, major barriers exist discouraging most small-to-medium sized agribusinesses from exporting energy generated on-site to the national electricity grid. The high cost of upgrading on-site and local electricity transmission infrastructure, to enable an agribusiness to export power to the grid, is an important factor. When coupled with difficult regulatory processes and the low tariffs small generators receive for the electricity they feed into the grid, this adversely impacts the attractiveness of connecting on-farm waste-to-energy plants to the grid.

As a result, the financial business case for these investments can depend on the business's ability to productively use both the thermal and electrical energy they generate on-site, 'behind the meter' (IE-03; IE-07; AM-07). Meat processors and sugar refineries are able to do this, which is one of the reasons they lead Australian agribusiness transitions to organic waste-to-energy technologies (see Figure 5.6). On the other hand, bioenergy business cases for agribusiness types with limited on-site applications for heat and electricity (e.g. broadacre cropping farmers and livestock graziers), are generally unattractive (IE-03; IE-07; AM-01).

One approach to overcome this barrier is for agribusinesses to collaborate to improve the financial business case for investment in organic waste-to-energy approaches. In many other parts of the world, a range of collaborative business structures have been implemented to enable smaller agribusinesses and other stakeholders to engage with bioenergy systems (Beggio & Kusch, 2015; Mangoyana & Smith, 2011; Minas, 2019; Roesler, 2019). Essentially, these entities provide the business structures for agribusiness stakeholders to combine their organic by-products to reach the critical volumes of feedstock required for the business case for investment in a bioenergy plant to be financially viable.

Section 5.3.1 highlights some examples of Australian agribusinesses collaborating with stakeholders to build creative business cases supporting organic waste-to-energy developments (AM-02; AM-04; AM-07; AM-10). While these examples are few and relatively small-scale, opportunities exist for much greater collaboration of stakeholders, to support organic waste-to-energy on a much greater scale. These types of collaborative bioenergy projects are possible, given Australian agriculture's experience in developing collaborative business structures. Australian farmers have numerous examples of collaborative business approaches, such as farmer cooperatives, community collaborations and local partnerships, that have been developed to support the processing and handling of sugar, dairy, grain, wool and livestock production (Patmore et al., 2021). Similar approaches could be adopted to support local organic waste-to-energy projects.

6.1.4 Socio-technical landscape

The socio-technical landscape is MLP's exogenous context under which both the socio-technical regime and niche-innovations sit. This is the global environment from which pressures, trends and developments emerge to influence the MLP levels that sit under this landscape. Up until now, the Australian regime has been stable and thwarted transitions of organic waste-to-energy technologies, that are currently niche. With the exception of biomass combustion technologies embedded in the sugar processing sub-sector, organic waste-to-energy technologies are locked out of becoming established energy and waste management approaches for Australian agribusiness. The landscape influences relevant to this transition include global commitments to action on climate change, pressures to reduce carbon emissions associated with food and fibre production, global energy market changes, and the impacts of these on Australian prices for energy from fossil fuels.

Anthropogenic climate change is a profound global challenge that reaches into almost every human endeavour. The unavoidable imperative for humankind to radically reduce the accumulation of greenhouse gases in Earth's atmosphere, has led to global commitments from most of the world's countries to substantially reduce their greenhouse gas emissions. Australia is a signatory to multiple global agreements to take action on climate change and is one of most countries to have committed to achieving net-zero carbon emissions by 2050 (United Nations, 2023). These commitments are especially relevant to the Australian agriculture, energy and waste industries, given these sectors are significant contributors to Australia's emissions of greenhouse gases (Commonwealth of Australia, 2016).

For more than two decades, there have been sustained calls for countries to take urgent action to reduce their emissions of greenhouse gases, but this pressure from the global landscape is yet to fundamentally change the Australian regime. While there is evidence of some disruption in this regime, particularly in the energy sector, the incumbent actors, technologies and approaches continue to dominate the regime (Iles, 2021). These disruptions have not created the instability in the regime that are required to unsettle the established technologies and approaches supporting energy and waste management approaches in Australian agriculture (Iles, 2021).

That is not to say the climate-related pressures from the landscape have gone unnoticed. The global landscape's climate change imperative is also influencing actors at Australia's niche-innovation level, where inventors, entrepreneurs, researchers and agribusinesses, such as AM-01, AM-03 and IE-10, have been inspired to develop and adapt agribusiness applications for bioenergy technologies for operation in a carbon-constrained world. The Australian agriculture sector is aware of international calls to reduce the carbon intensity of its food and fibre production. This research has noted that the peak bodies and research affiliates in this space are exploring low-carbon innovations and opportunities for this industry, but this activity is at niche-innovation level and is yet to have a major impact on the regime.

Agribusiness managers and industry experts interviewed for this study identified the carbon benefits of organic waste-to-energy as a second or third order driver encouraging their interest in adopting organic waste-to-energy technologies (AM-01; AM-02; AM-03; AM-04; AM-05; AM-06; AM-07; AM-08; AM-10). The prevailing view is that the low-carbon credentials of organic waste-to-energy technologies are a desirable feature or a 'nice to have' bonus, but they are not a primary motivation for changing their energy and waste management approaches.

While climate change concerns are not the main drivers prompting the adoption of organic waste-to-energy approaches in Australian agriculture, some managers see investments in these technologies as preparing for regime changes that will inevitably happen in the future. These managers are aware of regime changes that have affected their industry in other parts of the world and expect these changes to be introduced to the Australian regime. Examples include European restrictions placed on the burning of stubble (Nikolov, 2011; Yakupoğlu et al., 2022) and the seasonal spreading of raw manure on pasture (Köninger et al., 2021; Liu et al., 2018); two organic waste management practices currently permitted in Australia. Some interviewees did mention the supportive influence of international stakeholders (agribusiness owners and prospective buyers) in prioritising the climate-related benefits of their investments in bioenergy plants (AM-04; AM-12). However, overall organic waste-to-energy adoption from the MLP perspective has been very slow.

6.2 Organic waste-to-energy adoption and SPA

In addition to the MLP, this study also applies social practice theory to explore the role of human agency in Australian agribusiness's adoption of organic waste-to-energy technologies. SPA focusses on the everyday practices and routine ways of doing and saying things that shape socio-technical systems (Keller et al., 2022). Collections of social practices are embedded in the consumption of products/services and resources in the socio-technical regime, where established social practices can become locked in and resist change. According to SPA, sustainability transitions require a change of established social practices to more sustainable consumption patterns (Keller et al., 2022; Liedtke et al., 2017).

The key drivers and barriers identified in Chapter 5 indicate that social practice has critical impacts that can help or hinder transition processes in the adoption of organic waste-to-energy by Australian agribusiness. The main drivers relevant to SPA are explained in the next section, and these relate to negative impacts of agribusiness waste management practices on the everyday routines of stakeholders. The barriers with human agency implications are also explored, and these generally stem from the lack of awareness and understanding Australian agribusiness stakeholders have of organic waste-to-energy applications. These drivers and barriers were introduced in Section 3.4 as examples applying SPA to organic waste-to-energy in other parts of the world, but these have emerged to be particularly relevant as barriers in the Australian context as well, as identified in the findings of this study.

6.2.1 Organic waste-to-energy drivers and SPA

Australian agribusiness desire to reduce the detrimental impacts of their practices on stakeholders was a significant driver in this study for prompting agribusiness managers to consider the adoption of organic waste-to-energy technologies. For agribusinesses such as dairies, piggeries and meat processors, unpleasant odours emanating from manure and liquid waste management practices can adversely impact local air quality, reducing the amenity of the environment in which stakeholders engage in social practices.

In these case studies, odours from established organic waste management practices, such as the use of open effluent ponds or the spreading/spraying of raw manure and organic liquid wastes on surrounding farmland, are having a detrimental effect on everyday practices and routines of stakeholders within the odour's reach. Affected stakeholders include residential and industry neighbours, nearby communities, agribusiness staff and regulatory authorities responsible for monitoring agriculture's environmental impacts. Farm practices seen as the main cause of a loss of amenity in the environment in which stakeholders perform their social practices, can harm agribusiness relationships with local stakeholders.

Section 5.2.2 in the findings identified encroachment as a factor increasing the importance of odour management for some agribusiness types in some parts of Australia. Odour issues relating to organic waste management practices have become particularly important concerns for agribusinesses that are also experiencing encroachment of their sites by residential and/or other development. Demographic and land use changes that contribute to encroachment of established farming areas represent a disruption to the regime that is generally beyond the control of agribusinesses. These changes bring new stakeholders and new sets of social practices into farming areas, disrupting the stability of the regime. This disruption can manifest as complaints, negative attitudes and opposition towards those agribusinesses, their industries, and their waste management routines. These negative impacts can prompt disrupted agribusinesses to consider changes to their established organic waste management practices.

For agribusinesses wishing to reduce complaints about their existing organic waste management practices and to improve relationships with stakeholders, organic waste-to-energy technologies such as anaerobic digestion can be particularly attractive (AM-02; AM-04; AM-07; AM-08). A key benefit of anaerobic digestion is its ability to process the malodourous component of wet-waste streams and thus reduce a farm's deleterious impact on the amenity of local stakeholders (AM-07). In most cases, adopting these technologies requires varying degrees of change to an agribusiness's established organic waste management practices and routines. Resistance to these changes can present substantial barriers to the adoption of organic waste-to-energy technologies; these barriers are explored in the next section.

6.2.2 Organic waste-to-energy barriers and SPA

This study's narrative inquiry and case study data collection strategies identified several barriers to Australian agribusiness adoption of organic waste-to-energy technologies, related to human agency. The lack of knowledge and understanding of organic waste-to-energy technologies in Australia is a key barrier to the adoption of these approaches by the agribusiness sector (IE-02; IE-03; IE-04; IE-05; IE-07) (see Section 5.4.2). This lack of awareness can contribute to unsupportive attitudes and stakeholder uncertainty about the impact a change to organic waste-to-energy approaches may have on their everyday work routines and social practices. This issue is really about the desirability of a change in agribusiness energy and/or waste management practices and routines, and the extent to which stakeholders perceive that a change to bioenergy approaches would make their life easier or harder; whether they would be better off or worse off.

For agribusiness managers and workers, this can present as concerns about changes to staffing requirements and workloads; or additional skills, knowledge and/or training required to operate a bioenergy plant. The existing energy and waste management approaches at Australian agribusinesses are 'locked-in', as these processes and practices are known and understood by stakeholders. By contrast, organic waste-to-energy approaches are relatively unknown and poorly understood in Australia (IE-02; IE-04; IE-05; AM-03). As a result, agribusinesses can view organic waste-to-energy options less favourably if they believe the operation of a bioenergy plant would negatively affect their existing routines, or new processes would be less desirable than their current practices.

In Section 5.4.2, a bioenergy expert (IE-04) identified common misconceptions that needed to be addressed when talking with stakeholders about organic waste-to-energy options. Questions frequently raised by stakeholders included concerns about the extent to which change to bioenergy technologies would require staff to manually handle organic waste materials. These questions stem from concerns that the processes and routines associated with running a biomass boiler may be more onerous and less amenable to staff than their current organic waste and energy management practices. A belief that bioenergy work routines would take longer to complete and be harder, dirtier and/or smellier work for staff, can mean agribusiness stakeholders develop less favourable views towards organic waste-to-energy options.

Agribusinesses have similar concerns about the technical complexity of bioenergy plants and the technical skills, knowledge and competence required by farm workers to perform these new work routines. The adoption of organic waste-to-energy technologies such as biomass boilers and anaerobic digesters can require agribusinesses to develop skills and knowledge to operate these plants. The specific skills and knowledge required can vary substantially, depending on the agribusiness type, the bioenergy technology adopted and the primary waste feedstock fuelling the plant. For example, there is a substantial difference in the nature and complexity of the technical skills and knowledge required to spread raw manure on a dairy's/piggery's paddocks, as opposed to the operation of an anaerobic digestion system.

A key factor influencing the agriculture industry's awareness, understanding and knowledge of organic waste-to-energy approaches is strongly linked to the engagement of its stakeholders with the social networks and structures supporting bioenergy development in Australia. Organisations such as bioenergy industry bodies, agriculture peak bodies, government departments, research centres and universities play critical roles in raising the agriculture sector's awareness of organic waste-to-energy options and how to address SPA barriers to such options noted above.

6.3 Insights to the research question

This section examines the research findings detailed in Chapter 5 and discusses these in the context of this project's research question, as listed in Section 1.3. The primary research objective of this study is to develop an understanding of how Australian agribusinesses engage with waste-to-energy systems through the adoption of integrated organic waste-to-energy technologies. This section addresses this objective by answering the study's four research sub-questions, that focus on the types of Australian agribusinesses operating organic waste-to-energy technologies; the drivers and barriers to the adoption of these technologies and the impact these have on agribusinesses; and the dynamics of how these critical factors impact on agribusinesses attempting transitions to organic waste-to-energy approaches.

6.3.1 Characteristics of agribusiness adoption of organic waste-to-energy technologies

The first sub-question explores the characteristics of Australian agribusinesses that have invested in on-site organic waste-to-energy technologies. This question focusses on identifying the types of agribusinesses adopting organic waste-to-energy technologies in Australia. Who are these agribusinesses? Where are they located? In what agriculture sub-sector do they operate? What food and fibre commodities are they producing? What organic waste feedstocks are they utilising and from where are they sourcing these materials? What organic waste-to-energy technologies have they adopted? How are they utilising the energy they generate?

Research findings detailed in Section 5.1 reveal the penetration of modern bioenergy technologies in Australia is very low and behind that of other OECD countries (IE-01; IE-03; IE-05; IE-07). Bioenergy is a small contributor to Australia's electricity generation (KPMG, 2018), but there has been enthusiasm for bioenergy to play a more prominent role in the Australian energy space, and particularly in the agriculture industry. Substantial volumes of organic waste materials are produced as by-products of Australia's food and fibre production and processing, which has seen agriculture highlighted as a sector with substantial potential for bioenergy development (Clean Energy Council, 2008).

There are around 70 organic waste-to-energy plants in operation at Australian agribusinesses (see Appendix E). For more than a century, the sugar processing industry has led Australian agribusinesses in the utilisation of organic waste-to-energy technologies, but the adoption of these technologies by other agriculture sub-sectors is a far more recent phenomenon. Sugar producers and processors continue to be the dominant agribusiness sub-sector engaging with organic waste-to-energy technologies (see Figure 5.6), with 22 plants operating in New South Wales and Queensland. The remaining agriculture-based bioenergy installations in Australia are spread across meat processing, protected cropping, grain processing, piggery, dairy and other agribusiness sub-sectors. Every Australian state has at least one agribusiness running an organic waste-to-energy plant, but most installations are in Queensland, New South Wales and Victoria (see Figure 5.4). The majority (63%) of the bioenergy plants installed by Australian agribusinesses utilise biomass combustion boiler technologies, with 32%

operating anaerobic digestion plants and another 5% using other organic waste-to-energy approaches (see Figure 5.5).

The use of biomass boiler/direct combustion technologies is favoured by agribusinesses managing large volumes of dry organic by-products, and/or agribusinesses with a large demand for thermal and/or electrical energy (IE-03). In the sugar processing sub-sector, biomass boilers are an essential component in the management of what can be a problematic organic waste stream (AM-12). Sugar refineries produce vast volumes of sugar cane trash (bagasse) that need to be carefully managed. Bagasse is an ideal feedstock to fuel a biomass boiler to produce thermal energy (steam) and electricity, and as sugar processing has a large demand for steam and electricity, it makes economic sense for a sugar refinery to utilise its bagasse to produce its own heat and power behind the meter. This approach enables sugar refineries to effectively manage their main processing by-product and also offset costs associated with sourcing energy forms from external sources.

For other agribusinesses with dry organic waste streams but little demand for thermal and/or electrical energy, such as broadacre cropping farmers, the economic business case for investment in combustion boiler technologies can be less attractive (AM-01). While these growers may produce large volumes of straw and cropping residues suitable for a biomass boiler, most of these types of agribusinesses do not have the ability to use all (or most) of the thermal and electrical energy they might produce behind the meter. For these agribusinesses, exporting electricity to the national grid is an option, but the high costs of connecting to the grid, coupled with the low tariffs paid for the electricity they produce, makes the ROI unappealing (AM-01).

While biomass boilers are employed effectively in some agribusinesses as a key part of their management of organic waste streams, others are adopting these technologies purely to meet their needs for thermal energy. Over the last decade, biomass boilers have become attractive options for thermal energy generation for agribusinesses with a large demand for heat. A range of agribusiness types, such as meat processors, cheese factories and fruit, vegetable and seedling growers in the protected cropping sub-sectors, are adopting biomass boilers as an alternative to fossil-fuelled technologies. These agribusinesses have a large demand for thermal energy in the form of steam and/or hot water but may not have a suitable waste stream from their own operations to fuel a biomass boiler. Instead, these agribusinesses source a dry organic by-product from another business nearby.

Dry organic waste materials work well as feedstocks in biomass combustion boilers, but liquid/wet agriculture by-products such as manure, urine, food processing wastes and washdown water, are less suited to these forms of bioenergy generation. These putrescible waste materials are better suited to biogas technologies such as anaerobic digestion (Kartha, 2000; Vasco-Correa et al., 2018), which has been adopted by dairies, piggeries, meat processors, fruit and vegetable growers and processors in Australia (see Figure 5.6). The primary purpose of these installations is to manage problematic organic by-products (IE-02, IE-03, AM-07, AM-08, AM-13), but with fewer than 20 plants in operation around Australia, this technology is still in its early stages of development in terms of its adoption by agriculture.

6.3.2 Key drivers of adoption of organic waste-to-energy technologies

This section addresses the second of this study's research sub-questions, to discuss the key drivers prompting Australian agribusinesses to explore their organic waste-to-energy options. These drivers generally fall into one of two categories: agribusinesses that have a problem with their existing waste management practices, or agribusinesses that have a problem with their energy management practices. Challenges with energy and/or waste management approaches can reach a point where Australian agribusiness managers and other stakeholders may consider these incumbent practices to be no longer fit for purpose, and they consider opportunities to change their practices.

Managing organic by-products from agricultural production is an integral part of food and fibre production and processing. Managing large volumes of organic wastes is particularly important, as failure to manage organic waste streams effectively can create serious environmental, social, and economic issues for agribusinesses and their stakeholders (Massé et al., 2011; Steinfeld et al., 2006). Australian agribusinesses such as sugar refineries, dairies, piggeries, meat processors, broadacre croppers and poultry producers have explored biomass combustion boilers and anaerobic digestion technologies to manage their organic by-products more effectively or more efficiently (see Appendix E).

When existing waste management practices of these agribusinesses no longer meet their needs, and they are seeking to improve their waste management approaches, then some bioenergy modernisation options may become relevant in the process of managing the waste appropriately. This is the case for dairies and piggeries that have traditionally spread manure and other organic liquid wastes on surrounding paddocks, but the negative impacts on the amenity of their stakeholders means this practice is not as acceptable as it once was and a bioenergy option becomes viable (AM-07, AM-08, AM-13).

Australian broadacre croppers in high-rainfall areas are in a similar situation to dairies and piggeries (AM-01, Grains Research & Development Corporation (2011). One of the traditional waste management practices used by broadacre farmers has been the burning of cropping residues in the paddock. Stubble burning releases substantial volumes of greenhouse gases to the atmosphere, but with many countries now committing to reducing emissions of greenhouse gases, this practice is seen as less desirable (AM-01, IE-08). As a result, some farmers are exploring their bioenergy options, preparing for what they see as the inevitable introduction of regulation restricting or banning burning (AM-01).

For other agribusinesses, there is not the same urgency for them to modernise their waste management practices, but they still have a general desire to extract greater value from their organic by-products. That is, an agribusiness's waste management routines may still be effective approaches, but there is an awareness of opportunities to improve their approaches and a desire to modernise. This desire is borne from an awareness of the calorific value of their organic wastes and a level of frustration or dissatisfaction with the failure of their existing waste management practices to extract greater value or benefit for their operation.

The other main driver for Australian agribusiness adoption of organic waste-to-energy technologies is the need to address issues with the cost and/or quality of their energy supply. Agribusinesses impacted by substantial rises in the cost of natural gas and LPG, such as the protected cropping and meat processing sub-sectors, are being forced to explore alternative approaches to generating thermal energy for their operations. Sharp increases in Australian gas prices in the early-to-mid 2010s posed major risks to the on-going financial viability of many agribusinesses with a large demand for heat. In the face of such existential threats, these businesses began looking outside the conventional approaches, which included organic waste-to-energy options to bring energy generation in-house and behind the meter.

For agribusinesses in some rural and remote parts of Australia, the energy issues prompting their adoption of organic waste-to-energy approaches are more concerned with the quality and security of their electricity supply, rather than the cost of the supply. Agribusinesses on the fringes of national electricity network infrastructure suffer from issues with the quality of their electricity supply. Issues such as interruptions to supply (blackouts) and inadequate supply (brown-outs - low voltage) severely impact the productivity and efficiency of these agribusinesses. Agribusiness managers are motivated to overcome these impediments and explore organic waste-to-energy options as an approach to secure the electricity supply for their operations.

Agribusinesses with energy cost and supply issues are adopting organic waste-to-energy approaches to take greater control of their energy management and to reduce their exposure to insecurity in their energy supply and volatility in energy pricing. While energy security is a major driver of bioenergy development in many developing countries in Africa (Uhunamure et al., 2019) and Asia, this is not generally the case for OECD countries including Australia, with the exception of the United States (Edwards et al., 2015).

For agribusinesses with both large volumes of organic waste and high demand for thermal and electrical energy, the business case to adopt organic waste-to-energy technologies can be most attractive. Food processing operations, such as abattoirs and sugar refineries, are in Australian agriculture sub-sectors for which bioenergy technologies can provide significant cost savings, in both the waste management and energy consumption parts of their business. Sugar refineries have extremely large volumes of bagasse, that must be managed and is a suitable feedstock for biomass combustion technologies.

Abattoirs produce large volumes of offal and liquid wastes suitable for anaerobic digestion. Both agribusiness types have large on-site demands for electricity and steam, so much of the energy they produce can be consumed 'behind the meter' and off-set their requirements for externally sourced energy. Interestingly, not all abattoirs adopting organic waste-to-energy approaches have chosen biogas technologies to generate energy from their organic waste. For some, including AM-04, a more cost-effective option was to install direct combustion boilers, fuelled by dry biomass sourced off-site (Appendix E).

It is also important to acknowledge that there are some agriculture sub-sectors and operations for which organic waste-to-energy currently has limited appeal. For agribusinesses that do not have the main drivers of investment in organic waste-to-energy technologies (i.e. a problematic or abundant organic waste stream and/or high demand for affordable and reliable electrical, thermal and/or transport energy), the business case for this transition is not be supported. For example, livestock farmers (mainly grazing sheep, cattle and goats in open paddocks), do not have these pressures to change their energy and waste management approaches.

6.3.3 Key barriers to adoption of organic waste-to-energy technologies

The research sub-question addressed in this section, relates to the key barriers that can thwart the progress of agribusinesses engaging with transitions to organic waste-to-energy approaches. The barriers identified as impacting the adoption of organic waste-to-energy technologies by the participating Australian agribusiness managers are broadly aligned with barriers to investment in bioenergy technologies experienced by agribusiness in other parts of the world. Section 2.8 and the bioenergy drivers and barriers heuristic (Figure 3.1) identify a range of common barriers that have impacted agribusiness transitions to bioenergy approaches.

This study's findings support the impact of barriers identified in previous studies, which include financial barriers (Ackrill & Abdo, 2020; Capodaglio et al., 2016; Jensen & Govindan, 2014; Massé et al., 2011; Mesas & Morais, 2014; Mofijur et al., 2021; O'Connor, Ehimen, Pillai, Black, et al., 2021; O'Connor, Ehimen, Pillai, Power, et al., 2021; Romets et al., 2015; Stegelin, 2010; Tranter et al., 2011; Wilkinson, 2011), a lack of knowledge and/or awareness of bioenergy applications (Ackrill & Abdo, 2020; Kulla et al., 2022; McCormick, 2010; Mesas & Morais, 2014; O'Connor, Ehimen, Pillai, Black, et al., 2021; O'Connor, Ehimen, Pillai, Power, et al., 2021; Stegelin, 2010), a lack of technical expertise (O'Connor, Ehimen, Pillai, Black, et al., 2021; Piwowar et al., 2016; Romets et al., 2015; Stegelin, 2010), and regulatory barriers (Chasnyk et al., 2015; Mesas & Morais, 2014; Raven, 2007; Stræte et al., 2022; Tranter et al., 2011). This study's findings identify that each of these barriers is also present in the Australian context (see Section 5.4).

A key barrier affecting Australian agribusiness engagement with modern organic waste-to-energy technologies is related to the financial business case for investment in these technologies. This has been identified as a major barrier in many countries, such as United States (Massé et al., 2011; Stegelin, 2010), Ukraine (Romets et al., 2015), England/United Kingdom (Ackrill & Abdo, 2020; Tranter et al., 2011), Ireland (O'Connor, Ehimen, Pillai, Power, et al., 2021), Denmark (Jensen & Govindan, 2014) and other European Union countries (Capodaglio et al., 2016; Mesas & Morais, 2014; O'Connor, Ehimen, Pillai, Black, et al., 2021), and these financial factors present substantial impediments to agribusiness investment in bioenergy technologies in Australia as well.

As detailed in Section 2.8.1, the academic literature identifies a range of components that contribute to the economic business case for agribusiness investment in organic waste-to-energy technologies. Factors that have worked against the business case for such investments in other countries include high capital costs of bioenergy technologies, marginal ROIs and long-payback periods (Jensen & Govindan, 2014; Mesas & Morais, 2014; Prasertsan & Sajjakulnukit, 2006; Tranter et al., 2011), high cost of biomass feedstock transport/supply (Mesas & Morais, 2014), and relatively low prices for electricity and thermal energy (Edwards et al., 2015; IEA Bioenergy Task 37, 2017; REN21, 2016).

Research findings described in Section 5.4.1 show the business case components mentioned above are also critical considerations for Australian agribusinesses exploring their organic waste-to-energy options. According to industry experts interviewed, the combination of high capital costs for bioenergy plants and low rates of return on the energy they generate, can reduce the financial viability of Australian investments in these technologies (IE-03; IE-06; IE-07). Distance also plays a role in the assessment of the viability of agribusiness organic waste-to-energy proposals. Most of the combustion boilers and biogas technologies adopted by the agribusiness managers interviewed, were imported from overseas (AM-02; AM-04; AM-05; AM-07; AM-09; AM-10; AM-11;

AM-12), which contributes to the high capital cost of adopting these technologies. The shortage in bioenergy expertise in Australia, means the technical knowhow required to service and maintain organic waste-to-energy plants can be located long distances away from agribusiness installations. The cost of accessing this expertise can be significant (AM-03; AM-09; AM-10; AM-12; AM-14). Costs associated with transporting biomass feedstocks large distances can also impact organic waste-to-energy business cases. However, the ability for some Australian agribusinesses to find innovative solutions to overcome transport cost barriers, was a feature of business cases that did support organic waste-to-energy investments (IE-01; AM-04; AM-06; AM-09).

Another key barrier to Australian agribusiness adoption of organic waste-to-energy technologies is a lack of awareness, knowledge, and expertise relating to bioenergy systems, in the agriculture industry and across the Australian community more generally. This knowledge-related barrier describes three different, but linked factors, that can affect various stakeholders affected by agribusiness engagement with bioenergy systems. A lack of awareness of the potential opportunities for Australian agribusiness applications of organic waste-to-energy approaches is identified as a critical barrier primarily involving agribusiness managers and key decision-makers (see Section 5.4.2).

A lack of knowledge or information about specific bioenergy projects has been identified in several countries as a knowledge-based factor contributing to unsupportive stakeholder attitudes towards and a lack of acceptance of bioenergy applications (Capodaglio et al., 2016; Chasnyk et al., 2015; Kulla et al., 2022; Massé et al., 2011; McCormick, 2010; Mesas & Morais, 2014; O'Connor, Ehimen, Pillai, Black, et al., 2021; O'Connor, Ehimen, Pillai, Power, et al., 2021; Romets et al., 2015). The third component of these knowledge barriers relates to the lack of technical expertise to design, manufacture, install, maintain and operate organic waste-to-energy plants. This issue focusses mainly on the bioenergy industry itself but can also include agribusiness workforces.

Low levels of understanding of bioenergy systems and a shortage of technical expertise are identified in Sections 5.4.2 and 5.4.3 as substantial contributors to Australian agribusiness's slow progress in transitioning to organic waste-to-energy approaches. These sections describe the multiple ways in which Australia's lack of familiarity with bioenergy technologies works to lock-out these options for some agribusinesses. These negative impacts, identified by agribusiness managers and industry experts interviewed in this study, include agribusiness managers simply unaware of bioenergy technology applications and their operation's suitability or potential to generate energy from their biomass by-products. Agribusiness investment in organic waste-to-energy approaches is also affected by a lack of awareness of these technologies in the broader Australian community, contributing to stakeholders such as agribusiness financiers, managers, employees and neighbours, forming risk-averse and/or unsupportive attitudes to these technologies.

A lack of awareness of bioenergy technologies and opportunities for agribusiness applications is not just an Australian phenomenon, but there is substantial variability in the extent to which this is a factor in other parts of the world. Australia's ignorance of organic waste-to-energy opportunities as a significant barrier to its adoption by farmers is in line with the same ignorance in several developing countries in Africa (Diouf & Miezan, 2019; Marie et al., 2021; Muvhiiwa et al., 2017) and Asia (Dinanti et al., 2017; Jan & Akram, 2018; Prasertsan & Sajjakulnukit, 2006; Roubík et al., 2018; Xu et al., 2022). This has also been found to be an issue in some OECD countries, such as Greece (Tziolas & Bournaris, 2019), Poland (Igliński et al., 2012), United States (Halder et al., 2015; Stegelin, 2010), and various parts of the European Union (McCormick, 2010; Mesas & Morais, 2014). However, other studies from Europe conclude farmers already have enough information about bioenergy (Mesas & Morais, 2014), are generally aware of their bioenergy opportunities (Beer & Theuvsen, 2019), and that other barriers have a more critical impact on farmer decision-making about bioenergy (Capodaglio et al., 2016; O'Connor, Ehimen, Pillai, Black, et al., 2021; Reise et al., 2012).

For several bioenergy proponents in other countries, stakeholder knowledge barriers are not so much about a lack of awareness of bioenergy, but more about a lack of stakeholder acceptance of these technologies (Capodaglio et al., 2016; Chasnyk et al., 2015; Kulla et al., 2022; Massé et al., 2011; McCormick, 2010; Mesas & Morais, 2014; Romets et al., 2015). Section 2.8.2 explores factors contributing to the development of unsupportive attitudes amongst stakeholders and community objections to bioenergy developments. As a result, the timely provision of accurate and relevant information about bioenergy developments has emerged as a critical variable impacting stakeholder acceptance and support of these developments.

Based on the views of the industry experts and agribusiness managers interviewed in this study, the extent to which awareness of, knowledge about and attitudes to bioenergy approaches impact agribusiness adoption of organic waste-to-energy development in Australia is just as variable as in other parts of the world. In the narratives explored in the Stage 2 interviews, there is general agreement that awareness of organic waste-to-energy approaches is low in Australia (IE-02; IE-03; IE-04; IE-05; IE0-7), but this is not seen by all as being caused by a lack of information about bioenergy applications. Several industry experts (IE-01, IE-05, IE-08) and agribusiness cases (AM-05; AM-06; AM-10) suggested there was enough information available from a range of sources, for those agribusinesses engaging with their industry stakeholders and interested in learning about their organic waste-to-energy options. This implies Australian agribusiness's low levels of awareness of bioenergy approaches is less to do with a lack of bioenergy information, and more related to a lack of drivers prompting these agribusiness managers to seek organic waste-to-energy information. Section 5.2 identifies a range of drivers that are prompting agribusiness investment in organic waste-to-energy approaches, but these drivers have only prompted a small number Australian food and fibre producers to adopt these technologies (see Section 5.1.2).

The third of the main knowledge-based barriers to Australian agribusiness adoption of organic waste-to-energy surrounds the availability of the technical expertise to manufacture, install, service and operate these technologies. Bioenergy experts in Australia are few and far between, with Section 5.4.3 outlining the substantial challenges faced by Australian agribusinesses in accessing the specialist knowledge and skills needed to support their investment in organic waste-to-energy plants. This shortage of technical expertise and consultative capacity has been an issue for bioenergy development in Australia for more than a decade (McCabe et al., 2014; O'Connell et al., 2007; Scherger, 2017; Stucley, 2010), and is a common barrier to bioenergy development in other parts of the world as well (Igliński et al., 2012; McCormick & Kåberger, 2007; O'Connor, Ehimen, Pillai, Black, et al., 2021; Piwowar et al., 2016; Prasertsan & Sajjakulnukit, 2006).

Australia's access to specialist bioenergy technical expertise and consulting is a critical factor impacting the agriculture sector's development of bioenergy projects. Key findings identified from the Stage 3 cases (described in Section 5.4.3) indicate that when relevant technical expertise is available, the installation and operation of organic waste-to-energy plants can be a smooth and positive experience (AM-02; AM-04; AM-05; AM-08; AM-11). However, a lack of access to technical experts in a particular area can have a detrimental impact on the performance, efficiency, safety and longevity of the plant's operation, with all of these impacts having implications whether agribusinesses adopt organic waste-to-energy technologies (AM-03; AM-08; AM-09; AM-12; AM-14).

While not necessarily being drivers prompting this transition, the expertise of regulatory and funding bodies dealing with organic waste-to-energy developments, is also an important factor for the agribusiness cases studied. Regulators and financiers familiar with bioenergy technologies can be key stakeholders to support these developments, but a lack of knowledge and expertise in bioenergy projects can be barriers for agribusiness adoption. These barriers can present as unsupportive attitudes, creating regulatory uncertainty and risk-averse approaches to investment in bioenergy. While these barriers did not affect the agribusiness managers interviewed in this study, some managers (and industry experts) did identify a lack of bioenergy knowledge, experience and expertise as being a critical barrier for agribusiness adoption of waste-to-energy technologies (IE-07; AM-02; AM-03; AM-12).

6.3.4 Impact of drivers and barriers on Australian agribusiness transitions

The final sub-question explored in this research project analyses how drivers and barriers impact on the transitions of Australian agribusinesses to the adoption of organic waste-to-energy approaches. When studying businesses and industries, transition researchers tend to take a holistic and systemic perspective of the ways businesses and organisations change (Köhler et al., 2019). As such, the drivers and barriers identified in the sections above are all relevant to Australian agribusiness adoption of organic waste-to-energy technologies and their impacts on agribusiness transitions should be viewed holistically, rather than in isolation.

This study's bioenergy drivers and barriers heuristic provides a visual representation of the critical factors impacting agribusiness transition to adopting organic waste-to-energy technologies (see Figure 3.1). This journey begins when agribusinesses are first prompted to consider changing from their business-as-usual energy and waste management approaches and ends with the installation and operation of an organic waste-to-energy plant.

The drivers refer to the factors that initiate this journey and provide momentum to progress agribusinesses through a transformation process. This momentum is critical, not only to commence the transition, but to assist agribusinesses to overcome barriers they encounter on their transition journey. The section above discusses some of the critical barriers impacting Australian agribusinesses in their transition journey and can slow progress or completely halt the adoption of bioenergy technologies. Most of these obstacles are common barriers that impact these types of transitions in other countries and help to lock-in established, but problematic, energy and waste management practices. As discussed, these problematic management practices are particularly severe in the case of Australian agribusiness as the primary evidence indicates.

Section 5.2 identifies a range of drivers prompting Australian agribusinesses to explore alternative energy and waste management practices. For Australian agribusinesses, the impetus for change comes from dissatisfaction with their existing practices. The impact of their incumbent approaches is heavily dependent on the agriculture sub-sector in which they operate; the types of energy they use, the way they use it and how much they use; and the types of organic waste they generate, the volumes of waste they produce and how they manage these waste materials. However, for many Australian agribusinesses, the current size of the energy or waste management problem that could drive them to explore alternative approaches does not outweigh the barriers to changing the status quo. This implies that for most Australian agribusinesses, their current approaches are meeting their needs, despite the incompatibility of some of these practices with sustainable agriculture approaches.

6.4 Overall agribusiness engagement with waste-to-energy

To conclude the chapter, this section discusses this study's research findings from Chapter 5, and the insights they provide in terms of the investigation's major research question. Based on the insights to this research's four sub-questions, as discussed in the four sub-sections above, this section answers this study's major research question, to present an understanding of how Australian agribusiness engages with organic waste-to-energy systems.

Despite producing substantial volumes of organic by-products suitable for bioenergy production, Australian agriculture has limited engagement with organic waste-to-energy technologies. Most of Australian agriculture's bioenergy generation comes from sugar refineries in Queensland and New South Wales. Biomass combustion technologies are well-established in the sugar sub-sector but are niche innovations trying to gain a foothold in other Australian agribusiness segments.

The Australian regime is feeling some pressures from the global landscape and has experienced some recent disruption. However, this disruption has only prompted a small number of Australian agribusinesses to change from their incumbent energy and waste management practices, to adopt organic waste-to-energy approaches. Agribusinesses making the transition to organic waste-to-energy approaches include piggeries, meat processors and the protected cropping sub-sectors. The main factors driving such transitions are related to agribusiness problems with the cost or security of energy supplies from external sources, and/or problems with the acceptance of incumbent waste management practices.

The barriers frustrating Australian agribusiness transitions to organic waste-to-energy approaches broadly align with those identified in similar studies from overseas and the barriers featured in the bioenergy drivers and barriers heuristic (Figure 3.1). In the Australian regime, these barriers are exacerbated by the embedded stability of existing systems. A range of internal and external factors can combine to deliver marginal business cases for agribusiness bioenergy development; and along with a shortage of technical expertise, and a general lack of awareness and understanding of bioenergy systems, these form the main barriers impacting agribusiness adoption of waste-to-energy technologies.

The final chapter of this thesis concludes the study's discussion of its research question, and the implications of the findings for Australian agribusiness transitions to the adoption of organic waste-to-energy approaches. The significance of this research is discussed, along with the study's limitations and recommendations for future areas of inquiry.

7. Conclusions

In this final chapter, the study's responses to the research question are summarised, as are the main findings, the significance, and the implications of this research. The limitations of this study are also outlined, as well as opportunities for further studies to build on this research into Australian agribusiness adoption of organic waste-to-energy technologies.

As a research project adopting a pragmatism philosophical perspective, the title of this thesis, the main research question, and its accompanying sub-questions all stem '…from a desire to produce useful and actionable knowledge, solve existential problems or re-determine indeterminate situations' (Kelly & Cordeiro, 2020, p. 3). This research begins with an assumption that Australian agribusiness management of energy and organic by-products can be problematic, due to social, environmental and economic problems to which their existing approaches contribute. This investigation also assumes that a transition to the adoption of organic waste-to-energy approaches can assist Australian agribusinesses to address some of these social, environmental and economic challenges. However, the key problem at the heart of this research project, is that Australian agribusinesses have been slow to make this transition from agribusiness-as-usual energy and waste management approaches to the adoption of organic waste-to-energy approaches. The intention of this study is that the answers to its research question and sub-questions provide practical, useful and actionable insights in addressing this major problem.

7.1 Summary

This study's major research question seeks to understand how Australian agribusinesses engage with bioenergy systems through the adoption of on-site organic waste-to-energy technologies (see Section 1.3). To answer critical aspects of the major research question, four sub-questions are explored.

The first of this research question's sub-questions seeks to understand the nature of agribusiness adoption of organic waste-to-energy technologies and identify the features and characteristics of Australian agribusinesses that have invested in organic waste-to-energy technologies. This research found the application of most organic waste-to-energy approaches by Australian agribusinesses is still in its infancy. While bioenergy approaches have been a central component of energy and waste management approaches used by Australian sugar processors for more than a century, the adoption of similar approaches in other agriculture sub-sectors has been a more recent phenomenon.

Organic waste-to-energy approaches have been adopted by agribusinesses in most Australian states and in several agribusiness sub-sectors, including meat processors, piggeries, dairies, fruit and vegetable growers (protected cropping) and poultry/egg producers (ENEA Consulting and Deloitte Financial Advisory, 2021; McCabe, 2020). Agribusinesses investing in these technologies are generally managing large volumes of organic waste materials and/or they have a large demand for energy.

This study's next two research sub-questions seek to identify the key factors impacting agribusiness transitions to adopt organic waste-to-energy technologies. These factors are key drivers motivating Australian agribusinesses to invest in organic waste-to-energy approaches, and the key barriers that thwart agribusiness progress on these transitions. The main drivers prompting agribusiness engagement with bioenergy systems are related to a level of dissatisfaction with their existing energy and/or organic waste management practices. That is, agribusinesses experiencing problems managing their organic by-products, and/or problems with the cost and/or supply of energy, are motivated to explore organic waste-to-energy options as alternatives to their incumbent energy and organic waste management processes. However, these drivers have prompted only a small number of Australian agribusinesses to transition to organic waste-to-energy technologies, indicating current regulatory and incentive mechanisms are not supporting the business cases for change.

While this study's findings are based on a relatively small sample of the Australian agrifood sector, they broadly align with assessments by other researchers of sustainability transitions in Australian agriculture. Scholars such as Iles (2021) and Santhanam-Martin et al. (2015) contend that food and fibre producers in Australia operate in a productivist agriculture regime, that is increasingly large-scale, specialised, input-intensive and yield-maximising. Sustainability transitions in the Australian regime can be difficult and occur incrementally, with existing technologies and practices 'locked in'. This is reflected in the slow rate of adoption of organic waste-to-energy technologies by Australian agribusiness and the barriers they can encounter in their transition journey.

For agribusinesses that begin a transition to adopt organic waste-to-energy approaches, there is a range of common barriers that can hinder progress on this journey (Ackrill & Abdo, 2020; Minas, 2019; O'Connor, Ehimen, Pillai, Black, et al., 2021; Xu et al., 2022). The main impediments that impact this transition for Australian agribusinesses fall into two broad categories; financial challenges, and knowledge-based barriers. There are many factors that contribute to a business case for investment in organic waste-to-energy technologies, but high input costs and low ROIs are fundamental challenges that can adversely affect the financial viability of such investments. Critical cost factors include the high capital cost of bioenergy plant and equipment, high transport costs, and the expense of accessing bioenergy expertise. These costs are particularly problematic when coupled with low returns on investment, which are issues for agribusiness types with limited capacity to fully utilise the energy they generate, and/or those receiving relatively low financial returns for the sale of their surplus energy.

The impacts of these business case difficulties can be compounded by a range of knowledge-based challenges related to bioenergy in Australia. These challenges include a general lack of knowledge and understanding of organic waste-to-energy approaches in Australia; a lack of awareness amongst agribusiness managers as to their organic waste-to-energy options; and a lack of skills and expertise in the design, manufacture, installation, operation, regulation and maintenance of organic waste-to-energy plants.

The final sub-question this research aims to address relates to the way in which these drivers and barriers impact the transition processes of Australian agribusiness investment in organic waste-to-energy technologies. There is no one simple answer to this question, as the impacts of these drivers and barriers are as complex and diverse as the agribusinesses themselves. While these drivers and barriers are part of Australian regime and so have the potential to impact any agribusiness, the extent to which they influence specific agribusinesses transitioning to organic waste-to-energy approaches is highly variable. Each of these transitions in the agribusiness sector is bespoke, with the business cases and the application of bioenergy technologies extremely sensitive to the individual agribusiness's circumstances. Key factors such as an agribusiness's type, size, location, organic waste profile and energy demand can all have a critical impact on its transition to adopt organic waste-to-energy technologies.

Australian agribusinesses that have successfully made transition to an organic waste-to-energy regime have been able to manage this complexity to make the business cases and the technologies work, to meet their energy and waste management needs. This requires agribusinesses to engage with sources of bioenergy information and expertise; and to develop and foster relationships with bioenergy and agribusiness stakeholders, who could become partners in collaborative approaches to organic waste-to-energy projects.

7.2 Significance of the findings

The research findings summarised in the previous section are significant in helping to address knowledge gaps that exist in understandings of Australian agribusiness engagement with organic waste-to-energy systems. These findings make a contribution to knowledge of how Australian primary producers manage their energy and organic by-products and provide important insights to assist bioenergy proponents identify drivers and barriers to organic waste-to-energy adoption by Australian agribusinesses. This research also makes a contribution to research exploring sustainability transitions and the application of Multi-Level Perspective (MLP) and Social Practice Approach (SPA) frameworks to describe such transitions in the agribusiness sector. These contributions are described further in the following sections.

7.2.1 Contribution to bioenergy research

The primary contribution made by this research project is to address two main gaps in academic knowledge of agribusiness adoption of organic waste-to-energy. The first of these gaps is the relatively limited exploration of the business of bioenergy, and the second is the limited research into the transition of Australian agribusiness to organic waste-to-energy approaches.

A substantial body of grey literature and academic literature exists in Australia and abroad exploring a wide range of bioenergy-related research themes. Much of this literature is descriptive in nature or examines bioenergy from a technical or ecological perspective (Iakovou et al., 2010), or explores the theoretical potential of bioenergy applications in a given location or industry. However, a lacuna exists in research exploring the business and supply chain aspects of bioenergy (Jensen & Govindan, 2014; Sam et al., 2017). In identifying the factors impacting the transition journeys of businesses in the agro-food sector, this thesis provides insights that help to address the knowledge gap in this under-researched area.

The second lacuna to which this thesis makes an important contribution relates to literature exploring the drivers and barriers to agribusiness adoption of bioenergy technologies, such as anaerobic digestion and biomass combustion boilers. A reasonable body of literature exploring these areas exists in other countries, but there is little research on these themes in the Australian context (Mofijur et al., 2021; Tait et al., 2021; Wilkinson, 2011). In studying the insights of Australian agribusinesses with experience of this transition process, this research provides a contribution to address this gap.

One of this study's key contributions to bioenergy research surrounds the role of distance or agribusiness location in agribusiness transitions to organic waste-to-energy approaches. In a country with a vast land mass and a relatively small population that lives mainly in cities on the (Eastern) coastal fringes, distance-related challenges are an unavoidable part of the Australian regime. In assessing opportunities for the adoption of these approaches, costs associated with transporting biomass substantial distances is a critical factor, and this has been identified as a major barrier to bioenergy development by Australian agribusiness (ENEA Consulting and Deloitte Financial Advisory, 2021).

However, this study has identified that distance can play a more nuanced role in organic waste-to-energy business cases, where it can be a significant barrier or a driver. The location of an agribusiness relative to energy and waste management infrastructure, and key stakeholders (such as technical experts and neighbours) can be a critical factor in determining the strength of the drivers, and the urgency of the need for an agribusiness to make changes to their energy and waste management practices.

Another contribution made by this study is the alternative perspective taken in defining the scope of the research. While other studies have typically focussed on the application of specific technologies; usually anaerobic digestion or biomass combustion boilers, the unit of analysis for this study is Australian agribusinesses and their engagement with both technologies.

7.2.2 Contribution sustainability transitions research

This study makes an important theoretical contribution to the burgeoning field of sustainability transitions research, and the exploration of socio-technical transitions in the agro-food sector. While the activity of the sustainability transitions research community has experienced substantial growth since 2005 (El Bilali, 2019b; Markard et al., 2012; Nesari et al., 2022), the role of business model dynamics in these transitions remains under-researched (Wainstein & Bumpus, 2016) and research exploring transitions in the agriculture sector is still an emerging field of enquiry (El Bilali, 2018, 2019b; El Bilali & Allahyari, 2018). The findings and discussion explored in this study adds to the growth of knowledge in both areas of research.

For more than two decades, MLP has been the dominant theoretical framework for analysing the dynamics of sustainability transitions (Geels, 2002, 2010; Geels & Schot, 2007; Geels et al., 2017; Nesari et al., 2022). The application of this framework has been particularly popular in exploring socio-technical transitions in areas such as transport and energy systems (Arranz, 2017; European Environment Agency, 2018), but MLP has also been applied to research sustainable food production transitions (Bui et al., 2016; El Bilali, 2019a). However, in Australia, the MLP framework has been used by only a few studies to explore sustainability transitions in agriculture. This is an area in need of further development (Iles, 2021; Jakku et al., 2019) and one in which this study makes a contribution.

Similarly, while MLP has been used to examine socio-technical transitions to bioenergy adoption in other countries, this researcher is not aware of any such applications exploring the Australian context. This study's application of MLP to Australian agribusiness adoption of organic waste-to-energy technologies provides insights to address this knowledge gap. In identifying the drivers and barriers impacting the Australian agro-food sector's transition journeys, this study demonstrates the experience of Australian agribusinesses is similar to their counterparts in other countries, with similar drivers and barriers impacting their transition processes.

To address MLP's perceived shortcomings with human agency when exploring socio-technical transitions (Darnhofer, 2015; El Bilali, 2018; Hinrichs, 2014; Shove & Walker, 2010), this study combines MLP with SPA. The combination of these two conceptual frameworks has been used effectively by transition researchers overseas (El Bilali, 2018; Keller et al., 2022; Sovacool et al., 2020), but has not been employed to research socio-technical transitions in food and fibre production in Australia. This study's findings regarding the impacts on everyday routines and social practices of agribusiness stakeholders, provide important insights relevant to this lacuna in academic literature on the drivers and barriers to agribusiness adoption of organic waste-to-energy approaches in Australia.

Of particular significance are the findings relating to the potential impacts of adoption of organic waste-to-energy technologies on agribusiness routines and the relationship between these impacts and barriers to adoption. While a positive financial return-on-investment is a key consideration for most business cases for investment in organic waste-to-energy approaches, so too is the impact of such transitions on the day-to-day work routines, systems and processes of these operations. Fundamental questions around 'Will this change make my work easier or harder?', and 'What will it cost to develop/employ the skills and knowledge to operate and maintain these technologies?' play critical roles in Australian agribusiness transitions to these approaches.

7.3 Implications of the findings

This study has confirmed that, except for the sugar processing sub-sector, the Australian bioenergy market is immature, and the adoption of organic waste-to-energy approaches by the Australian agro-food industry is still in its early stages of development. This research has also identified the key drivers prompting Australian agribusinesses to explore their organic waste-to-energy options, and the critical barriers that can impede or completely halt agribusiness progress on these socio-technical transition journeys. These responses to this study's major research question and its sub-questions have implications for a range of key stakeholders: for Australian agribusiness; for the Australian organic waste-to-energy industry; and for the broader Australian and global communities.

7.3.1 Implications for Australian agribusiness

The key findings of this thesis have implications for Australia and its production of food and fibre. This study identifies that in the last 15 years, the main driver prompting the Australian agriculture sector to explore organic waste-to-energy options relates to agribusinesses experiencing a level of dissatisfaction with their existing energy and/or waste management approaches. This dissatisfaction stems from two main issues: problems with the cost and/or security of the agribusiness's energy supply; and/or problems with acceptance of existing waste management practices. Given the limited penetration of organic waste-to-energy technologies in the Australian agro-food sector, it can be implied that most Australian agribusinesses are relatively satisfied with their existing energy and waste management practices.

This perceived comfort of Australian agribusinesses with their incumbent energy and waste management approaches does not align with growing pressures from the global landscape to improve the sustainability of food and fibre production. At the MLP's macro-level, the need for the world's agro-food producers to reduce the carbon-intensity of their operations has been clearly articulated. Pressure for Australia to reduce greenhouse gas emissions from agriculture has emerged in the Australian Government's recent trade agreement negotiations with the European Union and the United Kingdom (ABARES, 2023). When commenting on these negotiations, Australian Minister for Agriculture, Fisheries and Forestry (DAFF), Hon. Murray Watt declared;

> Australian agriculture's ability to continue exporting to the world is really tied to our performance on sustainability … If you speak to farmers and farm groups, they get that their ability to maintain these markets depends on continuing to improve sustainability'. (Foley, 2023, para. 3 & 5).

If Australia's farmers and farm groups do understand the need for agriculture to improve its sustainability performance, this has not been transferred to agribusiness investment in organic waste-to-energy technologies, in the period in which this study was researched.

The minister went on to express confidence in the agriculture industry's current commitments to improving its sustainability and Australia's existing environmental regulation being sufficient to satisfy the sustainability requirements of its trading partners (Foley, 2023). This is not a view supported by all in the industry, with at least two of the cases studied seeing the introduction of regulation in Australia to improve farm sustainability as inevitable (AM-01; AM-02). These agribusinesses expect demands from stakeholders in Australia and abroad to result in regulatory change that will affect the way they manage their energy and organic waste. Their anticipation of additional regulation was a driver for these agribusinesses to investigate organic waste-to-energy alternatives.

In addition to expectations from Australia's trading partners for its agro-food industry to improve the sustainability of its production, another landscape pressure exists that could continue to be an important driver of organic waste-to-energy developments in Australian agriculture. A key finding from this study highlights the critical role played by steep increases in energy costs in prompting some Australian food and fibre producers to transition to organic waste-to-energy technologies. Rapid increases in the price of gas in the mid-2010s represented a disruption to the Australian regime and emerged as a substantial driver for some agribusiness managers, whose operations have a large requirement for heat, to explore alternative sources of thermal energy (AM-04; AM-05; AM-09; AM-11).

However, in the time that has passed since the interviews for this study were conducted, Australian gas prices have remained high. More recently, due to geopolitical factors affecting global supply and demand of gas, prices for gas spiked again to record levels on the Australian east coast in 2022 (ACCC, 2023). Prices in the middle of last year were double what they were at the start of the year (ACCC, 2023), threatening the viability of some food manufacturers highly dependent on gas for their heat requirements (Price et al., 2022). If Australian gas prices remain high or rise further, this could cause further disruption to the regime in Australia and prompt more agribusinesses with large requirements for thermal energy needing to explore their organic waste-to-energy options. However, the delayed response to transition leaves Australian agribusiness vulnerable to all the negative consequences that should have been addressed through greater organic waste-to-energy uptake in the last decade.

Business cases for bioenergy investments by Australian agribusinesses generally hinge on their financial viability, but the value proposition for organic waste-to-energy transitions go beyond purely economic returns on investment. The broader business case articulating the contribution organic waste-to-energy could make to Australia's transition to a circular economy, is yet to be made for Australian agribusinesses.

7.3.2 Implications for Australian organic waste-to-energy industry

A central objective of this research is to identify 'a place' for organic waste-to-energy in Australian agribusiness. The findings of this study indicate there are several sub-sectors in Australian agriculture where organic waste-to-energy approaches have been successfully applied and continue to form a viable part of the energy and waste management of these agribusinesses. While these places are relatively few at the moment, the adoption of organic waste-to-energy technologies should play a more substantial role in Australian agriculture's transition to more sustainable food and fibre production. To support this transition, bioenergy proponents in Australia need to address the two fundamental barriers identified in this study as being critical impediments to agribusiness investment in these approaches.

The knowledge-related issues surrounding bioenergy in Australia are substantial impediments to the uptake of these technologies in the agriculture industry. The lack of knowledge, expertise and awareness of bioenergy technologies and their applications in Australia presents multiple barriers to development of organic waste-to-energy. Raising awareness of agribusiness managers of bioenergy approaches and their potential opportunities is critical to development of these approaches in the agribusiness sector. The agribusiness managers and industry experts interviewed generally agree that Bioenergy Australia is doing a good job and is on the right track in advocating for bioenergy development in Australia. However, there is no such consensus on the performance of government and industry bodies in supporting agribusiness adoption of organic waste-to-energy approaches.

Some interview participants believe government and industry bodies are doing enough to provide information, advice, expertise and/or funding to support bioenergy applications, for the engaged and connected agribusiness managers seeking this support. However, unless agribusinesses are prompted by problems with their existing energy and organic waste management approaches, they might never seek this information and support, and remain unaware of their options. To engage the disengaged agribusiness managers, and/or farmers not interested in exploring their organic waste-to-energy options, or who do not see any value in changing their energy and waste management approaches, significant efforts are required.

Further research is needed in this area, to guide the development of strategies to raise awareness, knowledge and understanding of bioenergy opportunities in the Australian agri-food industry, and in the Australian community more broadly. This study's analysis of agribusiness transitions to organic waste-to-energy technologies identifies human agency as a critical contributor to the drivers and barriers to adoption of these approaches. Further research into social practices associated with agribusiness energy and waste management, and bioenergy adoption is needed.

While raising the awareness of agribusiness managers and stakeholders of organic waste-to-energy options is vital, so too is addressing the current lack of bioenergy skills and expertise in Australia. Building the consultative capacity of the bioenergy industry in Australia is critical to developing new projects in the agriculture sector, optimising the performance of existing installations, and reducing the costs associated with the development, operation and maintenance of these technologies. While enhancing technical expertise in Australia is necessary to address bioenergy skills shortages in these areas, development is also needed in the understanding and skills required to formulate business cases and structures to support viable organic waste-to-energy projects in the agribusiness industry.

The relatively high capital costs of bioenergy technologies have been a familiar barrier to investment in these technologies in many parts of the world, and this is a significant factor in Australia as well. Developing a viable business case for investment in organic waste-to-energy technologies can be especially challenging for smaller scale agribusiness operations, which may involve large capital costs and marginal or uncertain returns-on-investment. However, agribusinesses in Australia have shown these barriers, and others associated with the complexity and bespoke-nature of business case development for the adoption of organic waste-to-energy technologies, can be overcome. Managers interviewed in this study described efforts to develop innovative partnership arrangements to make the business case for their bioenergy investment work, but they are currently very limited. Opportunities exist for greater collaboration between agribusiness and energy stakeholders to develop socially, environmentally, and economically sustainable organic waste-to-energy approaches in Australia.

Australian agribusiness is experienced in working collaboratively. Agriculture sub-sectors such as sugar, dairy, meat and livestock producers have a long history of working collaboratively to create shareholder and grower-owned cooperatives for the processing, handling and/or marketing of their food and fibre production. Collaborative business structures such as joint ventures and farmer cooperatives, community-owned collaborations and partnerships with industry stakeholders may offer Australian agribusinesses alternative transition routes into organic waste-to-energy. The formation of larger collaborative entities could provide efficiencies and economies of scale to improve the business case for bioenergy investment, and present small-scale agribusiness operators with opportunities to technologically modernise their energy and waste management approaches.

7.4 Limitations of the research and methodology

When considering the key findings of this study, it is important to recognise limiting factors that may have impacted these research findings (Creswell & Plano Clark, 2018). These limitations centre around the selection and availability of interviewees, and the impacts of the COVID-19 pandemic on this research. These limitations are outlined below.

The first limitation to be acknowledged relates to the research design and methodological choices made by the researcher. This study's multi-method qualitative research design did not feature any on-site observation and analysis of Australian agriculture's energy and waste management practices, but instead includes interviews where agribusiness managers talk about their practices. This approach falls short of the 'gold standard' for social practice research, but does achieve the next best approach (Nicolini, 2017).

Another limitation related to the selection of participants for one-on-one interviews with bioenergy experts and Australian agribusiness managers with experience, expertise and knowledge of Australian agribusiness adoption of organic waste-to-energy technologies. This study's purposive approach to interview participant selection, relied upon the researcher being aware of and able to contact experts and managers that were broadly representative of the application of organic waste-to-energy technologies by Australian agribusinesses. The pool of agribusinesses that could potentially provide important insights to this study was largely informed by two online databases of bioenergy installations operating in Australia. However, it is likely these databases did not record every Australian agribusiness that has explored its organic waste-to-energy options. As a result, some agribusinesses operating organic waste-to-energy plants that may have made a valuable contribution to this research may not have been considered for interview, and the opportunity to gain important insights from these agribusiness managers may have been missed.

Another limitation to this project's purposive approach to interviewee selection, was that only agribusinesses which had installed or trialled organic waste-to-energy technologies were invited to participate in an interview. As a result, agribusinesses that had shown interest in adopting organic waste-to-energy approaches but had withdrawn their engagement at a relatively early stage in their transition journey did not feature in this study. Such agribusiness managers may have been impacted by drivers discussed in Section 5.2, had preliminary discussions with various bioenergy or industry stakeholders, but chose to pause or end their exploration of organic waste-to-energy options. The identity of these managers and their agribusinesses may not have been widely known to the broader bioenergy industry in Australia and/or they were not listed on the databases used in this study. Consequently, these managers, who may have provided important insights on the barriers they experienced to organic waste-to-energy adoption, were not invited to contribute to this research project.

The interviewee selection strategy was also dependent on invited interviewees agreeing to participate in an interview. This approach was successful in ensuring this study heard from a range of relevant voices from most Australian states and most of the relevant agribusiness sub-sectors. However, more than half of the agribusiness managers interviewed were based in Victoria, which could suggest the research findings may have a Victorian bias. This was not intentional; every Victorian manager invited to an interview accepted the invitation, while several managers in other states declined their invitations. The reasons for the differences in response rates from state to state are unclear. Nevertheless, it is reasonable that Victoria would feature strongly in this research, as there has been a relatively high level of interest in organic waste-to-energy options from a diverse range of agribusiness types in Victoria, in the period being studied (see Section 5.1.2).

Another limitation related to the profile of this study's interviewees is this that no agribusiness managers from Tasmania or from the poultry sub-sector agreed to participate in an interview. These two cohorts are important parts of Australian agriculture and its engagement with organic waste-to-energy systems. Agribusiness managers from Tasmania and egg and poultry producers were invited to be interviewed, but none agreed and this is a limitation of this study. Given these issues with participant selection and the relatively small sample of cases of the agribusiness managers interviewed, there are limits to the extent to which the views of this sample can be interpreted as being representative of the Australian agriculture industry.

The COVID-19 pandemic in Australia also impacted this research project. The arrival of COVID-19 (Coronavirus) in Australia early in 2020 prompted a range of Commonwealth and State Government responses, which included restrictions on travel and the gathering of people in indoor and outdoor spaces (Cassells et al., 2021; Storen & Corrigan, 2020). These lockdowns coincided with this study's Stage 2 and 3 research interviews, which were originally planned to be conducted face-to-face, on-site at the participating interviewee's office or agribusiness. The COVID-19 restrictions on travel meant face-to-face interviews were not possible and so were replaced in the research methodology by online interviews, conducted on the Microsoft Teams platform. This change provided some benefits to this project, as online interviews were a more time-efficient and cost-effective way to conduct the industry expert and agribusiness manager interviews. However, in Stage 3, this change also robbed the researcher of the opportunity to experience agribusiness use of organic waste-to-energy technologies. Such experiences enable visitors to see, hear, touch and smell these technologies and their feedstocks (IE-7), to help contextualise the participant's responses to the interview questions and to develop a richer understanding of how bioenergy approaches are applied in Australian agribusinesses.

The impacts of COVID-19 may also have affected the availability of agribusiness managers to participate in this project's Stage 3 interviews. During this time, the coronavirus crisis and government responses to it, had substantial impacts on businesses around the world (Ratten, 2020), including businesses in Australia. Disruptions to some businesses were profound (Cassells et al., 2021) and it is possible that managing the additional business challenges associated with COVID-19 may have reduced the availability and/or inclination of agribusiness managers to participate in an interview; whether face-to-face or online.

The final limitation of this study relates to the timing of the research project. As a part-time PhD investigation, research activities have been conducted over the last seven years and the responses to the research question and sub-questions represent a snapshot of Australian agribusiness engagement with organic waste-to-energy systems at a particular point in time. However, four years have passed since the beginning of this study's data collection stages, and in this time the engagement of Australia's food and fibre producers and processors with organic waste-to-energy technologies has continued to evolve. Significant developments relevant to this project that have occurred in this time, such as the release of *Australia's Bioenergy Roadmap* (ENEA Consulting and Deloitte Financial Advisory, 2021) and commitments from Australian agribusiness peak bodies to achieve carbon neutrality (ABARES, 2023), have not been reflected in data collected and research findings discussed.

7.5 Recommendations for future research

While the research findings described in this thesis provide valuable insights into knowledge gaps identified in several areas of research, there is still much to be done to address these lacunae. The limitations of this study, as outlined in the previous section, point to some areas for additional research. Discussion of the key findings of this research (see Chapter 6) also identifies themes that require further investigation.

Given the scale, significance and urgency of global challenges such as climate change, and the critical need for Australia to play its part to improve the sustainability of its socio-technical systems, there is clearly a need for more research investigating sustainability transitions in the Australian agribusiness sector. This study confirms the findings of research from overseas, that combining MLP and SPA theoretical frameworks is a useful approach for studying these transitions in Australian food and fibre production. There are many opportunities to apply these models to the technology and farm management transitions required to improve the sustainability performance of Australian agriculture.

While this research has investigated how critical drivers and barriers impact Australian agribusiness transitions to organic waste-to-energy technologies, opportunities exist to apply the MLP-SPA combination to understand other important sustainability transitions to specific technologies and/or agriculture sub-sectors. Biomass combustion boilers and anaerobic digesters are the main bioenergy technologies identified in this study as currently seeking to transition from MLP's niche innovation level to the Australian regime. These approaches feature different technological processes and have different organic waste-to-energy applications, so transitions to these specific technologies would be obvious areas for further investigation. There are also opportunities to apply MLP-SPA combination to specific agriculture sub-sectors in Australia.

One of the substantial barriers to Australian agriculture's adoption of bioenergy technologies is the lack of expertise, knowledge and awareness of these technologies and their application. Given the major impact this barrier has at multiple levels on transitions to these technologies in the Australian agribusiness context, there is a need for further research into these knowledge-related factors. In particular, research is needed to identify strategies to increase community awareness of bioenergy technologies, as well as the substantive consultative expertise and capacity in Australia.

This thesis' final recommendation for further research relates to the challenges some Australian agribusinesses experience in building the financial business case for investment in organic waste-to-energy technologies. Business case development must move beyond purely financial considerations, to reflect the broader value proposition for organic waste-to-energy investment, and the contribution adoption of bioenergy technologies can make to Australia's transition to CE. Also, section 7.4.2 features discussion of the opportunities for agribusinesses, especially smaller scale operations, to explore the feasibility of collaborative business models for local organic waste-to-energy developments. This is an area for further investigation to evaluate and develop innovative business models and structures to enable small scale agribusinesses to engage with organic waste-to-energy systems.

The recommendations for further study outlined in this section are by no means the only opportunities for development in the fields of research explored in this thesis. Despite the increase in interest and activity in the field of sustainability transitions research in the last decade, more research is needed with a focus on agriculture, to assist the world's agro-food producers to find their place in a sustainable future.

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9. Appendices

9.1 Appendix A - Interview invitation emails

Interview Recruitment Emails

Federation UNIVERSITY • AUSTRALIA

Federation Business School

PROJECT TITLE:	Finding a place for waste-to-energy in Australian agribusiness
PRINCIPAL RESEARCHER:	Assoc. Prof. Jerry Courvisanos (Principal PhD Supervisor)
OTHER/STUDENT RESEARCHERS:	Dr Jackie Tuck (Associate PhD Supervisor) Craig Hurley (PhD Student)

1. Interview recruitment email - Experts

Hi (Expert's name)

I am writing to invite you to participate in an interview as part of a PhD research project being undertaken by myself, under the supervision of Associate Professor Jerry Courvisanos and Dr Jackie Tuck, to explore the impact of drivers and barriers to the adoption of waste-to-energy technologies by Australian agribusiness.

As someone with substantial expertise/experience in the development of waste-to-energy systems in Australian agribusiness, your opinions and views on agribusiness engagement with waste-to-energy systems are important to assist stakeholders to understand the drivers encouraging agribusinesses to consider waste-to-energy options, and may enable agribusinesses to anticipate potential barriers and develop strategies to overcome their impacts.

For information about this research and the interview process, please refer to the attached Plain Language Information Statement. Also attached is the Informed Consent Form, which will need to be completed and provided at the interview. If you have any queries about the proposed interview or any other part of this research project, please contact me by return email or telephone (03 5335 3717) to discuss these.

If you would be willing to participate in this research project, please confirm this by return email and provide written confirmation from your organisation of their approval for your participation in an interview. I will then contact you by telephone to arrange a time and place for the interview.

Many thanks,

Craig Hurley
PhD Candidate
Federation Business School
Federation University Australia

2. Interview recruitment email – Agribusiness manager – Did invest

Hi (manager's name)

I am writing to invite you to participate in an interview as part of a PhD research project being undertaken by myself, under the supervision of Associate Professor Jerry Courvisanos and Dr Jackie Tuck, to explore the impact of drivers and barriers to the adoption of waste-to-energy technologies by Australian agribusiness.

As the contact listed #####someone with substantial expertise/experience in the development of waste-to-energy systems in Australian agribusiness, your opinions and views on agribusiness engagement with waste-to-energy systems are important to assist stakeholders to understand the drivers encouraging agribusinesses to consider waste-to-energy options, and may enable agribusinesses to anticipate potential barriers and develop strategies to overcome their impacts.

For information about this research and the interview process, please refer to the attached Plain Language Information Statement. Also attached is the Informed Consent Form, which will need to be completed and collected before an interview. If you have any queries about the proposed interview or any other part of this research project, please contact me by return email or telephone (03 5335 3717) to discuss these.

If you are to participate in this research project, please confirm this by return email. I will then contact you by telephone to arrange a time and place for an interview.

Many thanks,

Craig Hurley
PhD Candidate
Federation Business School
Federation University Australia

3. Interview permission email – CEO or supervisor of expert/manager

Hi (name of CEO or supervisor)

I am writing to request permission to interview (name of expert/manager) as part of a PhD research project being undertaken by myself, under the supervision of Associate Professor Jerry Courvisanos and Dr Jackie Tuck, to explore the impact of drivers and barriers to the adoption of waste-to-energy technologies by Australian agribusiness.

As an expert/manager with substantial expertise/experience in waste-to-energy development in Australian agribusiness, (name of expert/manager)'s opinions and views on agribusiness engagement with waste-to-energy systems are important to assist stakeholders to understand the drivers encouraging agribusinesses to consider waste-to-energy options, and may enable agribusinesses to anticipate potential barriers and develop strategies to overcome their impacts.

For information about this research and the interview process, please refer to the attached Plain Language Information Statement. If you have any queries about the interview process or this research project, please contact me on 03 5335 3717.

If you are willing for (name of expert/manager) to be participate in this research project, please confirm this by return email.

Many thanks,

Craig Hurley
PhD Candidate
Federation Business School
Federation University Australia

9.2 Appendix B - Plain Language Information Statements

Plain Language Information Statement

Experts

Federation UNIVERSITY•AUSTRALIA

Federation Business School

PROJECT TITLE:	Finding a place for waste-to-energy in Australian agribusiness
PRINCIPAL RESEARCHER:	Assoc. Prof. Jerry Courvisanos (Principal PhD Supervisor)
OTHER/STUDENT RESEARCHERS:	Dr Jackie Tuck (Associate PhD Supervisor) Craig Hurley (PhD Student)

You have been identified as someone with substantial expertise in bioenergy development in Australia, and are invited to participate in this PhD research project being undertaken by Craig Hurley, under the supervision of Associate Professor Jerry Courvisanos and Dr Jackie Tuck. This project will explore the impact of drivers and barriers to the adoption of waste-to-energy technologies by Australian agribusiness. Your opinions and views on the uptake of waste-to-energy technologies by Australian agribusinesses are important to assist stakeholders to understand the drivers encouraging agribusinesses to consider waste-to-energy options, and may enable agribusinesses to anticipate potential barriers and develop strategies to overcome their impacts.

Purpose and Background:

The major purpose of this study is to gain a better understanding of why Australian agribusinesses have been slow to engage with waste-to-energy systems as a central part of their waste management practices. The objective of this study is to explore reasons for this, with a focus on the adoption of waste-to-energy technologies in Australian agribusinesses, to identify the critical factors that influence their decision-making on waste-to-energy investments. This proposal aims to identify the drivers inducing agribusiness investment in on-site waste-to-energy technologies with accompanying social and economic configurations, and the barriers affecting this transition.

The information collected from you will be used for the purpose of this research project and may be retained for other studies exploring the drivers and barriers to waste-to-energy adoption. All collected data is highly confidential and no identifying information will be used in any publication arising from this research. If any direct quotes are used you will be referred to by pseudonym, however, given the sample size in this project is small, it may be impossible to guarantee anonymity or confidentiality of your responses. There are no right or wrong answers, we are only interested in your opinion. Participation in the interview is voluntary. You may withdraw your involvement at any time and should you do so the interview will immediately cease and any information collected from you during the interview will not be used. You should note, however, that once identification has been removed from the data it is not possible to withdraw consent to participate. No personal details identifying individuals will be made available to anyone.

The interview notes and audio-recordings will be stored in a locked cabinet and/or password protected computer file and can only be accessed by the researchers and audio-transcribers involved in the study. Upon completion of the research, interview participants will receive a copy of the research summary report and the thesis can be provided upon request from the researcher.

Plain Language Information Statement
Experts

Procedures:
Participation in this project will involve an interview which will take approximately 60-90 minutes of your time, notes will be taken and the interview will be audio-recorded subject to your consent. The interview will explore your opinions and views on the adoption of waste-to-energy technologies by Australian agribusinesses. The interview will focus on your experiences and insights gained relating to the uptake of waste-to-energy technologies by Australian agribusiness, through your involvement and/or observations of these projects.

Risks and Support:
Although it is unlikely, it is possible that you may experience some minor psychological distress from consideration of some issues in this study. You should note that you are able to withdraw from the interview at any time. If you do not feel comfortable contributing on a particular issue or answering any question you are not required to do so. You can also contact the researcher listed below if you have any concerns, or in the unlikely event you become distressed you can contact the Lifeline Counselling Service on 13 11 14.

Data Protection:
In order to protect confidentiality of your data, the collected data will be stored securely, only accessible to the researcher. You should note however that the confidentiality of information that you provide is subject to legal limitations (e.g. subpoena or a freedom of information claim).

Once you understand what this part of the project is about and if you agree to take part in it, please sign the informed consent form (attached) and return it to the researcher. By signing the informed consent form, you indicate that you understand the information and that you give your consent to participate in the interview.

If you have any questions, or you would like further information regarding the project titled **Finding a place for waste-to-energy in Australian agribusiness**, please contact please contact the Principal Researcher, Assoc. Prof. Jerry Courvisanos of the Federation Business School:

PH: (03) 5327 9417
EMAIL: j.courvisanos@federation.edu.au

Should you (i.e. the participant) have any concerns about the ethical conduct of this research project, please contact the Federation University Ethics Officer, Research Services, Federation University Australia, PO Box 663, Mt Helen VIC 3353. Telephone: (03) 5327 9765, Email: research.ethics@federation.edu.au

CRICOS Provider Number 00103D

Plain Language Information Statement – Managers

FEDERATION BUSINESS SCHOOL	
PROJECT TITLE:	Finding a place for waste-to-energy in Australian agribusiness
PRINCIPAL RESEARCHER:	Assoc. Prof. Jerry Courvisanos (Principal PhD Supervisor)
OTHER/STUDENT RESEARCHERS:	Dr Ben Wills (Associate PhD Supervisor) Craig Hurley (PhD Student)

Your company has been identified as an agribusiness that has invested in waste-to-energy technologies as an integral part of your operation's waste management practices. As the owner/manager of this business, you are invited to participate in this PhD research project being undertaken by Craig Hurley, under the supervision of Associate Professor Jerry Courvisanos and Dr Ben Wills.

This project will explore the impact of drivers and barriers to the adoption of waste-to-energy technologies by Australian agribusiness. Given your experiences with and consideration of waste-to-energy technologies, your opinions and perspectives on agribusiness engagement with waste-to-energy systems are important. Your insights will assist stakeholders to understand the drivers encouraging agribusinesses to consider waste-to-energy options, and may enable agribusinesses to anticipate potential barriers to waste-to-energy development and to develop strategies to overcome their impacts.

Purpose and Background:
The major purpose of this study is to gain a better understanding of why Australian agribusinesses have been slow to engage with waste-to-energy systems as a central part of their waste management practices. The objective of this study is to explore reasons for this, with a focus on the adoption of waste-to-energy technologies in Australian agribusinesses, to identify the critical factors that influence their decision-making on waste-to-energy investments. This proposal aims to identify the drivers inducing agribusiness investment in on-site waste-to-energy technologies with accompanying social and economic configurations, and the barriers affecting this transition.

The information collected from you will be used for the purpose of this research project and potentially other studies exploring the drivers and barriers to waste-to-energy adoption. All collected data is highly confidential and no identifying information will be used in any publication arising from this research. If any direct quotes are used you will be referred to by pseudonym, however, given the sample size in this project is small, it may be impossible to guarantee anonymity or confidentiality of your responses. There are no right or wrong answers, we are only interested in your opinion. Participation in the interview is voluntary. You may withdraw your involvement at any time and should you do so the interview will immediately cease and any information collected from you during the interview will not be used. You should note, however, that once identification has been removed from the data it is not possible to withdraw consent to participate. No personal details identifying individuals will be made available to anyone.

The interview notes and audio-recordings will be stored in a locked cabinet and/or password protected computer file and can only be accessed by the researchers and audio-transcribers involved in the study. Upon completion of the research, interview participants will receive a copy of the research summary and the thesis can be provided upon request from the researcher.

Procedures:
Participation in this project will involve an interview which will take approximately one hour of your time, notes will be taken and the interview will be audio-recorded subject to your consent. The interview will explore your opinions and views on the adoption of waste-to-energy technologies by Australian agribusinesses. The interview will focus on your experiences and insights gained through your company's consideration of waste-to-energy options and your broader observations of the application of waste-to-energy technologies by Australian agribusiness.

Risks and Support:
Although it is unlikely, it is possible that you may experience some minor psychological distress from consideration of some issues in this study. You should note that you are able to withdraw from the interview at any time. If you do not feel comfortable contributing on a particular issue or answering any question you are not required to do so. You can also contact the researcher listed below if you have any concerns, or in the unlikely event you become distressed, you can contact the Lifeline Counselling Service on 13 11 14.

Data Protection:
In order to protect confidentiality of your data, the collected data will be stored securely, only accessible to the researcher. You should note however that the confidentiality of information that you provide is subject to legal limitations (e.g. subpoena or a freedom of information claim).

Once you understand what this part of the project is about and if you agree to take part in it, please sign the informed consent form (attached) and return it to the researcher. By signing the informed consent form, you indicate that you understand the information and that you give your consent to participate in the interview.

If you have any questions, or you would like further information regarding the project titled **Finding a place for waste-to-energy in Australian agribusiness**, please contact please contact the Principal Researcher, Assoc. Prof. Jerry Courvisanos of the Federation Business School: PH: (03) 5327 9417 EMAIL: j.courvisanos@federation.edu.au
Should you (i.e. the participant) have any concerns about the ethical conduct of this research project, please contact the Federation University Ethics Officer, Research Services, Federation University Australia, PO Box 663, Mt Helen VIC 3353. Telephone: (03) 5327 9765, Email: research.ethics@federation.edu.au CRICOS Provider Number 00103D

9.3 Appendix C - Informed Consent Form

Consent Form

Human Research Ethics Committee

Federation UNIVERSITY • AUSTRALIA

PROJECT TITLE:	**Finding a place for waste-to-energy in Australian agribusiness**
RESEARCHERS:	**Jerry Courvisanos** **Jackie Tuck** **Craig Hurley**

Consent – Please complete the following information:

I ____ of

____+

hereby consent to participate as a subject in the above research study.

The research program in which I am being asked to participate has been explained fully to me, verbally and in writing, and any matters on which I have sought information have been answered to my satisfaction.

I understand that:

- All information I provide will be treated with the strictest confidence and data will be stored separately from any listing that includes my name and address, but as the sample size in this project is small, it may be impossible to guarantee anonymity or confidentiality of my responses.
- Aggregated results will be used for the purpose of this research project and potentially other studies exploring the drivers and barriers to waste-to-energy adoption and may be reported in scientific and academic journals.
- I am free to withdraw my consent at any time during the study in which event my participation in the research study will immediately cease and information/data obtained from it will not be used.
- I understand the exception to this is if I withdraw after information has been aggregated - it is unable to be individually identified - so from this point it is not possible to withdraw my information/data, although I may still withdraw my consent to participate.
- Subject to my consent, this interview will be audio-recorded.
- Confidentiality of information I provide is subject to legal limitations (e.g. subpoena or a freedom on information claim).

SIGNATURE:_________________________________ **DATE:** ___________________.

9.4 Appendix D - Interview questions – Stage 2 & Stage 3 interviews

Interview Questions
Phase 2 – Experts/Stakeholders

Federation UNIVERSITY • AUSTRALIA

Federation Business School

PROJECT TITLE:	Finding a place for waste-to-energy in Australian agribusiness
PROJECT NUMBER:	B18-127
PRINCIPAL RESEARCHER:	Assoc. Prof. Jerry Courvisanos (Principal PhD Supervisor)
OTHER/STUDENT RESEARCHERS:	Dr Jackie Tuck (Associate PhD Supervisor) Craig Hurley (PhD Student)

Interview questions – (Phase 2) waste-to-energy experts and stakeholders

Details describing the expert (name, organisation, experience, area of expertise etc.) will be sourced from information available online, but if any gaps exist in this information, questions may be asked to address these gaps prior to the following open-ended structured questions.

1. How would you describe the current state of organic waste-to-energy deployment (and development) in Australia, generally? In the agribusiness sector?

2. What has been your involvement in supporting adoption of organic waste-to-energy by Australian agribusinesses? How do you provide this support?

3. For what reasons do agribusinesses in Australia invest in waste-to-energy technologies? What are the main factors that prompt their decision to explore their waste-to-energy options? Factors from inside their business? Factors from outside? How/why do these factors impact on their business?

4. What awareness/knowledge do agribusiness managers have about organic waste-to-energy and its agribusiness applications? How do agribusinesses build their knowledge about waste-to-energy and its suitability to their business? Could you describe this process?

5. What are the factors that have the greatest influence on decision-making of agribusiness managers through this process? How do these factors influence them and why are these important?

6. When an agribusiness takes some steps to learn more about organic waste-to-energy technologies and how they could be applied in their operations, what are the factors that might end this interest?

Or, for agribusinesses that have progressed further down the waste-to-energy path, what are the major barriers that can derail their projects? How do agribusinesses overcome these barriers and succeed? Why do other agribusinesses find these barriers so overwhelming that they reject going down this waste-to-energy path?

7. Through this process, who do agribusinesses turn to for financial, technical, regulatory, business-planning, etc. support and advice? In what ways does this support/lack of support impact their decision-making?

8. To what extent do local, state and federal government policies (environmental, energy, economic development) impact on agribusiness investment in waste-to-energy? How?

9. To what extent do you believe waste-to-energy technologies currently deployed by agribusinesses have the potential to be replicated in other agribusinesses? Why/not?

10. How could those involved in waste-to-energy (policy, financial, technical, regulatory, business-planning etc.) work more effectively to better support agribusinesses investment in waste-to-energy?

11. For the agribusinesses that you have worked with, what have been major benefits and drawbacks from their decisions to invest in waste-to-energy technologies?

12. What advice would you give to agribusinesses interested in adopting waste-to-energy technologies?

13. Is there anything else you would like to add that is relevant to agribusiness adoption of waste-to-energy technologies?

14. Can you suggest any other waste-to-energy or agribusiness experts whose insights could be relevant to this research?

Federation University

Interview Questions – Agribusiness Managers

FEDERATION BUSINESS SCHOOL	
PROJECT TITLE:	Finding a place for waste-to-energy in Australian agribusiness
PRINCIPAL RESEARCHER:	Assoc. Prof. Jerry Courvisanos (Principal PhD Supervisor)
OTHER/STUDENT RESEARCHERS:	Dr Jackie Tuck (Associate PhD Supervisor) Craig Hurley (PhD Student)

Final interview questions – (Phase 3) agribusiness managers who explored investment in waste-to-energy technologies

Preliminary descriptive details of the business (e.g. company size, agribusiness type, number and type of waste-to-energy plants) being interviewed should be available from online sources previously accessed, but if any gaps exist in this information obtained, questions may be asked to address these gaps prior to the following semi-structured questions.

1. Before you explored waste-to-energy, to what extent did you believe such technologies were a realistic option for *your business*?
   Prompts:
   - Why/why not?
   - How and when did you first learn about the waste-to-energy potential of *your industry* sector AND/OR its potential for your agribusiness operation?

2. What were the main factors that prompted your business to explore waste-to-energy more deeply?
   - Factors from inside your business?
   - Factors from outside?
   - How/why were these factors impacting on your business?

3. Briefly describe any waste-to-energy technologies which your business has explored, and any organic waste feedstocks/waste-streams you wanted to process?

4. How did you go about learning more about waste-to-energy and its suitability for your business?
   - What examples of waste-to-energy plants did you see/visit/read/hear about? And/or, who did you talk to?
   - How did this experience influence your thinking?

5. Can you describe the journey the business took from first looking at its waste-to-energy options, to deciding to invest in a plant … or not?

6. Once you decided to start down the waste-to-energy path, what were the major blockages/hurdles that impacted on your journey?
   - These were the major obstacles – were there any others that impacted your business's progress down the waste-to-energy route?

7. Describe the process of working through and customising the technical design and business case for the business's waste-to-energy solution.

8. When considering your business's waste-to-energy options, where did you go for support and advice?
    - That is, for financial, technical, regulatory, business-planning, support and advice?
    - How did this support/lack of support impact your decision?

9. What did you see as the key to the overall success or failure of the business's implementation of waste-to-energy?
    - Why did waste-to-energy work [OR not work] for you?

10. In what ways could Australian agribusinesses be better supported when considering investment in these technologies?
    - To what extent did/do you receive the support you need/ed?
    - Financial, technical, regulatory, business-planning support?
    - Government (Local, State & Commonwealth)

11. What advice would you give to other agribusinesses interested in adopting organic waste-to-energy technologies?

12. Is there anything else you would like to add that is relevant to your business's exploration/adoption of waste-to-energy technology?

9.5 Appendix E - Organic waste-to-energy plants in Australian agribusiness

Business Name	Location	State	Ag. Sector	Size	Technology	Waste type	Date of install	Source of data	Status
New South Wales									
Baiada Poultry	Beresfield	NSW	Poultry	1 MW?	Biogas (blended with natural gas) CHP	Wastewater	2016?	http://biomassproducer.com.au/project/baiada-poultry-eases-costs-with-onsite-biogas-production/#.W_PaqzgzbRY https://www.baiada.com.au/our-commitment	Operating
Bindaree Beef	Inverell	NSW	Abattoir		Biogas	Organic waste/water	2014	http://biomassproducer.com.au/project/binderee-beef-produces-biogas-from-on-site-wastes/#.W_PhGTgzbRY	Operating
Blantyre Farms	Young	NSW	Piggery	0.16 MW	Biogas	Food and ag wet waste	2019	http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Capital Dynamics	Broadwater	NSW	Sugar Mill	8 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Capital Dynamics - Cape Byron Power	Broadwater II	NSW	Power station	30 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Capital Dynamics	Condong	NSW	Sugar Mill	3 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Capital Dynamics - Cape Byron Power	Condong II	NSW	Power station	30 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Earth Power	Parramatta	NSW	Energy company	3.9 MW	Biogas	Food and ag wet waste		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Family Fresh Farms	Peat's Ridge	NSW	Vegetable glasshouse	5 MW	Wood chip boiler	Wood chips	2017	http://biomassproducer.com.au/project/biomass-provides-the-heat-to-the-	Operating

Business Name	Location	State	Ag. Sector	Size	Technology	Waste type	Date of install	Source of data	Status
								family-fresh-farm-glasshouses/#.W_PY8DgzbRY	
Moxey Farm	Gooloogong	NSW	Dairy	3.1 MW	AD	Manure wet waste	2019	https://www.afmh.com.au/sustainability/	Under construction
NSW Sugar Milling Co-op (Sunshine Sugar)	Ballina	NSW	Sugar Mill	4.5 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Pacific Pyrolysis	Ballina	NSW	Energy company	6,000MW	Pyrolysis			MRA Consulting ppt	Not in operation
Rivalea	Corowa	NSW	Piggery?	550kW?	CHP	Manure wet waste	2017	http://biomassproducer.com.au/project/agrifood-company-rivalea-reduces-environmental-impact/#.W-65PjgzbRY	Operating
Southern Meats - Goulburn abattoir (and ReNU Energy)	Goulburn	NSW	Abattoir	1.6 MW?	Anaerobic	Wastewater	2018	http://biomassproducer.com.au/project/renu-energy-goulburn-abattoir-powering-itself-using-bioenergy/#.W_PeEjgzbRY	Operating
Northern Territory									
CJ Ord River Sugar	Kununurra	NT	Sugar Mill	6 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Queensland									
AGL	Gympie	QLD	Energy company	1.5 MW	Biogas	Food and ag wet waste		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
AJ Bush	Bromelton	QLD	Animal waste/rendering	1.26 MW	Biogas	Food and ag wet waste		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Bundaberg Sugar	Bingera	QLD	Sugar Mill	5 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Bundaberg Sugar	Millaquin	QLD	Sugar Mill	5 MW	bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating

Business Name	Location	State	Ag. Sector	Size	Technology	Waste type	Date of install	Source of data	Status
COFCO	Tully	QLD	Sugar Mill	21.4 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Darling Down Eggs	Pittsworth/ Kincora	QLD	Egg producer	250 kW	Anaerobic digestion	Poultry manure	2014	http://biomassproducer.com.au/project/darling-downs-eggs-generate-heat-and-power-from-chicken-manure-and-organic-waste/#.W_vl1jgzbRY	Operating
FPC Green Energy	Rocky Point	QLD	Energy company	30 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Isis Central Sugar Mill	Isis	QLD	Sugar Mill	11.5 MW	bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
JBS Meats Australia	Dinmore	QLD	Abattoir	10 MW?	Anaerobic Digestion	Waste water	2017	http://biomassproducer.com.au/project/jbs-australia-uses-meat-processing-waste-to-generate-biogas-and-reduces-costs/#.W_vCyTgzbRY	Operating
Kalfresh	Ipswich	QLD	Vegetable grower & processor	1.6 MW	Co-digestion	Vege/liquid waste		Presenter - Bioenergy Australia webinar	Under construction
Mackay Sugar	Farleigh	QLD	Sugar Mill	13 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Mackay Sugar	Marian	QLD	Sugar Mill	18 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Mackay Sugar	Mossman	QLD	Sugar Mill	11.85 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Mackay Sugar	Racecourse	QLD	Sugar Mill	38 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Mitr Pohl Sugar Corp MSF Sugar	Mareeba (Tableland Mill)	QLD	Sugar Mill	7 (24) MW	Bagasse Cogen	Bagasse	2016	http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating

Business Name	Location	State	Ag. Sector	Size	Technology	Waste type	Date of install	Source of data	Status
Mitr Pohl Sugar Corp	Maryborough I	QLD	Sugar Mill	4.75 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Mitr Pohl Sugar Corp	Mulgrave	QLD	Sugar Mill	10.5 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Mitr Pohl Sugar Corp	South Johnstone	QLD	Sugar Mill	19.3 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Sucragen	Inkerman	QLD	Sugar Mill	10 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Sucragen	Invicta	QLD	Sugar Mill	50.5 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Sucragen	Kalamia	QLD	Sugar Mill	9 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Sucragen	Macknade	QLD	Sugar Mill	8 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Sucragen	Pioneer II	QLD	Sugar Mill	68 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Sucragen	Plane Creek	QLD	Sugar Mill	14 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Sucragen	Proserpine	QLD	Sugar Mill	20 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Sucragen	Victoria	QLD	Sugar Mill	19 MW	Bagasse Cogen	Bagasse		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Suncoast Gold Macadamias	Gympie	QLD	Nut processing	1.4MW	Steam boiler & turbine	Nut shells/husks	2003		Operating

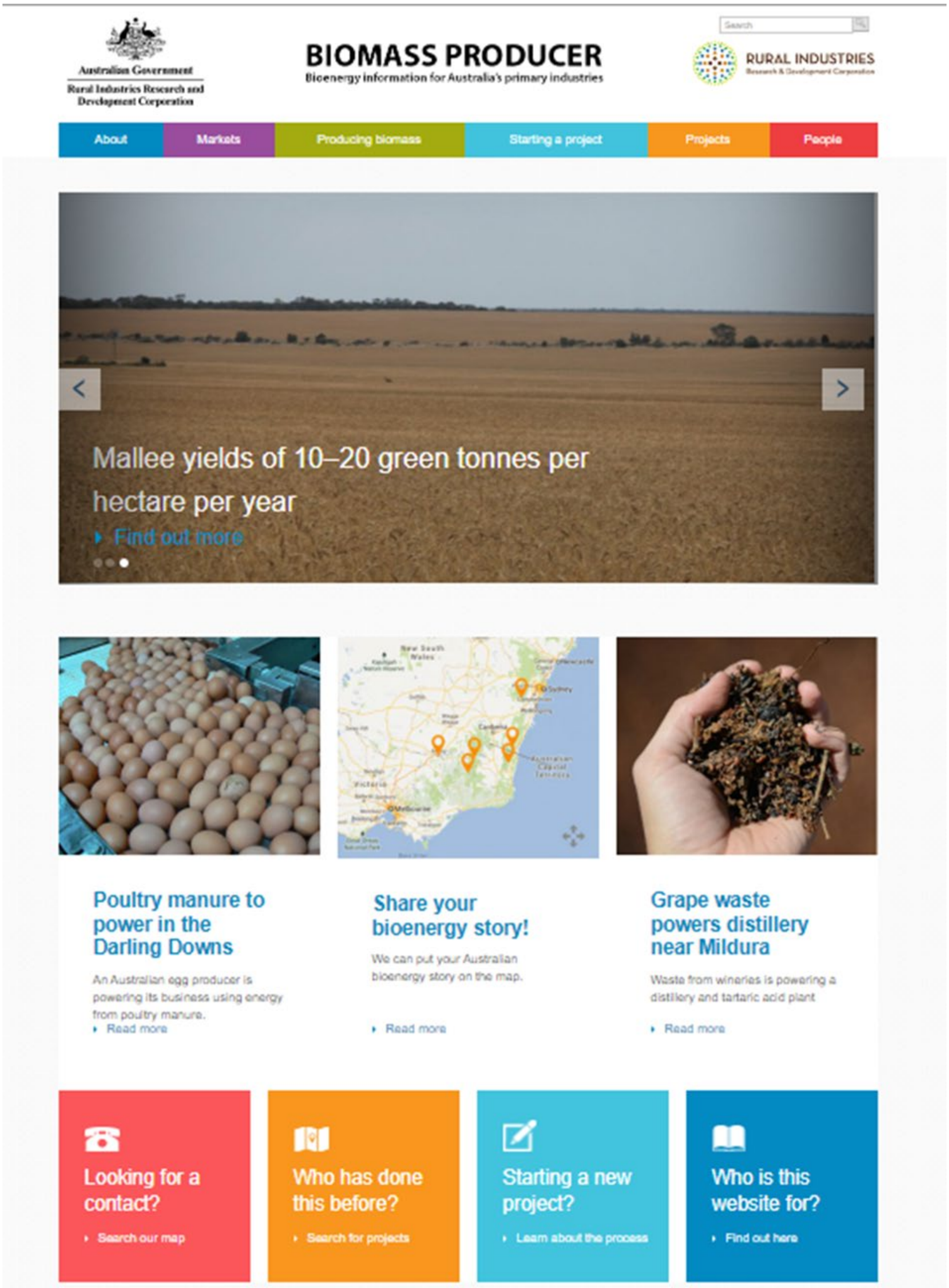
Business Name	Location	State	Ag. Sector	Size	Technology	Waste type	Date of install	Source of data	Status
Trisco Foods	Carole Park (Ipswich)	QLD	Food processor (sauces, syrups, cordials and jams)		Anaerobic Membrane BioReactor	Food waste	2017	http://biomassproducer.com.au/project/pilot-trisco-foods-turn-sweet-scraps-into-power/#.W_vAvTgzbRY	Pilot
Whitton Heat Plant (Southern Cotton?)	Toowoomba	QLD	Cotton processor		Continuous Carbonisation Technology	Cropping residue		http://biomassproducer.com.au/project/whitton-heat-plant-uses-walnut-shells/#.W_vGUDgzbRY	
	Grantham	QLD	Piggery		Anaerobic lagoon	Manure wet waste		http://biomassproducer.com.au/project/piggery-waste-to-heat-worth-30000/#.W_vFODgzbRY	
South Australia									
Yorke Biomass Energy	Ardrossan	SA	Biomass Co-op	15 MW	Straw-fired boiler	Straw	~2020	http://biomassproducer.com.au/project/coming-soon-2018-bioenergy-from-straw-on-the-yorke-peninsula/#.W_Nn1DgzbRY	Proposed -did not proceed
Peats Soil & Garden Supplies	Willunga	SA	Organics Composter		Anaerobic Digestion (and biodiesel)	Organic waste and ag waste		http://biomassproducer.com.au/project/peats-soils-solve-onsite-challenges-and-open-up-export-opportunities/#.W_NubDgzbRY https://www.peatssoil.com.au/news/waste-not-want-not-peats-landline-exclusive-on-the-war-on-waste/	Under construction
Tasmania									
Greenham Meats	Smithton	TAS	Abattoir		Pyrethrum marc boiler	Pyrethrum briquettes (waste)	2016?	http://biomassproducer.com.au/project/greenham-meats-fires-its-cookers-on-local-pyrethrin-marc-briquettes/#.W_Pk6zgzbRY	Collaboration
Hills Transplants	Devonport	TAS	Vegetable glasshouse	2.5 MW	Wood chip boiler	Wet wood chips (waste)		http://biomassproducer.com.au/project/hills-transplants-wood-chips-to-heat-greenhouses/	
Victoria									

Business Name	Location	State	Ag. Sector	Size	Technology	Waste type	Date of install	Source of data	Status
Australian Tartaric Products	Colignan	VIC	Viticulture	0.6 MW	Cogen – biomass combustion	Grape marc		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Berrybank - Charles IFE	Windemere	VIC	Piggery	0.23 MW (?)	Anaerobic Digestion	Manure wet waste		http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Don KR/ MASG	Castlemaine	VIC	Meat processor		Anaerobic Digestion	Meat processing wet wastes		Bioenergy Australia webinar & https://www.abc.net.au/news/2021-06-07/planned-bioenergy-facility-for-castlemaine/100194430	Under construction
Frew Foods International	Stawell	VIC	Abattoir	3 MW	Boiler	Saw dust		Bioenergy Australia webinar https://vicbioenergy.com.au/projects/	
George Weston Foods - Bears Lagoon Piggery	Bears Lagoon	VIC	Piggery	250 kW	Anaerobic lagoon	Manure wet waste	2008	http://frds.dairyaustralia.com.au/wp-content/uploads/2012/07/Bears-Lagoon-Piggery-covered-anaerobic-pond.pdf	Not in operation
Gippsland Greenhouse Produce	Yarragon	VIC	Tomato and eggplant glasshouse	2 MW	Wood chip boiler	Waste wood	2014	http://biomassproducer.com.au/project/gippsland-greenhouse-produce-uses-waste-wood-for-glasshouse-heating/#.W_NrAzgzbRY	
Hancock Victorian Plantations - Gelliondale Nursery	Gelliondale	VIC	Nursery/glasshouse	1.5 MW	Wood chip boiler	Wet sawdust	2010	http://biomassproducer.com.au/project/gelliondale-nursery-wet-sawdust-heats-greenhouses/#.W_OS8zgzbRY	
Kia-Ora Piggery	Yarrawalla	VIC	Piggery		Anaerobic Digestion	Manure wet waste		http://biomassproducer.com.au/project/kia-ora-piggery-poo-heats-and-powers-the-site-with-some-to-spare/#.W-6uXjgzbRY	Operating
Leslie Dairy	Euroa	VIC	Dairy		Anaerobic lagoon	Manure wet waste	2009	http://biomassproducer.com.au/project/lagoon-issues-at-leslie-dairy/#.W-66wzgzbRY	Proposed - did not proceed
Meredith Dairy	Meredith	VIC	Sheep and goat dairy	240 kW	Wood chip boiler	Wood waste	2017?	http://biomassproducer.com.au/project/meredith-dairy-heats-up-with-wood-waste/#.W_OYpzgzbRY	

Business Name	Location	State	Ag. Sector	Size	Technology	Waste type	Date of install	Source of data	Status
Murphy Fresh Hydroponics	Mansfield	VIC	Tomato glasshouse	6 MW	Wood chip boiler	Wood chips (2nds logs)	2013 & 2015	http://biomassproducer.com.au/project/murphy-fresh-grows-tomatoes-with-renewable-biomass/#.W-6uYzgzbRY http://www.murphyfresh.com.au/	
Murray Goulburn Cooperative	Leongatha	VIC	Dairy Processor	0.76 MW	Anaerobic digestion	Food and ag wet waste	2010	http://www.cleanenergycouncil.org.au/technologies/renewable-energy-map.html	Operating
Unigrain - Smeaton Mill	Smeaton	VIC	Grain processor	3 MW	Seed husk boiler	Grain/seed husks		https://vicbioenergy.com.au/projects/	
Trigg's Dairy & Gekko Systems/Gaia	Bungaree	VIC	Dairy/potatoes		Anaerobic Digestion	Cow manure		https://www.abc.net.au/news/2018-02-17/gekko-systems-use-poo-to-power-ballarat-dairy-farm/9455734	Operating, but not generating electricity yet
Van Wyk Flowers	Lyndhurst	VIC	Wholesale florist	2.95 MW	Wood chip boiler w/-storage	Waste wood	2018	http://enriva.com.au/projects/lyndhurst-vic/ https://biomass.polytechnik.com/wp-content/uploads/2018/08/Polytechnik_Australian_Forest_Timber_News_082018-pdf.jpg	
Yarragon Tomatoes	Yarragon	VIC	Tomato glasshouse	1.6 MW	Wood chip boiler	Forestry & milling waste	2014	https://www.goodfruitandvegetables.com.au/story/4038143/wood-warms-tomato-glasshouse/?cs=4928	
	Beaufort/ Skipton	VIC	Cropping - straw pellet producer		Straw-fired boiler	Straw pellets		Stage 2 interview – IE-07	
Western Australia									
Chandala Poultry	Gingin	WA	Poultry		Pyrolysis	Poultry waste/litter		http://biomassproducer.com.au/project/chandala-poultry-turns-chicken-litter-to-energy/#.W-6uSTgzbRY and http://www.energyfarmers.com.au/get-involved/bioenergy/chandala-poultry/	Operating
Energy Farmers Australia	Geraldton	WA	Cropping		Pyrolosis	Cropping residue		http://biomassproducer.com.au/project/grain-harvest-waste-potential-in-geraldton/#.W_JK_egzaUk http://www.energyfarmers.com.au/get-involved/bioenergy/mid-west-waste-to-energy/	Trial

Business Name	Location	State	Ag. Sector	Size	Technology	Waste type	Date of install	Source of data	Status
Fairbrossen Winery	Carmel	WA	Winery		Biogas (AD) generator	Grape marc		http://fairbrossen.com.au/sustainability	Trial
Fletcher International Abattoir	Narrikup	WA	Abattoir		Wood chip boiler	Wood chips (pine plantation)	2015	https://www.abc.net.au/news/rural/2015-12-09/western-australian-abattoir-moves-to-burning-woodchips/7013870 http://biomassproducer.com.au/project/plantation-waste-provides-the-steam-for-wa-abattoir/#.W_NFcjgzbRY	Operating
Macco Feeds Australia	Williams	WA	Cereal/Pellet mill	1.7 MW?	Wood chip boiler	Wood chips (plantation) & oil mallee	2013	http://biomassproducer.com.au/project/macao-feeds-makes-big-savings-after-switching-to-waste-wood-and-oil-mallee-wood-chips/#.W_M_IDgzbRY	Operating
Unigrain/ Morton Seed and Grain	Wagin	WA	Cereal Mill	600 kW	CHP	Oat husks/milling residue	2015	http://biomassproducer.com.au/project/turboden-turns-oat-husk-waste-into-heat-and-power-in-wa/#.W_JMX-gzaUk http://www.unigrain.com.au/	Operating
Trandos Hydroponics Growers	Neerabup	WA	Seedling grower	4 MW	Wood chip boiler	Woodchips (cabinet maker waste)	2011	http://enriva.com.au/wp-content/uploads/Carbon-Friendly-Aussie.pdf http://biomassproducer.com.au/case_study/heat-from-waste-wood-chips/#.W_NKKTgzbRY	Operating

9.6 Appendix F - Screenshot of Biomass Producer (RIRDC) website



9.7 Appendix G - Distribution of Stage 2 & 3 interview participants