

**Building critical mass of tree growers for bioenergy:  
The case of Central West New South Wales,  
Australia**

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## **Declaration**

I declare that this thesis is my own work and it has not been submitted in any form for any other degree or diploma at any university or other tertiary education institution. Any contribution made to this research by colleagues with whom I have worked at the Australian National University, the Commonwealth Scientific and Industrial Research Organisation, and the New Zealand Forest Research Institute Ltd. – Scion, during my candidature is fully acknowledged. Information based on the published or unpublished work of others has been acknowledged in the text and reference list of this thesis.



Sandra Judith Velarde Pajares



*To my beloved husband Pablo*



## Accepted work based on this thesis

After this PhD was submitted for examination, key results were presented at: (1) Advanced Biofuels Research Network symposium on 10 November 2016, Rotorua, New Zealand (Poster), (2) Australian Agricultural and Resource Economics Society (AARES) conference, Contributed paper session, 6-10 February, Brisbane, Australia, 2017.

AARES abstract: Lack of economic profitability is one of the main barriers to establish a new biofuel supply chain. However, once this barrier is addressed, policy, markets and the interests of different stakeholders will play an important role in the development of a supply chain and building critical mass. This research discusses potential pathways to build a critical mass of landholders to supply tree biomass to a hypothetical bio-ethanol plant in the Central West region in New South Wales, Australia. The proposed pathways integrate knowledge obtained through literature, a landholder survey, a biomass supply curve and break even analysis and discussions with other researchers and industry experts. These pathways outline how bioenergy production from biomass could emerge from the ‘valley of death’ to the market. These pathways are likely to be more effective if they are interlinked, though one may be more dominant. The interlinked pathways are: 1) Direct and indirect policies, 2) Bottom-up: Locally driven, and 3) Top-down: Corporate driven. The findings suggest that none of these pathways would work on their own but they need all actors to sit at the table combining their resources, capabilities, demonstration or pilot experiences from growers and trials on bioenergy plants. Given the large level of investment needed, it is argued that corporates may be the main actors with access to resources at all levels (federal and local governments, and local industry) and resources to invest in developing new bioenergy value chains.

Keywords: critical mass, bioenergy, adoption of innovation, new value chains, valley of death

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## Abstract

### **Building critical mass of tree growers for bioenergy: The case of Central West New South Wales, Australia**

The progression of the bioenergy industry needs to address concerns regarding the security of feedstock supply and the related environmental sustainability. Traditional first-generation biofuel feedstocks (e.g. maize, soybeans) are being questioned in favour of more environmentally-sound second-generation biofuel feedstocks (e.g. trees, perennial grasses). However, as an emerging industry, the commercial use of second-generation biofuel feedstock sources has several challenges to overcome. One of these challenges is landholders' willingness to plant second-generation crops on their farms. To understand the landholders' perspectives, this thesis used a conceptual framework based on adoption of innovation and diffusion theory, and applied this framework to a case study in the Central West region of New South Wales, Australia. The research questions addressed were:

- 1) what factors underlie landholders' willingness to plant bioenergy tree crops,
- 2) what are the landholders' preferences in the design of contracts for planting these trees, and
- 3) what are the potential pathways to build a critical mass of tree growers for bioenergy.

A mixed methods approach was used involving quantitative analytical tools (e.g. tobit and logit regressions, choice modelling, and break even analysis) and qualitative analytical tools (e.g. integrated analysis). Tobit and logit regression models estimates revealed three key traits that positively influence the decision to plant second-generation biofuel feedstocks: 1) the landholder's proportion of unproductive land, 2) the landholder's

membership in farming related organisations, and 3) the landholder's experience with planting blocks of trees.

Conversely, the landholder's older age-squared would negatively influence their decision to plant second-generation biofuel feedstocks. The choice model estimates revealed that landholders who had already planted blocks of trees would be less likely to need a flexible contract for planting trees as energy crops, while landholders with larger proportions of unproductive land would prefer higher returns. This thesis concludes that for a second-generation bioenergy industry to emerge, a critical mass of biomass growers needs to be secured; this can be achieved by developing interlinked pathways that include: 1) supportive policies, 2) local support and an innovation champion, and 3) corporate support and/or a potential biomass buyer or investor.

This research has identified critical pathways that can be developed to progress the bioenergy industry in Australia. The proposed pathways can be used to explore actors' participation and their potential roles in scaling up, and to better understand the process of building critical mass for a second-generation bioenergy industry.

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# Chapter 1

## Introduction

### 1.1 Background to the research problem

Biofuels are liquid and gaseous fuels produced from biomass which is organic matter derived from plants or animals (OECD/IEA 2011). Biofuels have the potential to play a larger role in the global bioeconomy and as a land use alternative (Berndes & Fritsche 2016; Dale et al. 2016; Lamers et al. 2016; Silveira & Johnson 2016). Globally, most biofuel production uses first-generation technologies, also referred to as conventional biofuel technologies. These include sugar- and starch-based ethanol, oil-crop based biodiesel and straight vegetable oil, as well as biogas derived through anaerobic digestion (OECD/IEA 2011). These technologies are well established and knowledge on their technical uncertainties and economic feasibility (i.e. techno-economics) is widely available (Tao & Aden 2009; OECD/IEA 2011). While these technologies run on a commercial scale, they have generated concerns about their environmental sustainability. For example, ethanol made from corn grain (using first-generation biofuel technologies), tends to emit more greenhouse gases (GHG) than ethanol made from lignocellulosic feedstocks<sup>1</sup> (using second-generation biofuel technologies) because of its higher requirements for fertilisers, pesticides, and increased soil disturbance, leading to land-use induced carbon emissions (Popp et al. 2014).

Second-generation biofuel technologies, also referred to as advanced biofuel technologies (OECD/IEA 2011), are being proposed as a means of reducing GHG, compared to fossil fuels and first-generation biofuel technologies, as well as being a source of energy security and regional development (Cambero

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<sup>1</sup> A feedstock is defined as ‘any renewable, biological material that can be used directly as a fuel, or converted to another form of fuel or energy product’ (U.S. Department of Energy 2013).

& Sowlati 2014; Sowlati 2016). Second-generation technologies include biochemical or thermochemical processes to convert lignocellulosic material and algae to biofuels. Second-generation technologies and biomass feedstocks are in the research, development and demonstration stage (Geoscience Australia & BREE 2014, p. 313). Potential feedstocks for second-generation biofuels production include agricultural residues, forest residues and bioenergy crops. Bioenergy crops are those crops dedicated to the production of energy. Second-generation bioenergy crops include perennial grasses (e.g. miscanthus and switchgrass) and woody crops (e.g. poplar, willow, and eucalyptus) used to produce lignocellulosic feedstocks, and bioenergy crops (e.g. jatropha, microalgae), used to produce biodiesel feedstocks (Carriquiry et al. 2011). Second-generation ethanol systems refers to second-generation technologies that produce ethanol.

Second-generation technologies face significant challenges in commercial deployment (Sims et al. 2010). Among these challenges are policy uncertainty (Bhutto et al. 2016), high production costs (Kelly 2016; Taha et al. 2016), and the availability and quality of feedstocks (Bhutto et al. 2016; Sowlati 2016). Even if policies are stable and biofuel production costs are reduced, providing a consistent supply of second-generation biomass feedstock remains a major challenge. This challenge comprises of planting, harvesting, treating, transporting, storing, and delivering competitively priced and sufficient biomass feedstock of a desired quality and in a desired timeframe (Sims et al. 2010; McEvelly et al. 2011).

Indeed, planting biomass feedstocks for bioenergy is a decision that the landholder needs to make, particularly in places where private individuals and not the state, own agricultural land. Therefore, understanding landholders' views on growing second-generation bioenergy crops is important to explore any future potential of such energy production system. In this regard, the concept of 'critical mass' is pivotal to understanding the diffusion of the innovation process of growing trees for bioenergy. Rogers (2003) postulates that critical mass happens when 'enough individuals in a system have adopted an innovation so that the innovation's further rate of adoption becomes self-

sustaining' (p. 343). In the context of this thesis, the innovation refers to the biofuel system, which requires a critical mass of actors (e.g. landholders, brokers, bioenergy developers), policy forces and market forces (see Section 1.3 Analytical framework). The focus of this study is critical mass of tree growers for bioenergy.

Despite its importance, the process of building critical mass for second-generation biofuels is an emerging topic in the literature. For example, only recently, Huenteler and Lee (2015) discussed the issue of critical mass for second-generation biofuel technologies in the context of the integration of biofuels into the existing vehicle and fuel infrastructure. In their analysis, farmers and retailers were identified as significant bottlenecks in the supply chain. Huenteler and Lee (2015) highlight the need for infrastructure investment along the supply chain by various actors who face different incentives. Similarly, Silveira and Johnson (2016) draw lessons on how biofuels can work, using socio-technical platforms for ethanol production in Brazil, and biomass for power and heating in Sweden. They note that policies and economic incentives are not sufficient to integrate new technologies into production systems and thus, stakeholder alliances are required.

Consequently, this research sets out to explore pathways for building critical mass of tree growers for regional bioenergy applications. The exploration of critical mass is done in four parts: 1) By assessing which landholder characteristics influence the adoption of or their willingness to grow trees for bioenergy; 2) By exploring landholders' preferences for attributes of contracts for tree planting for bioenergy; 3) By exploring an example of volume and cost for a second-generation bioethanol plant, in a case study where pilot tree bioenergy plantations and supportive policies existed (at the time of the study); and, 4) By exploring pathways to build critical mass of tree growers for a biofuel system, based on lessons from the case study and the literature on innovation diffusion, landholder adoption, bioenergy adoption, and Australian renewable energy policies and new wood plantings.

### 1.1.1 Overview of adoption and diffusion of innovation studies

In order to explore the issue of building critical mass of tree growers it is important to first understand what an innovation is and the process of adoption and diffusion of innovation. Rogers (2003) defines an innovation as ‘an idea, practice, or object that is perceived as new by an individual’ (p. 12). In his diffusion of innovations theory, he postulates that the adoption of innovation happens at the individual level, while the diffusion of innovation process requires communication over time among members of a social system about a new idea or product so that it is accepted by the market. This theory has been applied to most areas of knowledge and is extremely useful in understanding the adoption process which comprises (Rogers 1983, 2003; Pannell et al. 2006):

- Awareness about the innovation (knowledge stage)
- Evaluation through trial and non-trial (persuasion stage)
- The decision to adopt or not adopt or dis-adopt (decision and implementation stage), and
- The review and modification of the innovation (confirmation stage)

The adoption process will be further explained in Chapter 2.

More recently, Pannell et al. (2006) undertook an integrated review of the adoption of conservation practices. They found that landholder adoption is governed by ‘subjective perceptions or expectations rather than on objective truth’ (p.1408). This finding is relevant to this research because the production cost of second-generation bioenergy crops is recognised as a significant barrier to its commercial production in the medium term (Carriquiry et al. 2011). Consequently, following Pannell et al.’s (2006) findings, bioenergy adoption would need not only to appeal to landholders’ perception of economic bottom line goals but also to their perceptions on environmental and social aspirations. While the literature on adoption of traditional agricultural crops is abundant, and data is usually easy to obtain through local, regional or national statistics or standard mail surveys, the literature on adoption of bioenergy crops is relatively scarce in comparison. Studies that explore adoption of bioenergy crops in developed countries are even fewer and are mostly quantitative in nature (mainly using regression analysis) (Roos et al. 2000; Jensen et al. 2007;

Villamil et al. 2008; Rämö et al. 2009; Bocquého & Jacquet 2010; Paulrud & Laitila 2010; Joshi & Mehmood 2011; Clancy et al. 2011), with some exceptions that use qualitative methods, either exclusively or as part of a primarily quantitative study (e.g. Sherrington et al. 2008; Baumber et al. 2011; Convery et al. 2012). These studies will be explored in Chapter 3, Section 3.2.3.

The body of literature reviewed so far is important because it allows the distilling of specific influencing adoption factors for growing bioenergy crops (see Appendix 1). These factors can be grouped into four broader sets:

- Landholder's demographic characteristics (e.g. age, farming experience, education, education related to agriculture) and landholder's goals
- Landholder's awareness of bioenergy crops, economic expectations, risk, and opportunity cost of land
- Co-benefits of the bioenergy crops (e.g. recreation and landscape values) and non-market concerns (e.g. impacts on wildlife, visual impacts and nutrient balance of the soil), and
- Farm characteristics (location, size, farming activity and ownership).

These factors are explained in detail in Chapter 3, Section 3.2.3.

Studies that look at tree grower's views on new plantings are also relevant to this research because they identify landholder's concerns and positive perceptions about small-scale and large-scale forestry, which can be used, among others, for bioenergy production. In this regard, growing trees on farms is referred to as farm forestry<sup>2</sup>. Farm forestry involves commercial and/or non-commercial tree growing into farming systems that respond to landholders' objectives (Department of Agriculture, Fisheries and Forestry (DAFF) (DAFF 2005a, 2011). Landholders are at the centre of this definition, as their decisions are fundamental to undertaking any farm forestry initiative. Landholders'

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<sup>2</sup> In Australia, agroforestry and farm forestry are used interchangeably 'with respect to the establishment and/or management of trees on farm for productive purposes' (Nuberg et al. 2009, p. 1). Several definitions exist for agroforestry, e.g. Nair (2007), Lundgren (1982), World Agroforestry Centre (2008, p.1), and Somarriba (1992, p. 233), but the context of these definitions is developing countries.

reasons for starting farm forestry can be any one or a combination of the following: to produce wood for timber, to increase soil fertility, to decrease soil salinity, to use woody crops as wind breaks or as boundaries, to increase landscape beauty (DAFF 2005b), and/or to use woody crops as energy crops as explored in this thesis.

The adoption factors explored by the farm forestry literature in Australia are similar to those on bioenergy adoption cited earlier. The focus of most of these studies is however on tree growing for timber production (Race 1999, 2000, 2009; Race & Buchy 1999; Race & Curtis 2007; Schirmer 2007) and only a couple of studies have specifically addressed the adoption of growing trees for environmental services (Schirmer & Bull 2011, 2014). Therefore, the first gap identified in the literature is about the adoption of farm forestry for bioenergy in Australia.

### **1.1.2 Overview of bioenergy research in Australia**

Bioenergy assessments in Australia vary largely in scale and focus. At a national level for example, a seminal study by Farine et al. (2012) quantifies the biomass feedstock for bioenergy in Australia and related greenhouse gas mitigation. This study however does not cover economic aspects or regional estimations. Further, regional studies look at specific second-generation biofuel technologies, economics and the impacts of policies in addition to GHG assessment. For example, the assessment of lignocellulosic ethanol in Gippsland (Rodriguez et al. 2011c), small scale biomass fired electricity and lignocellulosic ethanol in the Green Triangle (Rodriguez et al. 2011a; Rodriguez et al. 2011b), and biomass for co-firing in the Central West New South Wales (Rodriguez et al. 2011c). The latter study explores bioenergy technologies suitable for regional Australia (Appendix 2) as explained next and generated softwood and hardwood biomass datasets and transport models that are used in this research (see Section 3.5.3 and Appendix 12 for further details).

A review of bioenergy production systems suitable for two regions in Australia points to fundamental differences in capital investment, scalability and level of maturity of the technologies among these systems (Rodriguez et al. 2011c).

Two promising technologies were identified for the Central West NSW and Gippsland region: Co-firing and biochemical conversion (bioconversion), respectively. Co-firing refers to the combustion of two or more materials at the same time to produce electricity, such as coal and wood pellets. Coal is the major source of electricity in Australia (Department of Industry, Innovation and Science 2016). The main advantage of co-firing is its low initial capital investment as (on the view of electricity generators) no infrastructure modifications are needed if up to 3 per cent of coal is replaced with wood pellets (McEvelly et al. 2011). Bioconversion produces ethanol and it is a scalable process, with moderately well-understood techno-economics but highly sensitive to cost of enzymes and feedstocks. These two technologies were selected as they suit the biomass and socio-economic conditions of the regions studied in Australia (Rodriguez et al. 2011c).

Other technologies assessed in the review by Rodriguez et al. (2011c) include:

- Combined Heat and Power (CHP) and gasification for electricity. Both technologies are scalable but the cost of electricity produced is high. To be economically viable, these technologies require demand of the heat produced. Both technologies are well-known in Europe, however, the warmer Australian climate may prevent its use for domestic heating while it may have industrial heating applications.
- Biomass-to-liquids (BTL) technologies produce a direct replacement for gasoline or diesel but require large scale implementation for Fischer-Tropsch system, probably not suitable for regional application and the technology was immature at the time of assessment.
- Pyrolysis, while promising scalable technology to produce liquid fuels, this technology was quite immature at the time of the study.

Other regional studies such as Bryan et al. (2010) and Bartle & Abadi (2010) argue for the economic potential of woody crops, specifically, oil mallee trees<sup>3</sup>

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<sup>3</sup> Oil mallee is the common name for *Eucalyptus polybractea* and *Eucalyptus kochii*.

in the Lower Murray region in South Australia and Western Australia, respectively. Mallee is a short multistemmed eucalyptus species harvested on a short cycle that regenerates through coppicing. While Bryan et al.'s (2010) study is primarily a spatial-economic modeling exercise, Bartle & Abadi's (2010) economic model is rooted in the experience of established mallee tree belts covering about 12,000 ha of Western Australia. This species was originally established about 20 years ago on broad acre farms to mitigate salinization. Bartle & Abadi (2010) investigated the use of woody crops as a complement to agricultural land use and found that this species has the potential to improve the economic and environmental outcomes of the whole agricultural system.

In contrast, Bryan et al. (2010) assessed the tradeoffs of replacing food crops with biomass for energy crops under climatic change and found that the extent of biomass production in economically viable areas expanded under climatic warming and drying. Both studies highlight the environmental benefits of woody bioenergy crops, including dryland salinization, carbon sequestration, and wind erosion. Both studies show positive economic impacts, either by integrating mallees into agricultural land (Bartle & Abadi 2010) or by replacing food crops with woody crops (Bryan et al. 2010). Other regional studies have investigated the supply and delivery costs of mallees (Abadi et al. 2012) and of pongamia trees (Abadi 2012) as part of a national report on opportunities for bioenergy in Australia (Stucley et al. 2012). Abadi et al. 2012 estimated that the delivered cost of biomass is likely to be in the range of AUD 53 to AUD 70 per green tonne (45% moisture), but this cost could be reduced to AUD 38 per green tonne if co-benefits were included. On the other hand, Abadi 2012 found that the delivered cost of pongamia oil was estimated to be between AUD 2.22 and AUD 0.64 per litre.

More recently, the focus of bioenergy assessments in Australia has been on scaling up and optimisation approaches. For instance, Murphy et al. (2015) developed a hypothetical scale up strategy of biomass production in the Fitzroy catchment in the state of Queensland, for which economic feasibility was later assessed by Hayward et al. (2015). Feedstocks included in this assessment

were native grasses, naturally regenerating woody vegetation (regrowth), and newly established plantings of short rotation trees. The lignocellulosic biocrude assessed in these studies would produce jet fuel, diesel and gasoline. Their main finding is that biomass-based jet fuel can contribute to supplying Australia's jet fuel needs in the future and the cost of biomass-based jet fuels is estimated between 0.70 and 1.90 AUD per litre, within the projected 2035 jet fuel price of 1.50 AUD per litre.

Moreover, Brinsmead et al. (2015a,b) developed national scale supply cost curves of production pathways for crop residues (stubble) for transport biofuels, electricity and aviation fuels. They focused on optimising scales and processes according to feedstock location and spatial concentration. Furthermore, Crawford et al. (2016) provided further quantification of feedstock distribution, location, spatial density and seasonal supply of biomass on an intermediate scale.

In addition to the bioenergy studies introduced above, the report 'Flight path to Sustainable Aviation - Sustainable Aviation Fuel Road Map' (CSIRO 2011) brought together industry, government and research bodies to assess the feasibility of producing sustainable jet fuels in Australia and New Zealand. Based on models developed by the CSIRO, they conclude that aviation fuels derived from biomass are a feasible option to meet the sustainability requirements of jet fuels in the future. However, there is a caveat in respect to the positive economic outlook of all of these studies. The international crude oil price plummeted in 2015, and consequently investment in the global biofuel industry halved from that of 2014<sup>4</sup> (OECD/IEA 2016b).

In addition to the low global oil price, major climate change policy shifts occurred during the period 2010-2014 in Australia, directly impacting the bioenergy industry. For example, the Emission Trading Scheme was put on hold in 2010, the carbon price became policy in July 2012 and was repealed by

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<sup>4</sup> On the other hand, global biofuel production kept rising in 2015 and is projected to keep rising towards 2025 under a 2 degree Celsius climate change scenario (OECD/IEA 2016b).

the Senate two years later. Although this research was designed during a period of more favourable policy framework, the key issues identified in the literature related to the development of biofuel crops such as land use complementarities, contribution to sustainability, and scaling up issues, remain valid. Furthermore, the challenge of establishing a local commercially viable supply chain – identified by the CSIRO (2011) – remains. In this respect, a recent government report has summarised the state of knowledge of the bioenergy sector in Australia (Rural Industries Research and Development Corporation 2014). This report highlights the need for private-public partnerships to catalyse bioenergy industry in regional Australia, based on straw and forest residues.

While these biomass assessments and industry studies are extremely valuable references for scoping bioenergy development in Australia from a biophysical and economic perspective, most of them lack inputs from landholders (i.e. potential biomass growers), who are arguably, the ultimate land use decision makers. The literature that focuses on landholders' perspectives on bioenergy in Australia is scarce, with very few exceptions such as Baumber et al. (2011) and McEvilly et al. (2011) who investigate growing natives for bioenergy in the Central Tablelands in New South Wales, and barriers to a potential co-firing supply chain in Queensland, respectively. Therefore, the second gap identified in the literature is the need for a better understanding of how to implement tree bioenergy cropping and how suggested recommendations in the literature can work and bring together different actors in a new tree bioenergy supply chain. Hence, the two knowledge gaps identified inform the research questions, introduced below.

## **1.2 Research questions and scope**

This thesis aims to answer the following overarching research question:

What are the potential pathways to build a critical mass of tree growers for bioenergy?

Understanding the decision-making process related to the adoption of tree planting does inform the design and development of a bioenergy supply chain. This research goes beyond current knowledge about the limitations of tree

planting incentives and conceptual policy solutions (Hoffmann & Weih 2005; Mola-Yudego & Pelkonen 2008) into a close to real case situation where a group of landholders are already planting tree bioenergy crops. The circumstances under which landholders would grow bioenergy tree crops in their farms, are explored. Three interlinked pathways are explored for building critical mass of landholders that plant trees for bioenergy. These pathways explain how tree planting for bioenergy passes from the ‘valley of death<sup>5</sup>’ to actual implementation (see Chapter 5).

In order to respond to the main research question posed above, the following supporting research questions need to be answered first:

- What factors underlie landholder's willingness to plant bioenergy tree crops?
- What are the landholders’ preferences in the design of contracts for planting these trees?

A landholder survey was used to answer the research questions above by investigating adoption factors and preferences for potential contracts to plant trees for bioenergy, assuming that there is currently a viable market for biomass from trees in place, that the potential buyer would take care of the establishment costs and harvesting costs, the landholder will have a say on the layout of trees that best suit their farming activities, and that one of their neighbours has signed a contract.

The scope of this thesis centres around the case study region of the Central West, New South Wales, Australia, as an exemplar for exploring regional bioenergy development pathways. The study was conducted between May 2010 and April 2014. The study uses primary data from participant observation during the same period, semi-structured interviews, a landholder survey conducted in October 2012, secondary biomass data and models from a 100 km radius area, from the town of Orange in Central West New South Wales and a

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<sup>5</sup> ‘Valley of death’ refers to a place where new technologies or ideas are ‘waiting’ to be used or uptaken (Ernst & Young 2010).

review of literature to build the bioenergy development pathways. Secondary data used in the biomass assessment was provided by the CSIRO (see Appendix 12 and Section 3.5.3). A reference 68 ML bioethanol plant requiring 210 kt biomass/annum is used as a hypothetical example of volume and cost estimations because:

- A biomass assessment (Rodriguez et al. 2011c) revealed that potential biomass volume at break even cost was insufficient for co-firing in the Central West region of New South Wales and that bioconversion to produce ethanol was worth exploring due to its potential scalability
- An emerging bioenergy market exists in the form of trial bioenergy plantings in the study region. These trials aim at supplying a co-firing plant from a local electricity provider. Also, there is awareness of biomass growing, interest in tree planting for bioenergy, high quality biomass data available, and data on economic activities
- Government support for bioenergy, specifically, the Mandatory Renewable Energy Target (MRET), the Carbon Farming Initiative (CFI) and a carbon price mechanism (in place from 1st July 2012 to 1st July 2014).

Out of the scope of this thesis are:

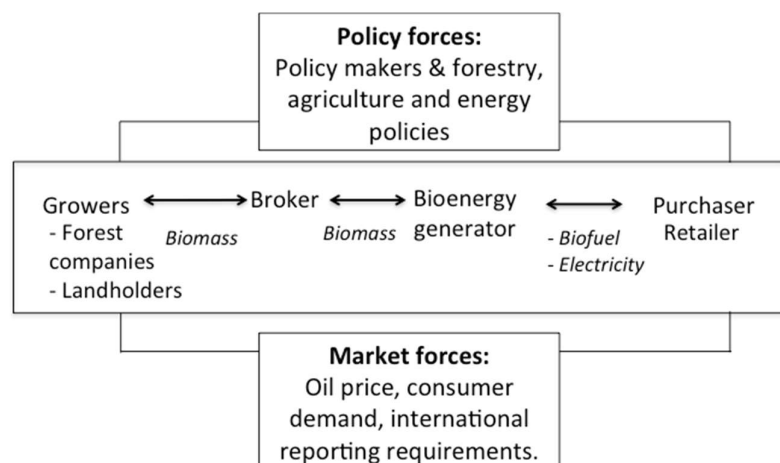
- A detailed farm level economic analysis of non-bioenergy agricultural land-use options in the study region. Instead, gross margins for these land-use options were obtained from the New South Wales Department of Primary Industries (see Chapter 3: Figure 8 and Figure 9)
- An assessment of different bioenergy production technologies. For the purpose of this study, only one technology was used but the methodology could be applied to explore other transformation technologies in the future
- Trade-offs between bioenergy tree crop production and water availability for food crops. Although this is recognised as a potential issue, special consideration was taken to focus on areas where rainfall is sufficient and the proposed systems would not affect crop yields dramatically.

### 1.3 Analytical framework

In order to answer the research questions, I draw on the following analytical framework. Integrating bioenergy knowledge presents several challenges. In the case of growing woody biomass for bioenergy, at least three sectors interact: forestry, agriculture, and energy. These sectors are heavily influenced by climate change policies. In the analytical framework used in this thesis, biomass and biofuels are two key products of interest across the bioenergy value chain (Figure 1). The framework identifies key actors and their roles as well as major policy and market forces.

There is no universal definition of biomass in the bioenergy literature. The two most common and non-exclusive definitions refer to biomass as: (a) the weight of living organisms, including plants and animals; and (b) organic matter, used as fuel. In many cases, the term biomass refers only to plant material. Biomass is one of the primary sources of solar renewable energy, as it includes materials directly or indirectly derived from photosynthesis. The temporal dimension of this definition is important to distinguish it from fossil fuels. Biomass can be obtained from agricultural energy crops, crop residues, wood, and wood residues; agro-industrial and animal by-products (van Loo & Koppejan 2008). In this thesis, biomass refers to plant agricultural products and sub-products, which, when used to make bioenergy, are referred to as feedstocks (e.g. chaff, stubble). Biofuel is fuel produced directly or indirectly from biomass (Food and Agriculture Organization of the United Nations 2004).

**Figure 1 Analytical framework for integrating bioenergy knowledge**



Biomass growers (on the left side of Figure 1) can be forest companies or landholders themselves. Compared to the number of landholders who could grow bioenergy crops, forest companies are only a few and are usually large organisations with different management, markets and products. Landholders have different objectives, size, and risk profiles, and vary from business orientated towards more lifestyle farmers, small to large industrial farmers, and from risk takers to risk avoiders. Landholders can also choose to participate in a biomass-growing scheme individually or as part of a group, and can decide to plant different proportions of their farms with biomass. Regardless of their type (company or landholder) and size, growers may need a broker or intermediary to connect them to the bioenergy generator (Roos et al. 2009). Brokers usually work based on a commission of the sold product, in this case, biomass. Bioenergy generators require quality biomass delivered to them at competitive prices in large volumes, and within an agreed timeframe (McEvelly et al. 2011). Generators produce biofuels from biomass and sell this to the purchaser or retailer.

The analytical framework illustrates that external policies and market forces influence the identified actors. External policies include forestry, agriculture and energy policies, renewable energy targets, and climate change policies such as carbon pricing. The main market force influencing the bioenergy value chain, presented in Figure 1, is the international oil price, as discussed in

Section 1.1.2. Other relevant market forces include consumer demand and increasingly, international reporting requirements.

In any new market, growing biomass may represent a risk to both the bioenergy generator and the grower. The generator cannot commit capital investments to modify its current energy generation processes or to build new dedicated bioenergy plants if there is no secured supply of biomass from growers. Growers, on the other hand, cannot commit to produce biomass if they have not secured demand for their biomass at an agreed price (Styles et al. 2008). Therefore, the amount and type of risk taken by the generators and growers depends on the market in place. Markets need to be designed in order to match potential demand with potential supply (Roth 2002) and therefore different growing arrangements, through outgrowing contracts (Alexander et al. 2012), joint ventures or other modes of economic organisation (Williamson 1990) can be put in place.

In a review of contract theory, Alexander et al. (2012) studied principles to inform the design of contracts for perennial bioenergy crops. These principles address risk, incentives, conflicts, and screening and contractual credibility. The initial terms of the contract need to be strong enough so they do not seem re-negotiable, otherwise they undermine the credibility of the original contract. The contracts should also have an optimal design but not be too complex to make them undesirable.

## **1.4 Outline of the thesis**

This thesis is composed of seven chapters structured as follows:

Chapter 1 introduces the research background, the research questions and scope and the analytical framework.

Chapter 2 introduces the theoretical framework, which includes adoption of innovation and diffusion theory, behavioural decision theory, and utility theory. It then summarises empirical approaches related to the adoption of bioenergy

crops, with a focus on developed countries, and explains the renewable energy policy context in Australia. A critical mass framework for understanding landholder's adoption of innovation is explained and proposed in this chapter as the basis for this research.

Chapter 3 introduces the research paradigm and hypothesis investigated, provides an overview of the case study region, the Central West, New South Wales, and the research tools and procedures for data gathering and methods for data analysis. The thesis uses a mixed methods approach with qualitative and quantitative components.

To investigate the research question about factors influencing the adoption of trees as bioenergy crops, the methods used were participant observation, face-to-face interviews and a face-to-face landholder survey questionnaire. To investigate preferences about attributes of contracts for tree planting, a choice experiment, as part of the landholder survey, was used. The overarching question about building critical mass was answered using information across the bio-physical, socio-economic, technological and policy spectrums, specifically using a biomass supply curve, break even and integrated analysis methods described in this chapter.

Chapter 4 presents the results of the potential adoption of trees as bioenergy crops as well as landholder's preferences for contract attributes (length, return, flexibility). The first part of this chapter explores factors influencing potential adoption. The second part explores the results of the application of a choice experiment to understand the trade-offs between landholder attributes and contract attributes. This chapter presents the results of the econometric models (logit and tobit regressions) and choice models.

Chapter 5 puts forward the 'critical mass' issue and explores pathways for building a critical mass of biomass growers. First, a biomass assessment is introduced that builds largely on the work of Rodriguez et al. (2011c). This assessment estimates the potential supply of woody biomass (softwood and hardwood) in the study region and explores different scenarios, given different ethanol excise policy scenarios. Break even analysis is used to assess how

biomass production cost compares with different oil price scenarios. Pathways to build a critical mass of tree growers are proposed using the combined results of the landholder survey, the biomass supply curves, the break even analysis and the integrated analysis.

Chapter 6 discusses the theoretical framework developed in Chapter 2, the results on the adoption factors and the preferred contract attributes to plant feedstocks for bioenergy (Chapter 4), and three potential pathways to develop a critical mass of landholders, growing trees as bioenergy crops (Chapter 5).

Chapter 7 presents the conclusions of this thesis, presenting its key findings and the contribution of this thesis as well as areas of future research.

## Chapter 2

# Theoretical and empirical approaches to the study of the adoption of bioenergy and tree crops

### 2.1 Introduction

Tree crops have the potential to complement and improve both the economic and environmental performance of intensive agricultural systems in drylands (Bartle & Abadi 2010). In order to fully realize this potential, a certain number of bioenergy tree crop growers are needed to build a biomass supply chain, as explained in Chapter 1.

If demand for tree crop biomass is secured, then achieving a critical mass of suppliers relies mainly on the farmers' decisions either to adopt or to not adopt a woody crop. Understanding the factors that underlie farmers' decisions can help to answer the overarching research question presented in Chapter 1: What are the potential pathways to build a critical mass of tree growers for bioenergy?

Landholders decide whether or not to grow tree crops on their farms through farm forestry or agroforestry. Hence, in order to conceptualise landholders' decision-making processes, this chapter reviews decision theory, with a focus on key elements of neo-classical economics and behavioural decision theory. These theories identify decision-making factors that are relevant to the adoption of innovation and diffusion processes of existing products or value chains. This chapter also reviews empirical cases of the adoption of second-generation bioenergy crops.

A conceptual framework that builds on the theoretical underpinning and empirical cases of adoption of bioenergy is also developed. This chapter concludes with questions related to the adoption factors that are subsequently explored in this thesis.

## 2.2 Overview of relevant theories and cross-cutting issues

### 2.2.1 Neo-classical economics paradigm

Under the neo-classical economics paradigm, individuals act rationally, maximise their utility and act on the basis of full information, whereas firms maximise their profits (Weintraub 2001; Dequech 2007). Neo-classical economics is the dominant paradigm in the economics field. Weintraub (2001) argues that its 'success' is connected to the mathematical formalisation of economics in the late nineteenth century and early twentieth century, mainly the work of William Stanley Jevons (1888), Leon Walras (1954), Carl Menger (1976), F.Y. Edgeworth (1881), and Irving Fisher (1930).

The neo-classical paradigm uses rational choice theory. This theory assumes that individuals are motivated by goals that are expressed in their preferences. Individuals act on the basis of information on the anticipated outcomes of their decisions given specific constraints, by choosing alternatives that provide them with the highest satisfaction (Scott 2000). Rational choice provides a basis for the theory of subjective expected utility (SEU). SEU theory 'defines the conditions of perfect utility-maximizing rationality in a world of certainty or in a world in which the probability distributions of all relevant variables can be provided by the decision makers' (Simon et al. 1987, p.12).

While rational theory is the basis of many farming decision-making models (Edwards-Jones 2006), SEU and rational choice theory are incompatible with the limitations of human cognitive and computational capacity (Arrow 1986). Despite these incompatibilities, a widely used economic assessment tool based on rational choice theory, cost benefit analysis (CBA), helps to translate rational theory into practice by computing the most relevant costs and benefits of different decisions. Moreover, policy makers regard CBA as highly relevant to decision-making (Ryan 2011). At the heart of CBA is a utilitarian principle where decision makers' objectives are based on expectations of higher-than-current levels of monetary profit, pleasure, happiness, or welfare (Spash 1993).

The concepts of rational choice, SEU, and CBA can help us understand individual decision-making processes from a neo-classical perspective, i.e. landholders would prefer a land use that would maximise their profits. However, decision-making is a complex process that goes beyond profit maximisation. This complexity is specifically recognized in the farming decision-making literature, where socio-economic and psychological variables influence farmers' behaviours (Willock et al. 1999; Gent et al. 2011; Graham 2011). To address the complexity of decision making, behavioural decision theory can help to better explain the psychological aspects that influence behaviour.

### **2.2.2 Behavioural decision theory**

Behavioural decision theory (BDT) has spurred new understandings of human decision-making processes. BDT has contributed to the relatively new field of behavioural economics as it provides a different framework to that provided by SEU. Although the large majority of decision-making studies use the neo-classical paradigm, some behavioural economics principles are embedded in these, mainly, risk aversion (Pannell et al. 2000; Marra et al. 2003; Gent et al. 2011) and trust (Doney & Cannon 1997; Osterberg & Nilsson 2009). It is argued however, that the concept of risk aversion is not enough to understand farmers' decision-making processes. Therefore, social and psychological factors such as farmers' perceptions have to be considered in agricultural adoption studies (Willock et al. 1999). Three BDT principles can be applied in the study of farmers' decision making: a) psychological anomalies; b) heuristics and bounded reality; and c) social preferences and norms.

#### **a) Psychological anomalies**

Risk and loss aversion, status quo bias, hyperbolic discounting and anchoring and adjustment are known as psychological anomalies. Risk aversion has been widely researched within the agricultural adoption studies. For example, Ghadim et al. (2005) and Marra et al. (2003) note the importance of trialing to learn about risk and consequently, reduce uncertainty. Gent et al. (2011) argue for the incorporation of subjective probabilities to reduce uncertainty. Seminal work by Guerin and Guerin (1994) identified several constraints in the

adoption of innovation by Australian farmers including farmer's attitudes towards risk and change. Although farmers are known for their risk-averse character, the degree of aversion varies depending on individuals, context and the amount of money at stake (Reeson & Dunstall 2009).

A related psychological anomaly to risk aversion is loss aversion, where people tend to value losses more than gains (Kahneman et al. 1991, cited in Etzioni 2011). Loss aversion is influenced by intentions, and intentions determine whether giving up that good is evaluated as a loss or a foregone gain (Novemsky & Kahneman 2005, p. 127). Emotional attachment and cognitive perspectives influence loss aversion. The more emotionally attached we are to something, the more difficult it is to part with it (Ariely et al. 2005). Cognitive perspective explains why items typically viewed as a loss are given more or less weight (Ariely et al. 2005). In the farming environment, when introducing a new practice, landholders may be more concerned about their losses if they stop their traditional practices, rather than being interested in the potential gains arising from new practices.

Status quo bias refers to 'a strong tendency to remain at the status quo, because the disadvantages of leaving it loom larger than the advantages' (Kahneman et al. 1991, cited in Etzioni 2011, p. 1101). A combination of loss aversion and status quo bias may imply that, when a decision is perceived as too complex, inertia rules (Reeson & Dunstall 2009). People prefer to do nothing even if doing something may provide benefits for them. Inertia may also be a consequence of risk aversion. A related issue, the endowment effect, implies that people tend to value things they already hold more than they value equivalent things they do not have (Thaler 1980, cited in Reeson & Dunstall 2009). This effect is reflected in discrepancies between buying and selling prices (Novemsky & Kahneman 2005). The combination of loss aversion and the endowment effect explains status quo bias (Samuelson & Zeckhauser 1988, cited in Reeson & Dunstall 2009).

Another psychological anomaly is hyperbolic discounting, which is shown when present gains are preferred to future gains or interests, even if the future gains are significantly higher than the present ones. Hyperbolic discounting

deals with issues of self-control and procrastination, and can explain why humans put off exercising or saving money (Reeson & Dunstall 2009). This anomaly clearly presents a challenge for long-term investments, such as those related to farm forestry plantations.

Anchoring and adjustment are important issues when prospecting different innovation options with farmers. These issues refer to how the perception of an initial value, even if unrelated to the matter at hand, affects the final responses of participants (Tversky & Kahneman 1974, cited in Etzioni 2011, p. 1100). Prospecting new farming practices usually involves the use of surveys. In these surveys, the order of different options and values shown may have an effect on farmers' responses because of the anchoring and adjustment anomaly. Therefore, the use of pilot surveys would help refine the survey questions that may present anchoring and adjustment problems.

#### **b) Heuristics and bounded rationality**

Heuristics are 'rules of thumb' that people use in decision making. Farmers use heuristics that are dynamic, that is, they change as they learn different characteristics of the innovation. While heuristics may help in dealing with complex information, they also establish cognitive constraints to any decision-making process. These constraints are called bounded rationality (Simon 1979). The concept of bounded rationality has been fundamental for behaviour decision research (Einhorn & Hogarth 1981, p.54). Reise et al. (2012) define farmers' bounded reality as: 'Farmers make suboptimal decisions due to incomplete information and limited cognitive abilities in processing information' (p. 133). Landholders may have developed their own heuristics about tree planting, and some of them may see trees as environmental assets only, e.g. useful for watershed protection, rather than as crops. Many of the reasons behind decision making are related to humans being part of a society and culture, having certain social preferences and norms, as explained below.

#### **c) Social preferences and norms**

Two social preferences and norms relevant in the farming context are conditional cooperation and reciprocity. Cooperation can be self-rewarding but is subject to specific conditions (Suzuki et al. 2010; Stanca 2011). For

example, Chaudhuri (2011) argues that cooperation for a public good happens if others do the same and contribute to the public good. On the other hand, Reeson and Tisdell (2010) note that cooperation may not happen and people may act more in their self-interest if market-like conditions are introduced for public goods.

Closely related to cooperation is reciprocity. For example, while we tend to cooperate with someone who has acted positively towards us, we also tend to act negatively and punish those who have not (Fehr & Gächter 2002). In this vein, cooperation is possible if there is room for 'altruistic punishment' (Fehr & Gächter 2002) because humans are 'strong reciprocators' (Tricomi et al. 2010; Buckholtz & Marois 2012). Altruistic punishment means that individuals punish, although the punishment is costly for them and yields no material gain (Fehr & Gächter 2002). Reciprocity is important in building trust in individuals and organisations. Landholders' past experiences, or those of their peers, may influence who they trust and therefore, with whom they cooperate. Trust is pivotal to cooperation and will be discussed in Section 2.2.4 Landholder adoption.

### **2.2.3 Innovation diffusion theory**

Innovation is defined as 'an idea, practice or object that is perceived as new by an individual or other unit of adoption' (Rogers 2003, p.43). In this definition, the objective novelty of the innovation is of little importance. Rather, the perception of novelty is what matters (Straub 2009). Rogers' innovation diffusion theory (Rogers 1962) was built across practices perceived as novel, across a wide range of fields, including sociology, education, psychology, geography, agriculture, medicine, and health.

Rogers' innovation diffusion theory emphasises the importance of relative advantage as crucial to the adoption of innovation (Pannell et al. 2006; Rogers 2003). Rogers (2003) argues that compatibility, complexity, trialability, and observability, are also necessary for the adoption of an innovation. According to his model, the more these characteristics are present as part of an innovation, the more likely the innovation is to be adopted.

Relative advantage refers to how the scheme compares with current farm based activities in terms of its benefits, i.e. the perceived net benefits of the innovation are positive (Pannell et al. 2006). Compatibility refers to the innovation being a good fit with current activities and/or values. Pannell et al. (2006) explain that in a farming context, this means how well the new activity or practice can be integrated with current practices. Complexity is how difficult it is to uptake the innovation, whether it would require extensive training, new knowledge or a change in farming management practices (Pannell et al. 2006). Trialability is the capacity to implement the activity at a pilot level. As mentioned earlier, trialing reduces the perception of risk (Marra et al. 2003; Ghadim et al. 2005). Lastly, observability refers to trials of pilot experiences being able to be seen by landholders in real life. Lindner (1987, p.150) stresses the importance of technology design in the innovation diffusion process: ‘technology design rather than technology transfer should be the primary consideration because, if the former is successful, the latter will by and large follow automatically’.

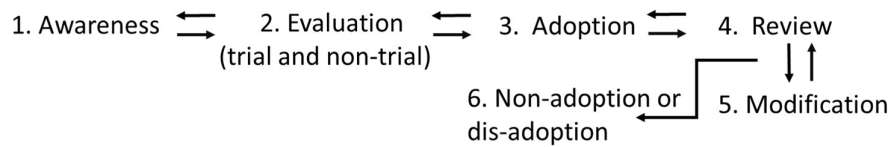
#### **2.2.4 Landholder adoption**

Adoption theory refers to ‘the individual and the choice an individual makes to accept or reject a particular innovation’ (Straub 2009, p. 626). While adoption theory looks at the individual factors that make up change, diffusion theory looks at ‘how an innovation spreads through a population’ across time (Straub 2009).

Pannell et al. (2006) built upon and expanded Rogers’ (1983) model of stages in the innovation decision process, which he depicted as linear. In contrast, Pannell et al. (2006) referred to adoption as a dynamic learning process with six phases (Figure 2). The main difference between Pannell et al. (2006) and Roger’s (1983) framework is the loop to dis-adoption introduced by Pannell et al. (2006). That is, even after decision-makers have adopted a practice or technology, they may change their mind and dis-adopt the innovation. Rogers’ confirmation stage is equivalent to the review and modification phase of Pannell et al. (2006). These six phases: awareness, evaluation, adoption, review, modification, and non-adoption or dis-adoption, emerged from a key

cross-disciplinary study (including economics, rural sociology, and psychology) of Western literature on adoption of land management conservation practices. It is worth noting that Rogers' persuasion phase may relate to both awareness and non-trial evaluation in Pannell et al.'s (2006) phases. Pannell et al. (2006) also indicated that any adoption activity will be related to, and will support, landholders' specific goals, which are economic, and also social and environmental.

**Figure 2 Six adoption phases**



**Source:** Elaborated based on Pannell et al. (2006) adoption phases.

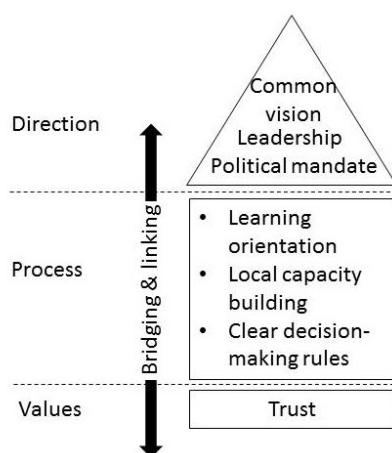
Other social factors influence the adoption decision. Within agricultural economics, these factors include: level of agricultural extension, information flows, local culture, social capital, attitudes of trusted friends, the policy environment, and the structure and impact of a range of institutions (Edwards-Jones 2006). More recently, Kuehne et al. (2011) built the “Adoption and Diffusion Outcome Prediction Tool” that helps the exploration of adoption factors that do not have high data demands. This tool is based on the exhaustive list of adoption factors identified by Pannell et al. (2006). The tool explores information networks, the family succession and management horizon, risk aversion, and the environmental costs and benefits among the non-financial factors influencing adoption. The issue of trust however, was not included in this tool because of the difficulties in obtaining reliable and comparable indicator data (Llewellyn 2012). Nonetheless, trust is argued to be of central importance for achieving cooperation (Ostrom 2010, cited in Graham 2014, p. 87), and as a key factor in the development of successful collaboration networks (Head 2008). Collaboration, trust and social capital are key influencing attributes of adoption as explained next.

**a) Collaboration**

Head (2008) describes collaboration as a robust longer-term multi-stakeholder commitment. In the case of bioenergy development, collaboration is required

among the different actors defined in the analytical framework in Chapter 1, e.g. landholder, broker, bioenergy generator, and different levels of policy makers. Whether landholders choose to adopt an innovation (e.g. a bioenergy programme) individually or collectively, specific processes and relationships would be critical for the success of such an endeavour. These processes and relationships are called success factors of collaboration. There are three types of success factors: direction, process and value factors (Figure 3).

**Figure 3 Success factors of a collaboration network**



**Source:** Velarde elaborated based on work from Head (2008).

The direction factors include sharing a common vision or aligning the perspectives of members and leadership that can lead to innovation. In addition, if the public sector is involved, it has to elicit a strong political mandate to find acceptable solutions to complex problems. Leadership is a key factor that would allow a collaboration network to succeed. In a bioenergy context, leadership can take many forms, for example, local champions to build networks and guide supply chain co-ordination (McCormick & Kåberger 2007, p. 451). Among the process factors are building of local capacity, having a learning orientation, and establishing clear rules for decision making and discussion. Trust is recognised as an ‘earned’ value developed through building relationships and linking across these different factors (Head 2008, p. 740). Therefore, trust is a fundamental value in a collaboration network. The skills for bridging and linking different sectoral stakeholder groups are cross-cutting

factors because they can only be developed with an understanding of all the factors that support the success of collaboration.

A gap in this successful collaboration network model is the dynamic and diverse nature of collaboration, which is not addressed by the factors mentioned above. Despite having a common vision, collaboration network members may need different incentives to keep them interested and committed throughout the time of a program or project. The incentives may vary in time as members and society interests vary.

#### **b) Trust & social capital**

Trust is the value upon which collaboration is built. Trust and networks are dimensions of social capital (Putnam et al. 1993). Social capital has been increasingly recognised as a factor of adoption of new practices by landholders (Schirmer & Bull 2014). It refers to the interconnectedness between individuals in society where relationships are a type of asset (Knowler & Bradshaw 2007, p. 37). It also facilitates collective action (Putnam et al. 1993, cited in Lochner et al. 1999, p.260) needed to build critical mass.

From a value chain perspective, trust is critical in a buyer-supplier relationship. Trust outcomes are stronger bonds and loyalty between buyers and suppliers, however, building trust is recognised as an expensive, time-consuming and complex process (Doney & Cannon 1997). Trust is based on the expectation of reciprocity and when the expectations are met, long term obligations develop (Pretty 2003, cited in Graham 2014, p. 87). Trust can be built or rebuilt if needed. For example, Leach et al. (2002) affirm: 'It takes time (typically 4 to 6 years) to educate participants, overcome distrust, reach agreements, secure funding, and begin implementation' (p. 666). Luhmann (1979) and Bigley and Pearce (1998) argue that two conditions are needed for trust to occur, uncertainty and vulnerability. Any new value chain will inherently be uncertain, and participants in a new value chain may feel vulnerable, as they would depend on each other to fulfil their expectations.

Moreover, at least two types of trust can be observed; interpersonal trust and trust in organisations. Interpersonal trust refers to trust between members of a

group. For example, within a cooperative context, trust is essential, both among members and members' trust in their leaders (James & Sykuta 2005, 2006 cited in Osterberg & Nilsson 2009, p. 187). Trust in organisations has been studied widely in the natural resources management literature. Sharp et al. (2013) discuss trust in depth, and Emtage and Herbohn (2012) recognise the critical role of trust in promoting new land management practices between government agencies and landholders.

Trust and activity in associations are commonly used as indicators of social capital (Beugelsdijk & van Schaik 2005) together with the density of membership in voluntary associations of all kinds, the extent of interpersonal trust between citizens, and their perceptions of the availability of mutual aid (Putnam et al. 1993). Memberships in associations are believed to create interpersonal trust that can allow various forms of social interaction and cooperation (Stolle & Rochon 1998). Further, the type of association will determine its capacity to create social capital (Stolle & Rochon 1998). Being connected to an agency or local networks of farmers or watershed groups, together with farmer access to and quality of information and financial capacity, are key factors in the adoption of best management farming practices (Baumgart-Getz et al. 2012). Moreover, trust is an important adoption factor because it improves coordination between supply chain partners, which in turn improves information flow (Kumar et al. 2015). Trust depends on relationship building over time. For a new industry, building trust in an uncertain environment is required. Formal agreements could overcome the lack of trust. Moreover, optimal contracts are needed to secure the supply of biomass feedstock in a new supply chain (Alexander et al. 2012).

In Australia, the land management and farming survey (Australian Bureau of Statistics 2011) reports some key indicators that can serve as proxies for measuring trust in organisations, including: sources of information or advice, membership of a Landcare group, and if the farmer participates in a specific project or receives funding. Furthermore, Landcare membership has been used as an indicator of social capital in the state of New South Wales (Brown et al. 2010). Trust plays an important role in determining how landholders will

respond to public policies and programs designed to improve natural resource management, particularly their appraisal of information sources.

Within the context of this thesis, trust has two interlinked dimensions, trust among actors in the biofuel system and trust in the biofuel innovation itself. The first dimension includes landholders who trust each other and trust the organisations in which they are members to provide them with information related to their farming practices. The second dimension refers to the legitimacy of the innovation. Legitimacy is ‘a generalised perception of assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs and definitions’ (Suchman 1995, p. 574). In this regard, a legitimate biofuel innovation makes sense to the actors involved, is perceived as feasible and credible. Hence, legitimacy is clearly linked to adoption factors such as relative advantage compatibility, complexity, trialability, and observability of the innovation (Rogers 2003; Pannell et al. 2006) (see Section 2.2.3 and 2.4.4).

### **2.2.5 Random utility theory**

This thesis uses choice models to elicit landholders’ preferences for attributes of contracts to plant trees as bioenergy crops. Choice model theory is based on Lancaster’s theory (Lancaster 1966) and random utility theory (Thurstone 1927). Lancaster’s theory states that the utility of a good is defined by its characteristics or attributes rather than the good itself. In this study, the ‘good’ in question refers to a contract for planting trees as bioenergy crops. The contract attributes explored are length of contract, annual returns, and flexibility to choose the harvesting company.

Random utility theory (RUT), proposed by Thurstone (1927) and further developed by Luce (1959) and Marschak (1960), states that the probability of an individual choosing a good depends on the utility this individual derives from the chosen good, relative to the utility of the alternative good. The RUT proposes a model with two components, the observed component (deterministic value) and the unobserved component, which is randomly distributed. More formally:

$$U_{ijk} = V_{ijk} + \varepsilon_{ijk} \quad (1)$$

In this model,  $V_{ijk}$  is the observable component of the utility that an individual  $i$  derives from alternative  $j$  in a choice situation  $k$ . The observed component of utility ( $V_{ijk}$ ) is a linear, additive function of the good attributes of the  $j$  different alternatives in the choice set (Hanley et al. 2001).  $\varepsilon_{ijk}$  is the unobserved component of the utility that decision maker  $i$  derives from alternative  $j$ . This unobserved component is called the random error term.

Following the neo-classical economics paradigm, since people are utility maximisers, the probability ( $P$ ) of an individual choosing alternative  $j$  can be expressed as the probability that the utility of alternative  $j$  exceeds the utility of all other alternatives  $q$ :

$$P_{ijk} = P [U_{ij} > U_{iq} \quad \forall q \neq j] \quad (2)$$

Replacing (1) in (2), we obtain:

$$P_{ijk} = P [(V_{ijk} + \varepsilon_{ijk}) > (V_{iqk} + \varepsilon_{iqk})] \quad (3)$$

Random utility theory implies that landholders make decisions based on the different attributes of the options presented, making trade-offs between specific attributes. The specific attributes investigated in this thesis will be detailed in Chapter 3 and the direct application of this theory in Chapter 4, when exploring landholders' preferences.

Innovation diffusion, adoption of innovation, and random utility theory provide the theoretical framework to explore landholders' adoption of bioenergy tree crops. The next sections introduce the empirical literature related to the adoption of bioenergy, including the internal and external adoption factors, incentives and business models.

### 2.2.6 Cross-cutting issues: Trade-offs, complexity and uncertainty

How do the behavioural principles explained earlier translate to the farming context? Trade-offs, complexity and uncertainty affect farming decision making. If farming goals are in conflict with each other, trade-offs are likely to occur. These trade-offs reflect farmers' values and influence farmers' choices.

These choices are typically based on multiple goals or criteria. These goals could be in conflict, if time is considered; for example, trade-offs may occur between short-term and long-term goals (Einhorn & Hogarth 1981) and so ‘bounded rationality’ may change with time as well.

When farmers perceive a decision as being too complex, they tend to apply rules of thumb (heuristics) and to meet their goals with an option, which is good enough, instead of optimising. The consumer behaviour literature recognizes these ‘good enough’ factors as ‘stopping criteria’ in a sequential choice. This means that these factors influence a decision-maker to stop acquiring additional information and actually make a decision (Saad & Russo 1996). On the other hand, choice overload and status quo bias may lead to inertia. Current farmers’ behaviour also provides a default point of departure for decision making. For example, if farmers have already diversified their production, the default may be to further diversify and to explore new farming alternatives, whereas farmers who have never diversified may delay the uptake of new practices.

Uncertainty is also a key issue inherent in decision making (Choi 1993), and has been well-studied in the fields of psychology and behavioural economics (Smithson 2013). While any innovation requires tolerating some uncertainty and risk (Bammer 2013), uncertainty will impact the performance of bioenergy supply chains (Awudu & Zhang 2012). Therefore, when faced with uncertainty, decision-makers in the bioenergy context can choose to either neglect uncertainty that actually exists, treat it as a conventional risk and apply risk-management procedures, or apply a precautionary approach (Di Lucia et al. 2012). These strategies are similar to those studied by Lipshitz and Strauss (1997) who recognised three broad strategies of coping with uncertainty: reducing uncertainty, acknowledging uncertainty, and suppressing uncertainty.

If the chosen approach is to treat uncertainty as a conventional risk, tools can help incorporate uncertainty in decision making. These tools include future scenarios, Bayesian belief networks, and others that reveal causal relationships between the variables (Lynam et al. 2007). Future scenarios have been explored as a suitable approach for the bioenergy and forest supply chains

(Awudu & Zhang 2012; Shabani et al. 2013). Shabani et al. (2013) reviewed mathematical models to deal with uncertainty in a value chain optimisation of forest biomass for bioenergy. They found that major uncertainties in the biofuel supply chain include uncertainties about raw materials, transportation and logistics, production and operation, demand and price (Awudu & Zhang 2012), high volatility of oil prices and technological uncertainties (CSIRO 2011).

Trade-offs and complexity issues and their related behavioural factors have been investigated widely in studies about willingness to pay for environmental services (Loomis et al. 2000; Christie et al. 2006; Naidoo & Ricketts 2006) and about the adoption of environmentally friendly practices such as organic farming (Padel 2001; Best 2009; Kaufmann et al. 2009; Naoufel 2011). In these studies, there is a tendency to investigate values, attitudes, and ethics related to feel-good factors. To a lesser extent, behavioural factors have been studied directly in relation to farming decision making (Wossink et al. 1997; Willock et al. 1999). These behavioural factors have not been explored yet in hypothetical markets of a latent product.

In this thesis, planting trees for energy purposes can be described as a 'latent product'. A latent product is built from features that do not currently exist in the product offerings but will be desired in future product launches (Tuarob & Tucker 2015). In this thesis, the latent product refers to bioenergy tree crops. Despite the existence of the end-product in the market (e.g. ethanol), the raw material to produce it (i.e. timber) has not been traditionally planted in the area, and ideal conditions need to be present in order to satisfy landholders' goals. This latent product has two potential outcomes: to provide profits through the sale of wood and to provide environmental services, such as a reduction of GHG emissions. Hence, this latent product has both private and public good aspects. Depending on the legislation in place, profits could also be obtained from trading carbon credits.

## **2.3 Empirical review of conditions and incentives for bioenergy adoption**

In this section, different incentives and conditions that have positive effects on the adoption of bioenergy production in developed countries, as well as potential barriers to adoption, are identified. The studies analysed vary in their research objectives, methodology, discipline, focus, and depth. Triangulation, economic and financial analyses are included in the research methods used in these cases; caveats on the interpretation of results therefore apply. The focus of this review is on developed countries; therefore, factors such as poverty alleviation as an incentive for adoption are not included. The next section harvests lessons learnt about factors of success in bioenergy adoption cases, then it examines the Australian policy context for renewable energy and new tree plantings.

### **2.3.1 Factors in the successful bioenergy adoption**

While the biophysical factors influencing specific species for energy cropping are well understood and have been modeled extensively, the local socio-economic aspects of energy cropping, in particular, the adoption of woody biomass growing by landholders, is a relative new research arena. Only a handful of studies have explored the views of potential woody biomass growers (Sherrington et al. 2008; Baumber et al. 2011; Convery et al. 2012). Very few studies have explored bioenergy crop production under contract (Bocquého & Jacquet 2010; Bergtold et al. 2014). Some of the cases explored by these studies are in the early stages of development or are research oriented. Evidence from successful bioenergy production cases is needed to derive success factors worth exploring for the development of a new bioenergy value chain.

Case studies of bioenergy adoption, mostly from Europe, are reviewed to identify a number of incentives and enabling conditions for the adoption of bioenergy technologies and crops. This review includes successful individual cases of bioenergy adoption (see Table 1) as well as review articles about emerging and potential bioenergy adoption cases.

The key enabling conditions for the development of bioenergy found in the literature include the development of a market for biomass, infrastructure and adequate policy environment, including subsidies and taxes. In turn, these conditions are influenced by the price of fossil fuels and the relative costs of converting biomass into fuels and the availability and costs of alternative energy sources (Table 1). The following factors of successful bioenergy adoption are present: low cost processes and technologies, removal of barriers to adoption, robust policy incentives, other non-market incentives and useful business models as explained next.

**a) Low cost processes and technologies**

It is likely that one of the most important enabling conditions for the success of biomass-based energy production initiatives is the low cost of biomass and of adapting existing technologies. The higher the costs of adoption, the less likely any bioenergy initiative is to succeed. For example, a review of 23 studies of bioenergy plantations of fast-growing poplars and willows shows that short rotation woody crops (SRWCs) are only financially feasible if a number of additional conditions regarding biomass price, yield and/or government support are fulfilled (El Kasmioui & Ceulemans 2012, p. 63). However, it is not possible to provide a full comparison across the studies because these studies use different conceptual frameworks, methodologies and scales. Knowledge about the economics of SRWCs is limited due to the low number of successful plantations.

**b) Removal of barriers to adoption**

Barriers to the adoption of woody bioenergy crops are more prominent in the literature than are reasons for their success. In this respect, the main factors limiting the utilisation of biomass in Sweden and Germany, that is, SRWCs or short rotation forestry, are: low plant productivity, high investment cost, lack of markets, poor awareness, and little infrastructure for management of woody biomass (Hoffmann & Weih 2005). Public opposition is also a major barrier to the adoption of biomass energy as observed in the United Kingdom, specifically, England and Wales (Upreti 2004). In these cases, although local communities recognise and value the environmental benefits of biomass energy, they are also concerned about the direct perceived negative effects of

establishing power plants. For example, perceived risks, and negative effects to ecology and landscape. It was also observed that these conflicts arose because of low level of awareness about bioenergy development (Upreti 2004). Furthermore, the high production costs of bioenergy crops are a major barrier to their adoption (Carriquiry et al. 2011).

Competition for biomass resources is also a key barrier to adoption of second-generation bioenergy. For example, in Switzerland, competition for biomass resources with the more mature wood-to-energy technology is one of the main reasons for the lack of adoption of bio-synthetic natural gas (Wirth & Markard 2011, p. 647). Competition for woody biomass resources between a traditional wood-based products industry (e.g. use of residues for particleboard manufacture) and wood for bioenergy has also been discussed within the Australian context (Cowie & Gardner 2007). Another issue is the competition for woody biomass within two renewable energy sectors, i.e. biomass for electricity production and biomass for transport (e.g. to produce biofuels) (Graham et al. 2011b). This competition is likely to increase as industries diversify away from fossil fuel (CSIRO 2011).

Some conceptual solutions to overcome the barriers to adoption discussed in the literature include setting a revolving fund (a fund that is continually replenished as withdrawals are made), and providing preparation, plants and mechanical care up to a first rotation at 21 years, including the cost of full tree removal and re-establishment, plus a maintenance fee paid to farmer (Hoffmann & Weih 2005). Another conceptual solution proposed is using bioenergy tree crops as ecological compensation. Specifically, bioenergy tree crops would compensate for the ecological damage caused by the compacted soil of conventional agriculture<sup>6</sup>. Collaboration across actors (central government, developers, local councils, environmental concern groups and local communities) is noted as fundamental for bioenergy development as well (Upreti 2004).

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<sup>6</sup> Ecological compensation occurs as long as tree plantations are small and nutrients loss is managed, or species used are of higher ecological value than the agricultural crop (Hoffmann & Weih 2005).

### **c) Robust policy incentives**

Policy incentives are also essential as an enabling condition, as they promote the progression of technologies from one stage to the next. Among them are investment grants and direct subsidies for planting biomass feedstock. For example, policy incentives are highlighted in a study about the innovation systems for new and renewable energy technologies in the United Kingdom (Foxon et al. 2005, p. 2135). Harmonisation of subsidies at different levels is also important (Madlener 2007). Some policy approaches to motivate the adoption of renewable energy include investments grants and market-based mechanisms such as green certificates and carbon taxes (Komor 2004; McCormick & Kåberger 2007). Green certificates, also known as tradable renewable certificates, serve as an accounting tool for the benefits of reduction in CO<sub>2</sub> emissions produced by using by renewable energy resources (Komor 2004). In Australia, these green certificates are known as Renewable Energy Certificates (RECs) and will be explained in Section 2.4 together with Australia's carbon policy. Other government support mechanisms and subsidies may positively influence adoption, as shown next.

### **d) Other non-market incentives**

Non-market incentives are also important to incentivise the adoption of bioenergy technologies. For example, in Enköping, Sweden, farmers receive a mixture of ash from the Combined Heat and Power plant (CHP) and digested sludge<sup>7</sup> from the waste water treatment facility (McCormick & Kåberger 2007) to be used as fertiliser. The most important pre-conditions for the adoption of tree planting for bioenergy identified in Enköping was the development of the appropriate infrastructure i.e. a Combined Heating and Power (CPH) plant, and a market for willow chips (Mola-Yudego & González-Olabarria 2010).

### **e) Useful business models**

While policies and subsidies are part of the enabling conditions for bioenergy adoption, different business models are used in the implementation of each case. For example, in Enköping, Sweden, the expansion of a CHP plant

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<sup>7</sup> Sludge: Thick, soft, wet mud or a similar viscous mixture of liquid and solid components, especially the product of an industrial or refining process (Oxford Dictionary).

resulted in an increase of number farmers who planted willow (Mola-Yudego & Pelkonen 2011). The option of leasing the land to a bioenergy company seems to have worked better than the option of involving farmers directly. Involving farmers directly means that there will be a need to overcome their initial reluctance due to lack of knowledge of planting and harvesting this crop, but they could also benefit from local leadership to build networks and guide supply chain co-ordination (McCormick & Kåberger 2007). More recently, Silveira and Johnson (2016), based on the cases of ethanol production in Brazil and biomass for power and heating in Sweden, applied the concept of socio-technical regimes. Socio-technical regimes are the ‘deep structure’ or grammar of a socio-technical systems, and are carried by the social groups (Geels 2004, p. 905). These regimes require stakeholder alliances in addition to policies and economic incentives to integrate new technologies into production systems.

**Table 1 Successful bioenergy adoption cases in Europe**

<b>Case / Biomass source</b>	<b>External factors</b>	<b>Internal factors</b>	<b>Incentives</b>	<b>Business model</b>
Enköping, Sweden: Combined Heat and Power (CHP) from forest residues and energy crops (willow) <sup>a</sup>	<ul style="list-style-type: none"> <li>- Strong local government support after the 1970s (energy independence)</li> <li>- Local demand and market for woody biomass (district heating plants)</li> <li>- New agricultural policy; lower grain prices and compensation for set-aside land and subsidies for willow on arable land</li> <li>- Higher taxes on fossil fuels</li> <li>- Existence of a biofuel market in Sweden based on forest fuels</li> <li>- Government subsidies for renewable energy plants up to 1997</li> <li>- Centralised planting and harvest and delivery (one company)</li> <li>- Carbon tax since 1991 &amp; sulphur tax increases</li> <li>- Extensive research and plant breeding programmes of willow since the 1970s</li> </ul>	<ul style="list-style-type: none"> <li>- Lack of knowledge of planting and harvesting</li> </ul>	<p>Current:</p> <ul style="list-style-type: none"> <li>- Investment grant (40% of total investment cost)</li> <li>- Fertilizer (by-product of CHP)</li> <li>- Subsidies for planting willows</li> </ul> <p>Potential:</p> <ul style="list-style-type: none"> <li>- Demonstrate short-term economic gains</li> <li>- Long term commitment</li> </ul> <p>Market:</p> <ul style="list-style-type: none"> <li>- Infrastructure and a market for willow chips.</li> </ul>	<p>Initial: direct planting by farmers</p> <p>Lease land from farmers</p> <p>Public/private partnership</p>

**Table 1 Successful bioenergy adoption cases in Europe (continuation)**

<b>Case / Biomass source</b>	<b>External factors</b>	<b>Internal factors</b>	<b>Incentives</b>	<b>Business model</b>
Mureck, Austria: Biofuel from rapeseed and used cooking oil <sup>b</sup>	<ul style="list-style-type: none"> <li>- Initial agricultural surplus created interest in biodiesel</li> <li>- Originally: economic and ecological problems with agriculture</li> <li>- Laws, policies, financial feasibility, technological innovations, but none strong</li> </ul>	- Knowledge: Farmers familiar with the crop	<ul style="list-style-type: none"> <li>- Investment grants (30%-75% of total investment cost)</li> <li>- Farmers get both diesel and rapeseed cake to feed their livestock</li> </ul>	Producers' cooperative and two companies
Lahti, Finland: CHP + Biomass gasifier from biomass and municipal waste <sup>c</sup>	<ul style="list-style-type: none"> <li>- Research and development, energy taxation, and investment grants for innovative projects</li> <li>- Existing infrastructure CHP based on oil (1976), then coal (1982), then biomass (since 1998)</li> <li>- Competitive costs of biomass and waste</li> <li>- High confidence in the viability of the biomass gasifier</li> </ul>	NA	<ul style="list-style-type: none"> <li>- Profits from the CHP plant flow back into the community</li> <li>- Reduced management costs for disposing of municipal solid waste</li> <li>- Low initial costs (adaptation to biomass gasifier)</li> </ul>	NA

**Table 1 Successful bioenergy adoption cases in Europe (continuation)**

<b>Case / Biomass source</b>	<b>External factors</b>	<b>Internal factors</b>	<b>Incentives</b>	<b>Business model</b>
Vorarlberg, Austria rural Biomass District Heating (BDH) <sup>d</sup>	<ul style="list-style-type: none"> <li>- Local initiatives</li> <li>- High capital grants</li> <li>- Standardisation and harmonisation of subsidy schemes</li> <li>- Introduction of techno-economic performance guidelines</li> <li>- Country biomass energy policy goals</li> <li>- Positive media support</li> </ul>	<ul style="list-style-type: none"> <li>- Pressing forestry problems</li> <li>- Clear vision and commitment of actors</li> <li>- Self-interest of forest-owning farmers</li> <li>- Know-how and networking among stakeholders</li> </ul>	<ul style="list-style-type: none"> <li>- High capital grants</li> <li>- Education and training</li> </ul>	Network: Local promoters of BDH project in touch with agents in each province (focal points) and planners and installers
Vienna, Austria Urban biomass cogeneration <sup>e</sup>	<ul style="list-style-type: none"> <li>- A priori political consensus: desirable project</li> <li>- Favourable economic conditions (see incentives column)</li> <li>- Intra-firm supporters at different levels</li> <li>- Green electricity Act (2002)</li> <li>- Positive corporate image (innovative, green) for utility companies participating</li> </ul>	<ul style="list-style-type: none"> <li>- Real problem and problem awareness</li> <li>- Critical mass of actors ('prime movers')</li> <li>- Institutional innovation and changes in the mindset of the main decision makers (through learning, study tours)</li> <li>- Change agents involved in the early stages of development</li> </ul>	Guaranteed buyback rates for electricity fed into the grid	Corporate led, mainly a core group from utility company as main promoter. Wood fuel supplies organised long before the construction of the plant is actually completed.

**Table 1 Successful bioenergy adoption cases in Europe (continuation)**

<b>Case / Biomass source</b>	<b>External factors</b>	<b>Internal factors</b>	<b>Incentives</b>	<b>Business model</b>
Juhnde bioenergy village, Germany, CHP plant from waste manure and woodchips <sup>f</sup>	<ul style="list-style-type: none"> <li>- Carbon taxes on fossil fuels.</li> <li>- Government subsidies (see incentives)</li> <li>- Demand for heat and power</li> <li>- Costs savings of combining heat and electricity production</li> <li>- Costs savings from shorter distribution network</li> <li>- Economic viability since installation (with subsidy) and a payback period of 5 years (estimated).</li> </ul>	<ul style="list-style-type: none"> <li>- Strong cooperation of the community</li> <li>- General desire to replace fossil fuels</li> <li>- Retention of community income locally.</li> </ul>	<ul style="list-style-type: none"> <li>German government EUR 1.3million grant</li> <li>Fixed feed-in tariffs for electricity and a bonus for the heat utilization.</li> </ul>	<ul style="list-style-type: none"> <li>Local cooperative (70% of villagers): residents' contributions of EUR1500.</li> <li>Synergies of the plant with local farmers, foresters and the community.</li> </ul>

**Source:** <sup>a</sup> McCormick (2011), McCormick & Kåberger (2007), Mangoyana and Smith (2011), Roos et al. (2000). <sup>b</sup> McCormick (2011), Tomescu (2005, cited in McCormick & Kåberger 2007); <sup>c</sup> Palonen and Nieminen (2005, cited in McCormick & Kåberger 2007); <sup>d</sup> Madlener (2007); <sup>e</sup> Madlener and Bachhiesl (2007); <sup>f</sup> Brohmann et al. (2006, cited in Mangoyana & Smith 2011) and IEA Bioenergy (no date provided).

## **2.4 Australian context: Renewable energy and wood plantings for environmental services and wood production**

### **2.4.1 Australian policy framework related to renewable energy**

Renewable energy policies are key factors for adoption of bioenergy tree crops. The following section describes the Australian policy framework related to renewable energy. It is important to note that the policy frameworks related to carbon price, climate change and renewable energy targets are constantly evolving in Australia. The assumptions made and policy frameworks in this thesis correspond to the period 2010 to 2012 before the election of the Liberal Party in 2013.

Burning coal produces 76 per cent of the electricity used in Australia (Australian Energy Regulator 2017). Electricity generation is responsible for 35 per cent of national greenhouse gases (GHG) emissions in 2016-17 (Commonwealth of Australia 2017). Incentive-based regulations are one way of reducing GHG emissions from electricity in Australia. One of these regulations is the Mandatory Renewable Energy Target (MRET) of 20 per cent electricity from renewable energy sources by 2020 (Parliament of Australia 2010). The MRET comprises the Large-scale Renewable Energy Target (LRET) and the Small-scale Renewable Energy Scheme (SRES) (Parliament of Australia 2010). Within the LRET, electricity generators may either buy large-scale generation certificates (LGCs) to comply with LRET or they can produce LGCs by incorporating approved renewable energy sources in their production processes. One LGC is equivalent to 1 MWh (megawatt hour) of eligible renewable electricity generated above the power station's baseline (Office of the Renewable Energy Regulator 2011). Despite the LRET and SRES, replacing coal for electricity generation has proven challenging for two main reasons; first, the extremely low price of coal compared to other sources of electricity; and second, the lack of a clear vision and an investment framework for renewable energy technologies, combined with a hidden bias that favours fossil fuel and nuclear energy (Schlöpfer 2009).

Regardless of the scale of use of renewable energy, three renewable energy sources are relevant to mainland Australia: solar energy, wind farms, and biomass. With regard to solar energy, solar hot water heaters have been the major generator of Renewable Energy Certificates (RECs). However, it has not only been the MRET that has stimulated the uptake of solar hot water heaters; federal, state and local government installation subsidies have also been important (Buckman & Diesendorf 2010). Urban and peri-urban residents have been the major uptakers of subsidies (now discontinued) for solar water heaters. In rural areas, wind farms have generated mixed reactions from the public, including concerns about their impact on health and landscape beauty (ABC 2011a, 2011b). Interestingly, biomass has been overlooked by specific renewable energy policies at the national level. Concerns about logging native forests, higher fuel procurement costs than coal, and higher transport cost due to lower energy density (Dopita & Williamson 2010), may have played a role in this issue being overlooked.

National policies such as the carbon pricing mechanism approved by the Senate in 2011 and implemented from July 2012 to July 2014, sought to drive a ‘long-term transformation to cleaner sources of energy’ (Commonwealth of Australia 2011b). It also aimed to be a key incentive for the reduction of carbon pollution, mainly by the largest emitters, such as the electricity generation sector. A carbon price aimed to incentivise the gradual replacement of polluting energy generating technologies with cleaner ones. This price mechanism was also a pivotal component of the ‘Clean energy future’, a policy package that included among others, the Carbon Farming Initiative (CFI) Act (Commonwealth of Australia 2011a) and the formation of the commercially oriented Australian Renewable Energy Agency (ARENA)<sup>8</sup> (Australian Renewable Energy Agency 2015). The CFI Act ‘sets up a scheme for the issue of Australian carbon credit units in relation to eligible offsets projects’ (Commonwealth of Australia 2011a).

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<sup>8</sup> ARENA aims at ‘improving the affordability of renewable energy technologies and increasing the supply of renewable energy in Australia’ (Australian Renewable Energy Agency 2015).

The Australian Energy White paper (Commonwealth of Australia 2015) provides a policy framework for the Australian energy sector and will directly influence the investment environment for bioenergy in the country. Specifically, the paper stresses that the Government prefers to not intervene to promote one technology or fuel source over another, i.e. markets should be left to operate freely. This contrasts with earlier policies in Australia such as the carbon pricing mechanism (Commonwealth of Australia 2011b) and former policies that supported biofuels, including reimbursement of excise, the Cleaner Fuels Grants Scheme and the Ethanol Production Grants Program (Commonwealth of Australia 2011b, 2014).

The outlook for long term support for clean energy in Australia seems positive. Australia is signatory of the Paris agreement that aims at reducing emissions by 26 per cent of 2005 by 2030. The forecast for energy generated from renewable sources is 20 per cent increase by 2034-35, supported by three main policies: Emissions Reduction Fund (ERF), Renewable Energy Target and National Energy Productivity Plan (Abela Rebiscoul 2017). The ERF is in place since July 2014, whereby the Federal Government buys emissions abatement from polluters (Nong & Siriwardana 2017). In 2016, the safeguard mechanism of the ERF came into effect to ensure that the emission reductions purchased through the ERF are not offset elsewhere in the economy (World Bank & Ecofys 2017). Moreover, the Australian Trade and Investment Commission indicates that ‘second-generation technologies will open up new feedstock for biofuels and electricity generation’ (AusTrade 2017) and the Australian Renewable Energy Agency (ARENA) includes biomass for bioenergy in its call for expressions of interest for the successful demonstration of renewables and made available AUD 20 million for these projects (Australian Renewable Energy Agency 2017).

#### **2.4.2 Australian new wood plantings for environmental services and wood production**

Trees planted on farms can provide several environmental services such as offsetting carbon emissions, reducing or controlling soil erosion, and controlling salinity. Tree plantings for environmental services can be incentivised through carbon markets. Before July 2012, planting trees for carbon sequestration in

Australia was conducted mostly in response to open market demands and not to government incentives. From July 2012, specific government incentives, such as the CFI Act (Commonwealth of Australia 2011a), aimed to obtain voluntary carbon offsets in the farming and forestry sectors. The CFI has increased the interest in tree planting and soil carbon sequestration practices.

Taxation rules may have an important role in farm forestry. Since the mid-1990s, Managed Investment Schemes (MIS) have resulted in widespread plantations of trees on farms, in particular hardwood eucalypt plantations for woodchips (Hassall 2010). MIS are a collective form of investment, usually done under a unit trust structure. The advantage of the MIS is the ability to claim losses in the development stage against income earned from other sources (O'Toole & Keneley 2010). Despite these advantages, poor management and lack of technical know-how about plantation management on the part of farmers, and a lack of infrastructure and market for the wood, have resulted in poor results, which have led to a Senate inquiry (Parliament of Australia 2015). MIS established almost one million hectares of timber plantation in Australia between 1998 and 2008 (New Forests 2014). The total investments in plantation forests were of 4.1 billion Australian Dollars in the period 2002-2012 (Commonwealth of Australia 2016). By 2004-05 MIS owned 26 per cent of Australian plantations, however, this ownership decreased to only 5 per cent in 2015-16, totalling 98,700 hectares (Downham, & Gavran 2017). This steep reduction in MIS plantation ownership is due to the failure of the major MIS agribusiness schemes in 2009, Timbercorp and Great Southern, followed by the collapse of Willmott Forests Ltd and Gunns Plantation Ltd (Commonwealth of Australia 2016). While MIS increased forest plantations, they were poorly implemented by pushing 'new plantations into areas of low rainfall, poor market access or areas of limited historical forestry experience' (New Forests 2014). These negative technical factors combined with alleged unscrupulous financial advisers practices, product issuers and systematic irresponsible lending, has negatively impacted thousands of individual investors, not only financially (e.g. lost life savings, bankruptcy) but also had negative effects on wellbeing (e.g. broken separation, broken relationships, depression, self-harm and families placed under enormous stress) (Commonwealth of

Australia 2016). Understandably, the MIS may have undermined the legitimacy of any tree based forestry by eroding the trust of tree growers.

#### **2.4.3 Adoption of farm forestry in Australia**

Adoption factors of farm forestry have been investigated in a series of studies for wood production and environmental services in Australia. Three factors are likely to be important in the adoption of farm forestry (Race 2009): economic factors such as cost-efficiency and price-competitiveness in relation to existing economic activities, specialised labour such as equipment handling and repair, market agents and brokers, and mechanisation. Race (2009) also raises the need for financial investment to address establishment costs. Race and Curtis (2007) argue that uncertainty, uncompetitive regional markets and property turnover are key concerns related to the low adoption of farm forestry for small-scale growers. They go on to say that the assumption of profitability is at the core of federal and state governments' policies that promote farm forestry (Race & Curtis 2007).

Equally important, the viability of farm business, proximity and accessibility to competitive markets, and opportunities for alternate farm enterprises also influence the adoption of farm forestry (Race 1999, p. 184; 2009). Other factors that influence investment decisions in farm forestry include: sufficient land, labour or capital to invest in new enterprises or industries, suitable soils and rainfall, good economies of scale, access to infrastructure (e.g. roads, processing facilities), low operating and harvesting costs and opportunities for integrating agroforestry with current farming enterprises (Race 2009). Farm family dynamics, links to support and information networks and local community perception of farm forestry's potential are also important adoption factors (Race 1999, p. 184). Evidence found by Schirmer (2007) implies that maintaining ownership and control of the land is the main reason for the positive perception from farmers associated with small-scale forestry. This preference for control of their land is strongly rooted in farmer's culture (Schirmer 2007).

In terms of willingness to adopt tree planting for carbon sequestration, Schirmer and Bull (2011) found that a clear carbon market supported by a legislative

framework, and confidence in the market in the long term are required. Key factors that determine willingness to adopt include: landholders' perception of the potential to provide a diversified income stream, its impacts on flexibility on land management, and social acceptability about planting trees and agricultural land, and community views on afforestation (Schirmer & Bull 2014). Design factors also play an important role for potential adopters. Positive design factors include small areas of trees planted on their marginal land, using native species, achieving co-benefits, and ideally not having to maintain the trees for the long term (100 years or more) (Schirmer & Bull 2011, p. 47; 2014). Adoption becomes less likely if farmers are required to plant large areas of their productive land with exotic species with few or no co-benefits for a long term period. The preferred model by farmers however is not ideal for achieving the lowest cost and most efficient carbon sequestration, because increased transaction costs occur (Schirmer & Bull 2011). Reiterating the findings by Lindner (1987), design factors therefore have a crucial influence on willingness to adopt; in this case, afforestation for carbon sequestration. These factors need to favour a wide range of socio-economic benefits beyond income, to minimise disruption to land management flexibility, and to be compatible with landholder beliefs on appropriate use of agricultural land (Schirmer & Bull 2014, p. 306).

Although farm forestry in Australia is at a pioneering stage, understanding the views of landholders—the ultimate decision-makers on land use—is fundamental to better informing and targeting policies for bioenergy production. Large numbers of landholders may need to adopt new practices in order to realise the potential of a bioenergy supply industry and to build critical mass.

#### **2.4.4 Australian adoption of conservation practices**

Australia has a history of agri-environmental schemes from which we can draw lessons for the understanding of potential adoption factors of tree planting for bioenergy. Greiner & Gregg (2011) propose a conceptual framework that captures the decision making process of participation in these schemes, including: a) characteristics of the scheme, b) external incentives, c) farmer motivations and

perceptions, and d) characteristics of the farm. These factors are explained as follows:

- a) The characteristics of the agri-environmental scheme refer to the relative advantage and trialability of the innovation (Pannell et al. 2006). Relative advantage refers to how the scheme compares with current farm based activities in terms of its benefits, whereas trialability refers to how easy it would be to learn and implement the innovation on the farm (Pannell et al. 2006). Relative advantage depends on a range of economic, social and environmental factors (Pannell et al. 2006). Examples of these factors related to the adoption of tree planting include:
  - The (actual or perceived) profitability of the innovation compared to current practice. For those landholders who are profit focused, the farm-level economics of a new conservation practice will be important. If the practice is not profitable or is not perceived as profitable, then it tends to be adopted by farmers with strong conservation goals (Pannell et al. 2006). The profitability of woody crops is negatively influenced by high establishment costs and delayed financial benefits, e.g. woody crops for salinity mitigation in Western Australia.
  - The impact of the innovation on other parts of the system within which it will be embedded, for example, trees may reduce the flexibility of land use for those landholders who switch crops annually in response to weather conditions, in particular in dry areas (Kingwell et al. 1993).
  - The compability with existing technologies, practices and resources (Kaine & Lees 1994), for example, for wheat farmer, tree crops are unlikely to be as compatible as other crops with existing machinery and fertilisers' input, hence increasing the cost of transition (Pannell et al. 2006).
  - The complexity of managing the innovation (Rogers 2003), for example, for a farmer that has already diversified, adding a crop to the suite of current crops, converting an annual production to

include perennial crops or if the new crop requires more intense management than traditional crops, may cause increase inconvenience, stress and risk to the farmer, even if the additional crop would be profitable (Pannell et al. 2006). More recently, low administrative load and transaction costs are identified as positive adoption factors of conservation tenders (Rolfe et al. 2017), while fixed covenants, onerous management conditions and poor program design were all major disincentives to participation (Comerford 2013).

- The compatibility with existing beliefs and values. For example, in north-central Victoria, tree planting was based on ‘symbolic beliefs’ of concern for the public good (Cary 1993).
- Long time scales to realise land restoration from issues such as dryland salinity, soil acidification, decline of native vegetation, may negatively impact adoption.
- Riskiness, increased by the long time lags between planting and harvest, which can be up to decades for woody perennials. Risk is also increased by natural hazards such as fires or pests.

Factors that influence the the trialability of a practice include (Pannell et al. 2006):

- Observability of results. It is important to have trials to reduce uncertainty in participation and increasing the chances of learning between landholders (Larkin & McMullen 2014). For example, Abadi Ghadim et al. (2005) suggest to provide information about the performance of similar innovations, by facilitating physical observation (e.g. through farm visits or field days) or when it is not possible to observe the benefits (e.g. groundwater processes), provide results of physical measurements.
- Potential threats such as drought, diseases, pests, and establishment failure. Of particular interest are large scale trials as the potential losses are relatively large, hence discouraging risk-averse landholders.

- b) External incentives refer to price signals and policy instruments that can motivate the landholder to participate (Greiner & Gregg 2011). Greiner (2016) argues that program and contract design and administrative features influence participation. Contract design features include length, payment frequency and flexibility. Greiner (2016) reports that some level of contract flexibility positively influences adoption. For example, preferences for the length of conservation contracts vary, Comerford (2013) and Cocklin (2011) reported long term preferences by non-producing landholders, whereas Miles (2008) and Blackmore and Doole (2013) reported landholders preferences for medium term contracts over short term contracts. Also, in a recent review of conservation tenders in Australia, Rolfe et al. (2017) identified that relationships between landholders and agencies are important factors that encourage or hinder landholder participation. An important limitation on participation in conservation schemes is lack of awareness, despite extensive communication of them (Coggan et al. 2013).
- c) Farmer motivations and perceptions are influenced by the goals and beliefs of landholders. For example, pastoralists in the Northern Territory in Australia are ‘profoundly driven by non-financial motivations’ in their decision making such as stewardship and lifestyle (Greiner & Gregg, 2011, p.258). Landholder adoption is influenced by socio-cultural and personal influences as well (Pannell et al. 2006), such as lack of time or financial resource required by the establishment of conservation practices (Gole et al. 2005). The reason for holding land (e.g. agricultural production vs lifestyle) can also influence adoption (Pannell et al. 2006). Literature on specific landholder characteristics as adoption factors is abundant. While these characteristics have been identified by Rolfe et al. (2017) as influencing adoption of conservation tenders, a detailed description of these factors in the context of bioenergy is provided in

Section 3.2.3. It is worth noting that the influence of these characteristics is not always consistent.

- d) Characteristics of the farm such as property size are often but not always related to innovation adoption (Pannell et al. 2006), in northern central Victoria, it was found that property size was related with adoption of perennial pastures but not related to the adoption of tree planting (Wilkinson & Cary 1992).

## **2.5 A critical mass framework for understanding landholder's adoption of innovation**

This section integrates the theoretical underpinnings, empirical cases and policy framework to develop an initial 'critical mass' conceptual framework for building a biomass-based energy market in Australia, with emphasis on landholders' adoption and diffusion of innovation. Critical mass can be understood as 'enough individuals in a system have adopted an innovation so that the innovation's further rate of adoption becomes self-sustaining' (Rogers 2003, p. 343).

The study of pathways to build a critical mass of tree growers for a woody biomass supply chain needs to start with an understanding of adoption factors. The theories of adoption of innovation and diffusion and related empirical evidence provide elements used to build the conceptual framework (Figure 4) to be used in this thesis. This framework combines neo-classical and behavioural decision-making factors. It has farmers' goals as the main driver, and takes into account internal factors such as learning capacity, attitudes and values, and external factors that reduce landholders' perception of risk and uncertainty. Adoption studies for bioenergy tree crops and other tree planting have contributed to the key adoption factors listed at the end of this chapter.

The conceptual framework introduced here (Figure 4) expands Pannell's adoption phases outlined in Section 2.2 and adds external factors such as conditions that reduce perceived risk and uncertainty, and internal factors such as learning

capacities of the adopter, attitudes towards the technology, intrinsic value systems, and farmer life stage. These factors have been explained extensively in the adoption literature (Abadi Ghadim & Pannell 1999; Marra et al. 2003; Leviston et al. 2011; Merson et al. 2011).

The perception of risk varies when farmers better understand the crop or when they are moving along different adoption phases. For example, a farmer may consider that introducing a new crop in their portfolio could be a risky decision if they are currently testing another crop. But trialing reduces uncertainty and improves decision making (Ghadim et al. 2005). The level of farming experience may also influence their decision making. For example, given two 50-year old farmers, the decisions of one with 30 years of experience in farming may differ from one who has recently started farming or if he/she is a lifestyle farmer.

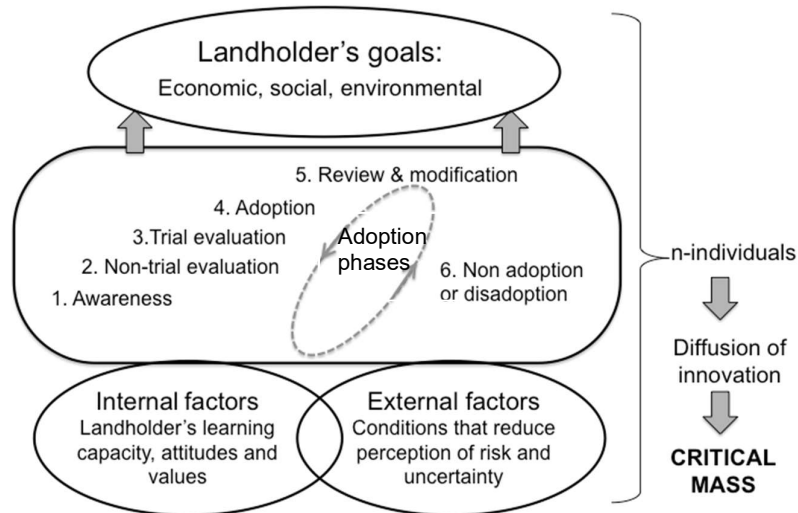
Non-adoption or dis-adoption<sup>9</sup> can occur if at any point the landholders are not convinced that the management practice is good for their interests or goals. Therefore, the model presented here is not linear but, rather, cyclical. Even if the landholder adopted a particular management practice, external circumstances such as changes in the national or international economy can make them disadopt (Pannell et al. 2006). In a similar way, Rogers' (2003) confirmation phase involves a continuum of decisions that leads to continued adoption, discontinuance or continued rejection of the practice. When the adoption process is repeated by enough number of landholders ('n-landholders') (Figure 4), it would be possible to build a critical mass of landholders to support a bioenergy tree crop industry in the study region. The issue of critical mass will be further discussed in Chapter 5 and Chapter 6.

Landholders' decisions to adopt or not to adopt also depend on the characteristics of the contract available to them in return for their production. Random utility theory presented earlier, is used in this thesis to explain landholders' preferences on contracts for bioenergy tree crops in Chapter 5.

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<sup>9</sup> Dis-adoption is the process by which an adopter abandons an innovation (Pannell et al. 2006).

**Figure 4 Critical mass framework for understanding landholder’s adoption of innovation**



**Source:** Velarde, built based on work from Pannell et al. (2006); Rogers (2003); Marra et al. (2003); Leviston et al. (2011), and Merson et al. (2011).

In addition to a solid economic case, as argued by neo-classical economics, bioenergy development requires long-term solid commitment, i.e. real collaboration to succeed among biomass growers, brokers, bioenergy generators, and policy makers as highlighted in the analytical framework in Chapter 1.

This chapter has explained a suite of adoption factors relevant to bioenergy, farm forestry and conservation practices. The following list documents these factors following Greiner & Gregg’s (2011) framework:

**Factors inherent to the innovation itself/characteristics of the scheme**

- Relative advantage (Pannell et al. 2006), e.g. actual or perceived profitability; low cost processes and technologies (El Kasmioui & Ceulemans 2012); cost-efficiency, price competitiveness (Race 2009); proximity and accessibility to competitive markets, opportunities for alternate farm enterprises (Race 1999)
- Compatibility with existing technologies, complexity, trialability, and observability (Rogers 2003; Pannell et al. 2006), low transaction costs

(Rolfe et al. 2017); design (configuration, species, low maintenance) of the plantation (Schirmer & Bull 2011); familiarity with the crop (McCormick 2011); opportunities to integrate with current farming enterprises (Race 2009); diversify income stream (Schirmer & Bull 2014); legitimacy of the innovation (Suchman 1995)

### **External incentives**

- Robust policy incentives, e.g. establishment grants (Foxon et al. 2005) and direct subsidies, harmonisation of subsidies (Madlener 2007), green certificates and carbon taxes (Komor 2004; McCormick & Kåberger 2007); financial investment, labour or capital investment (Race 2009); regional markets (Race & Curtis 2007)
- Other non-market incentives: access to by-products (McCormick & Kåberger 2007); infrastructure development (Mola-Yudego & González-Olabarria 2010); structure and impact of a range of institutions (Edwards-Jones 2006)
- Useful business models, e.g. leasing land to bioenergy companies, public/private partnerships (McCormick & Kåberger 2007), local retention of income (Brohmann et al. (2006), cited in Mangoyana & Smith (2011))
- Level of agricultural extension, information flows (Edwards-Jones 2006)

### **Farmer/Landholder motivations and perceptions**

- Landholder's goals (Pannell et al. 2006); low impact on flexibility on land management (Schirmer & Bull 2014); awareness (Hoffman & Weih 2005),
- Compatibility with landholders' beliefs (Schirmer & Bull 2014; Greiner & Gregg 2011); clear vision and commitment of actors (Madlener 2007)
- Socio-cultural and personal influences (Pannell et al. 2006), e.g. social acceptability about planting trees (Schirmer & Bull 2014); local community perception of farm forestry potential (Race 1999); links to support and information networks (Race 1999); local culture, social capital, attitudes of trusted friends (Edwards-Jones 2006); strong

cooperation of the community (Brohmann et al. (2006), cited in Mangoyana & Smith (2011); farm family dynamics (Race 1999)

### **Characteristics of the farm**

- E.g. Property size (Pannell et al 2006), biophysical characteristics.

In order to build a supply chain for bioenergy woody crops, it is therefore necessary to understand the factors that underlie farmers' decisions. Based on the review of cases of bioenergy adoption and incentives for tree planting and the theories explored in this chapter, including success factors for collaboration, the following issues will be further explored in this thesis:

- Awareness/knowledge: Does past experience in planting tree contribute to the potential adoption of trees as bioenergy crops? If so, what level of experience is needed?
- Relative advantage: There is a need to offer an innovation that would be competitive with current farming practices, and that would present a low risk, for example, through contracts. These contracts should offer returns that satisfy landholder economic expectations and other goals. What contract characteristics would the landholder be interested in?
- Investment cost: What is the level of investment needed?
- Trust/social capital: What organisations is the landholder a member of and how many of them are there? How well connected is the landholder?
- Business models preferences: Would landholders prefer individual or collective agreements?

The next chapter introduces the research hypotheses and research design of this thesis, using a mixed-methods approach.

## Chapter 3

### Research hypotheses and research design

#### 3.1 Introduction

The literature review in Chapter 2 introduced a critical mass framework for understanding landholder's adoption of innovation. This framework builds on both neo-classical economics principles and behavioural economics, and adoption and diffusion of innovation theories. Chapter 2 also discussed empirical cases of the success factors of bioenergy adoption and noted the need for optimal contracts to secure the supply of biomass feedstock in a new supply chain (Alexander et al. 2012). Key adoption issues were identified and used to develop specific hypotheses for the study.

This study uses a mixed methods approach (Johnson & Onwuegbuzie 2004; Creswell & Plano Clark 2011), by combining qualitative and quantitative methods within a case study that aims to effectively integrate the different results obtained. While quantitative methods provide breadth to the analysis, qualitative methods provide depth to it.

The methodology was built based on a review of adoption studies of tree planting in Australia (Race 1999, 2009; Race & Curtis 2007; Baumber et al. 2011; Merson et al. 2011; Schirmer & Bull 2011, 2014) and adoption of bioenergy crops, specifically, grasses (e.g. miscanthus and switchgrass) and short rotation coppice<sup>10</sup> in Europe (Bocquého & Jacquet 2010; Sherrington & Moran 2010) and in North America (Villamil et al. 2008; Villamil et al. 2012). This methodology also builds on a social process of research, where the preliminary phase helps better understanding of the priorities of landholders and the agricultural supply chain in a case study region. The preliminary phase included attending and participating in

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<sup>10</sup> Coppice is a tree, shrub or woodlot that regrows from the stump after it is cut close to the ground level.

local and national conferences, field day visits and events, about bioenergy and rural issues, and interviewing a set of key informants as explained later in this chapter.

The remainder of this chapter is constructed as follows. Section 3.2 introduces the research paradigm and hypotheses investigated, followed by a description of the research setting and participants (Section 3.3). Then it explains the research tools and procedures for data gathering (Section 3.4), and the methods for data analysis (Section 3.5). Next, it addresses the limitations and caveats of the methodology (Section 3.6). The final section adds concluding remarks, mapping the hypotheses to research questions (Section 3.7).

## **3.2 Research paradigm and hypotheses**

### **3.2.1 Research paradigm**

One of the first challenges that a researcher faces early in the research process is the choice of research paradigm (Cameron 2011). In choosing a paradigm, researchers will most often follow their own beliefs about the nature of the research problem and the philosophical views of the community of scholars they are part of (Graff 2012). The following paragraphs discuss various paradigms to establish the best approach for answering the research questions of this thesis.

Positivism and constructivism are two of the most predominant paradigms available to researchers and are positioned at the extremes of the paradigm spectrum. Lincoln et al. (2011), in their analysis of various research paradigms, indicate that positivists believe in the existence of only one truth, which can be explained through verifying a quantifiable hypothesis. Researchers should stand distant from the research subject and remain strictly objective. Hence, the researcher becomes a ‘disinterested’ inquirer that informs decision makers, policy makers and change agents. Thus, positivism is objective, value-free, hypothesis driven and measurable (Graff 2012).

However, the positivist paradigm presents clear shortcomings. The positivist philosophy of ‘only one truth’ is incompatible with the social researcher exploring complex problems such as human decision-making. Thus, it is not surprising that

this paradigm has been widely critiqued. The main shortcomings of this paradigm identified by Tacconi (1998), include: 1) theory development depends on the researcher's values and interests, i.e. there is no 'objectivity' as such, 2) observation cannot be neutral as it involves selection and interpretation, guided by the theoretical construct developed, or subscribed to, by the researcher. Further, Hedrick (1994, cited in Reza 2007, p. 28) argues that positivism cannot capture the complexities of social life.

Constructivism is positioned at the other end of the research paradigm spectrum. Constructivism holds the idea that many realities are constructed in the research process (Graff 2012). In this sense, both researcher and subjects co-create knowledge through experience and interacting with each other (Reza 2007). Critics of this paradigm highlight that reality exists without being socially constructed as well, e.g. the biophysical world that exists even without humans (Tacconi 1998).

As mentioned earlier, the nature of the problem and the researcher's values support the choice of paradigm. In this thesis, the research problem involves complex decision-making within a multi-sector environment, and my own values include a plurality of viewpoints and interdisciplinary values. There is a risk in choosing a paradigm on any end of the spectrum, given these shortcomings explained. To overcome these shortcomings, pragmatism is a philosophical approach that supports the idea that no methodological approach is better than another in generating knowledge (Biesta 2010, cited in Teddlie & Tashakkori 2011, p. 290). Thus, pragmatism was identified as a suitable paradigm to use for this thesis. Under this paradigm, instead of choosing between quantitative and qualitative methods, the researcher determines how both methods will answer their research questions (Graff 2012). Pragmatism 'promotes the active mixing of methods and integration of research findings' (Greene 2007, cited in Teddlie & Tashakkori 2011, p.290) and also results in a 'problem-solving, action-oriented inquiry process'.

### **3.2.2 Mixed methods**

Mixed methods can be considered a response to the identified need for convergence of qualitative and quantitative research (Brannen 2005). Although

several definitions of mixed methods have been proposed, for the purpose of this research the following definition was used (Johnson et al. 2007):

Mixed methods research is the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purposes of breadth and depth of understanding and corroboration (p. 123).

While mixed methods research has been linked to pragmatism, using mixed methods does not necessarily imply following a pragmatic paradigm. The choice of paradigm comes first and needs to be in line with the values of the researcher as well as the nature of the research question. The research questions then guide the methods to answer them.

Research questions formulated using mixed methods require narrative and numeric information, where quantitative data is obtained most often through probability sampling and qualitative data is mostly obtained through purposive sampling (Graff 2012). The analysis and interpretation of the data needs to consider the methods and assumptions by which they were generated (Brannen 2005). This thesis addresses three nested research questions: factors that underlie landholders' willingness to plant bioenergy tree crops, their preferences in the design of contracts for planting these trees, and potential pathways to build a critical mass of tree growers for bioenergy using a mixed methods research design (Table 2).

Following Bryman (2006, p. 98), mixed methods research can be described in terms of order of data collection (simultaneously or sequentially), types of data strands, priority of data (quantitative vs qualitative), stage(s) in the research process where the multi-strategy research occur and function of the integration (e.g. triangulation, explanation or information). These aspects of mixed methods are interpreted within this thesis as follows:

The data was collected sequentially, starting with the use of qualitative methods such as participant observation, semi-structured interviews, and literature review, followed by quantitative methods including landholder survey and choice model.

The qualitative methods inform the quantitative methods, which in turn inform the discussion and conclusions of the research. In this thesis, the quantitative data collection (landholder survey, choice model) are prioritized over the qualitative data collection (e.g. participant observation). However, while the methods to address the first two research questions rely heavily on quantitative approaches, the methods to address the overarching research question about factors to build critical mass combine quantitative and qualitative approaches. Thus, quantitative research hypotheses were formulated for the first two research questions, while qualitative working hypotheses were formulated to address the overarching research question. The rationale for integration in this research includes the complementarity of methods to inform, illustrate and clarify the results, develop and expand the understanding of a complex problem.

While the mixed methods research design (Table 2) shows a relative linear list of procedures, the research started with a literature review and participant observation. The description of the research tools and procedures for data gathering in Section 3.4 will follow the order in which the tools were applied.

**Table 2 Overview of research design using mixed methods**

<b>Research question</b>	<b>Participants</b>	<b>Research tools and procedures for data gathering</b>	<b>Data analysis</b>
1. What factors underlie landholders' willingness to plant bioenergy tree crops?	Landholders from Central West New South Wales who participated in the survey	Landholder survey	Tobit regression – intensity of adoption  Logit regression – likelihood of planting > 50 hectares
2. What are the landholders' preferences in the design of contracts for planting trees as energy crops?	As above	Choice model to analyse contract attributes (as part of landholder survey)	Multinomial Logit model  Random Parameters Logit model
3. What are the potential pathways to build a critical mass of tree growers for bioenergy?	As above and key informants from study area, bioenergy experts, rural experts	Participant observation and interviews  Interpretation of results from landholder survey, choice model and literature review	Integrated analysis  Biomass assessment

### 3.2.3 Factors and issues investigated and research hypotheses

#### a) Factors investigated in this study

A set of factors influencing adoption was obtained from the literature of adoption (Chapter 2), bioenergy adoption (Appendix 1) and discussions with bioenergy experts at the CSIRO. The pre-pilot and pilot study helped to refine the scope of the analysis and to select relevant factors and hypotheses that are feasible to test in a face-to-face survey. The initial list factors included the following:

##### a.1) Landholder demographic characteristics and landholder goals

Among the key demographic factors are: age, farming experience, education, and education related to agriculture. Goals are related to economic expectations as

well as farming traditions. Younger landholders are more willing to supply bioenergy crops or to allocate more land to bioenergy crops (Jensen et al. 2007; Paulrud & Laitila 2010; Joshi & Mehmood 2011). Farming experience determines potential adoption of the bioenergy crop miscanthus (Villamil et al. 2008). A qualitative study in Australia also found that experience with climate variability, regulatory change, and government support would mean that farmers would accept up to 50 per cent lower returns for planting commercial mallee crops, depending on the consistency of these returns, the relative flexibility of the land use of energy cropping versus carbon sequestration, presence of co-benefits such as reducing wind and water erosion, and the possibility of integrating mallee with existing land uses (Baumber et al. 2011).

Another adoption factor found in the literature is education, which includes agricultural education and general education. While agricultural education was found to be a significant and positive adoption factor of bioenergy crops in Ireland (Clancy et al. 2011), general education presented mixed results. General education was significant and positively correlated with adoption of switchgrass as a bioenergy crop in the USA (Jensen et al. 2007), but not significant in a case in Ireland (Clancy et al. 2011).

Reluctance to change, lack of confidence in the market and sense of farming tradition are negative adoption factors (Convery et al. 2012). Farmers were concerned about how growing biofuels would fit with current operations (Convery et al. 2012). Information may help overcome these concerns. Sherrington et al. (2008) concluded that there is a need for trusted information so that farmers can make decisions. These decisions involve financial considerations at the individual farm level.

#### **a.2) Landholder's awareness of bioenergy crops, economic expectations, risk, and opportunity cost**

Landholder's awareness about second-generation bioenergy crops is low given the recent nature of such crops (e.g. only two of 313 of respondents in a survey on miscanthus knew about the crop before completing the survey) (Villamil et al. 2008). In a study about bioenergy crops in the USA, potential adopters expressed their information needs about agronomy and markets and environmental services,

while potential non adopters expressed concerns about miscanthus (Villamil et al. 2008). Villamil et al. (2008) conclude that the information needs of farmers should be fulfilled by their preferred media. Interestingly, contact with extension agents is not a significant adoption factor as found in Ireland (Clancy et al. 2011). In addition to awareness of bioenergy crops, the economic expectations related to these crops are key adoption factors as explained next.

Expectations on stability and income from the bioenergy crop influence adoption. Earlier studies (Rämö et al. 2009; Paulrud & Laitila 2010) found that net income from the bioenergy crop and the price of the energy crop are significant factors in adoption. Whereas a qualitative assessment in the United Kingdom found that a positive expectation of economic returns would benefit adoption (Convery et al. 2012). On the other hand, landholders expressed concerns for adopting a short rotation coppicing crop in the United Kingdom related to security and stability of income from contracts, disruption to cashflow, and reduced farm business flexibility (Sherrington et al. 2008). A case in the Central Tablelands, New South Wales, Australia, found that the size and consistency of returns from energy cropping are related to adoption but this relationship varies (Baumber et al. 2011). Baumber et al. (2011) found that about 50 per cent of landholders would accept lower returns to plant these trees, and 25 per cent will require higher returns. Further, Bocquého and Jacquet (2010) found that liquidity constraints and price risks are important adoption factors, negatively correlated with loan-like contracts, and positively correlated with fixed-price contracts. The latter has a lower perception of risk attached to it.

Risk reduction strategies for adoption of bioenergy crops could be grants to cover plantation establishment costs (i.e. establishment grants). In a qualitative study Sherrington et al. (2008) found that very few farmers said they would consider growing energy crops without an establishment grant. Baumber et al. (2011) found a positive view of establishment support in the adoption of commercial blue mallee in the Central Tablelands, New South Wales, Australia. In turn, high establishment costs are recognised as a negative adoption factor in markets (Convery et al. 2012).

The opportunity cost of land is a barrier to adoption, in particular if the price of current crops is high (Sherrington et al. 2008) or volatile (Convery et al. 2012). But the evidence is contradictory as farm profit alone was found to be a insignificant adoption factor as well (Clancy et al. 2011). Although Convery et al. (2012) found that economic returns are not the main driving force for switching to biomass production, a strong financial case for growing bioenergy crops should be in place. In particular, higher gross margins than the current farming activity are important to overcome the reluctance to change mentioned earlier (Convery et al. 2012). More recently, Bergtold et al. (2014) found that if net returns are higher than the next best alternative land use, then farmers would be willing to sign a contract to grow bioenergy crops such as switchgrass and cornstove. Off-farm income is a positive adoption factor, whereas higher net farm income negatively influences adoption (Jensen et al. 2007).

#### **a.3) Co-benefits and non-market concerns**

The objectives of potential adopters influence the adoption of bioenergy crops. For example, Rämö et al. (2009) found that in Finland, forest management requirements, recreation, forest nature and landscape positively influence the adoption of woody energy crops. On the other hand, a study in Tennessee, USA, found that if the landholder has a desire to provide wildlife habitat, then he/she may not be willing to supply a bioenergy crop (e.g. switchgrass) (Jensen et al. 2007). If the region where a bioenergy crop may be planted is an iconic landscape (e.g. National Park, heritage site), landholders would also be reluctant to adopt as per the findings of a qualitative study in Cumbria, United Kingdom (Convery et al. 2012). Other non market concerns about growing short rotation coppice also include worries about damage to field drains from the roots of willow (Sherrington et al. 2008), visual impacts on the landscape and rotation period (Paulrud & Laitila 2010) and impacts on the nutrient balance of the forest soil (Rämö et al. 2009).

#### **a.4) Farm location, size, farming activity, and ownership**

Other factors directly related to the adoption of bioenergy crops are: geographical location (Paulrud & Laitila 2010), farm size which can have both a positive (Villamil et al. 2008; Clancy et al. 2011) and negative influence (Jensen

et al. 2007; Paulrud et al. 2010) on the adoption of bioenergy crops. The extension of arable land, forest land and other types of land also influenced the decision to plant willow as an energy crop in Sweden (Roos et al. 2000). The area of forage of pasture is a negative adoption factor as well as animal production (Roos et al. 2000; Clancy et al. 2011). Type of farming and other farm characteristics such as leased land, rented land, share of set-aside land, had an insignificant effect on the willingness to grow energy crops as found in Sweden (Paulrud & Laitila 2010).

The perception of the impact on land use flexibility is also important, as revealed in a qualitative study by Baumber et al. (2011), who found that energy cropping was perceived as more flexible than a scheme for carbon sequestration. They also warned about potential barriers for an energy cropping scheme if it imposes restrictive rules over an extended period of time.

Finally, land ownership influences adoption. Roos et al. (2000) claim that tenancy on the land decreased the likelihood of adoption but others such as Clancy et al. (2011) did not find a significant effect. Collectively owned farms resulted in higher adoption rates than individually owned farms. The same was found to be true for leasing out the land (Roos et al. 2000). Other positive adoption factors include tractor ownership and irrigation on the farm (Roos et al. 2000).

#### **a.5) Key assumptions**

The adoption factors reviewed above directly influenced the design of the landholder survey. The survey was designed to capture the assumptions that would make growing trees for bioenergy more palatable to the respondent. The main standing assumption was that landholders who agreed to plant under a contract would be satisfied with the profits offered. The contract options were designed to offer levels of return that would respond to this requirement. Therefore, the survey did not test if the relative economic advantage of a tree energy crop was an adoption factor. This factor was assumed to be implicit. Four key assumptions were verbalised to the landholder during the survey:

- i. There is currently a viable market for biomass from trees in place
- ii. The buyer of the biomass will take care of the establishment costs of planting the trees and all harvesting costs.

- iii. You can choose the layout of trees that fits better with your current farming activities.
- iv. One of your neighbours has signed a contract already.

In order to reduce the perception of risk, the levels of returns offered were made equivalent to a land rent agreement where the buyer of the biomass would take care of the plantation establishment costs and all harvesting costs and the landholder would have a say on the species to plant. This scenario would minimize the perception of risk to the farmer and make the option of planting more palatable. More details about the levels of returns offered and other contract characteristics will be explained in the next sections.

The list of factors discussed above was refined during the preliminary and pilot surveys to obtain a list of independent variables to investigate in the final survey. The reasons for discarding, adapting, and refining the initial variables or including new ones are detailed in Table 3. The expected signs of the coefficients of the final list of independent variables are shown in Table 4. Note that co-linearity is expected between some of these variables, for example, between farmer's age and farming experience. The variables included in the final survey were:

- Farming experience and farming goals: years of experience in farming and main farming goal and farming type
- Landholder tree planting related experience: experience in tree planting (scattered, strips of trees, blocks)
- Property characteristics: size, geographical location, extension of unproductive area and estimated property value
- Bioenergy crop contract characteristics: contract length, annual returns, and flexibility to choose the harvesting company in a contract. Preference between collective and individual agreements, species and layout preferred
- Landholder demographic characteristics: age, mortgage holder and highest level of education, Landcare membership and membership of organisations.

#### **a.6) Proxies**

This study uses various proxy indicators for factors that are difficult to measure through a survey:

- Landcare membership was used as a proxy for social capital, which as discussed in Chapter 2, is a likely adoption factor. Membership of organisations was used as a proxy for trust in organisations, which it is hypothesised, will determine adoption.
- Experience in tree planting was used as a proxy of awareness and level of understanding about the innovation.
- The need for a proxy for income arose from the difficulty to obtain income estimates in the pilot survey. Mainly, high income variation in the last year as this was unusually productive after a long drought. Property value was originally considered as a proxy for income but was found to be an inadequate proxy, particularly within the Australian context (South Australian Centre for Economic Studies 2004). Moreover, 11.6 per cent of landholders did not answer the question about property values, which in turn did not allow for modelling of this variable. The lack of income estimates and property values is a caveat of the dataset.

**Table 3 Factors explored in the preliminary, pilot and final survey**

Factors <sup>a</sup>	Survey			Reasons for discard, adapt or refine, if applicable
	Preliminary	Pilot	Final	
<b>Part 1: Landholder farming experience and goals</b>				
Farming experience	Y	Y	Y	..
Farming or land management goal	N	Y	Y	Intended to reflect the general farming orientation
Property size	Y	Y	Y	
Extension of unproductive area	Y	Y	Y	In this survey, unproductive means that no income is produced from the area
Type of farming	Y	Y	Y	Modified after preliminary survey from number and type of crops and animals, to type of farming
<b>Part 2: Landholder tree planting related experience and interest</b>				
Experience in tree planting	Y	Y	Y	Although most landholders have experience in tree planting, this variable was used as proxy of awareness and level of understanding about the innovation
Purposes for tree planting	Y	Y	N	Discarded after pilot. Majority of landholders have planted trees because of ecosystem services <sup>b</sup> . Responses did not provide enough variation needed for modelling
Planted trees for wood or commercial purposes	Y	Y	N	Discarded after pilot. No landholder in the pilot has planted trees for commercial purposes
Investment cost: management effort for planting and maintaining trees (days per year)	Y	N	N	Discarded after preliminary survey because it was confusing for landholders to understand

**Table 3 Factors explored in the survey, from preliminary to final (continuation)**

Factors <sup>a</sup>	Survey			Reasons for discard, adapt or refine, if applicable
	Preli-minary	Pilot	Final	
<b>Part 3: Bioenergy crop contract characteristics (choice experiment)</b>				
Flexibility to choose the harvesting company	N	Y	Y	Explored in choice experiment
Annual returns	Y	Y	Y	Explored in choice experiment
Contract length	Y	Y	Y	Explored in choice experiment
<b>Part 4: Bioenergy crop contract characteristics (out of choice experiment)</b>				
Preferred organisation to negotiate the agreement	Y	Y	N	Discarded from final to avoid asking similar questions (see membership in Part 5)
Periodicity of payment	Y	N	N	The payment offered was annual, based on the feedback to pilot, so this question was discarded
Preference between collective and individual agreements	Y	Y	Y	A modifier was added to collective agreement after the pilot: 'with higher negotiation power'.
Tree species preferred	Y	Y	Y	..
Tree plantation layout preferred	Y	Y	Y	..

**Table 3 Factors explored in the survey, from preliminary to final (continuation)**

Factors <sup>a</sup>	Survey			Reasons for discard, adapt or refine, if applicable
	Preli-minary	Pilot	Final	
<b>Part 5: Landholder demographic characteristics</b>				
Geographical farm location (nearest town)	Y	Y	Y	This variable was split in three dummy variables in the modelling stage, modified from the postcode in the preliminary survey
Membership in agricultural related organisations	Y	Y	Y	Landcare membership was used as a proxy for social capital and membership of organisations as a proxy for trust
Highest level of education	Y	Y	Y	..
Level of income	Y	N	N	Income figures reported in the preliminary and pilot surveys were extremely high
Estimated land value	Y	Y	Y	..
Mortgage	Y	Y	Y	..
Age	Y	Y	Y	..

**Note:** Y = included in this stage, N = not included in this stage. <sup>a</sup>The order of factors in this table follows the order of questions in the landholder survey;

<sup>b</sup> Example ecosystem services mentioned in the pilot survey include: shade or shelter for stock, improvement in how the property looks, increase in birds and animals on the property, rehabilitating degraded land. Most landholders mentioned all of these reasons.

**Table 4 Specific variables investigated in the final landholder survey**

No	Independent variable	Type of variable	Expected sign of coefficient
<b>Landholder farming experience and goals</b>			
1	Farming experience (years)	continuous	-
2	Main farming goal (income, improve land, both, other)	categorical	- for income only
3	Farming type (mixed, grazing, cropping, other)	categorical	- for cropping only
<b>Landholder experience in tree planting</b>			
4	Experience with tree planting (yes, no)	binary	+
5	Experience with tree planting (a few scattered, strips, blocks < 1 ha, blocks > 1ha)	categorical	+
<b>Property characteristics</b>			
6	Property size (acres)	continuous	+
7	Unproductive area (acres)	continuous	+
8	Property value (\$/acre)	continuous	-
<b>Landholder demographic characteristics</b>			
9	Membership (number of organisations)	categorical	+
10	Membership (Landcare = 1)	binary	+
11	Age (years)	continuous	-
12	Mortgage	binary	-
13	Education	continuous	+
14	Lifestyle (hobby farmer)	binary	-
<b>Bioenergy crop contract characteristics</b>			
15	Length (years)	continuous	-
16	Annual return	continuous	+
17	Flexibility to choose harvesting company	binary	+
18	Layout preferred (belts, blocks, combination)	categorical	+ for belts
19	Species preferred (no preference, Eucalyptus, natives, other)	categorical	+ for natives
20	Type of agreement preferred (collective or individual)	binary	+ for individual

## b) Hypotheses about factors influencing potential adoption

The first research question refers to the factors that underlie landholders' willingness to plant bioenergy tree crops. The potential adoption of trees as bioenergy crops was analysed in two ways:

- Willingness to plant under contract: yes or no (binary variable)
- Area considered to be allocated to plant trees as energy crops if landholder would go ahead with a contract (continuous variable)

Two hypotheses were tested about the factors related to potential adoption of bioenergy crops, as follows:

**Hypothesis 1:** Landholder characteristics (e.g. experience, education and number of organisations of which they are a member) and farm characteristics investigated do not determine the willingness of planting trees as energy crops or the area of planting.

$$pl = f(\alpha + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_p X_p)$$

Where:

$X_1$ =experience,  $X_2$ =education,  $X_3$ =number of organisations,

$X_4, \dots, X_p$  = other adoption factors (landholder and farm characteristics)

pl = willingness of planting trees as energy crops or area of planting

$\alpha$  = error term

For each covariate  $j=1, \dots, p$ , the null hypothesis is:

$H_0: \beta_j = 0$  (i.e. covariate is not associated with pl)

and the alternative hypothesis is:

$H_a: \beta_j \neq 0$  (i.e. covariate is associated with pl)

The null hypothesis ( $H_0$ ) implies that for each covariate  $\beta_j$  is not associated with willingness of planting trees or area of planting, that is, there is no influence of any of these variables on potential adoption. The alternative hypothesis ( $H_a$ ) implies that the covariate  $\beta_j$  have an influence on potential adoption. The *a priori* expectation is that  $H_0$  will be rejected and that there is at least one investigated

factor for which there is enough evidence to consider that it influences potential adoption.

**Hypothesis 2:** There is no difference in the willingness to plant trees as energy crops among those landholders whose properties are located in areas with lower biomass productivity values and those landholders whose properties are located in areas with higher biomass productivity values.

$$pl = f(\beta_i Z_1, Z_2, Z_3)$$

Where:

pl = willingness of planting trees as energy crops or the area of planting

Z<sub>1</sub> = location of farm site with lower productivity

Z<sub>2</sub> = location of farm site with medium productivity

Z<sub>3</sub> = location of farm site with higher productivity

The null hypothesis would then be:

$$H_0: \beta_i Z_{1,2} = 0$$

The alternative hypothesis:

$$H_a: \beta_i Z_{1,2} \neq 0$$

Another key factor influencing adoption is farm location. *A priori*, the expectation is that landholders' adoption decisions would be based on a biomass productivity gradient, for example, those whose properties are located in wetter, richer soil areas, would be less likely to be interested in planting trees for bioenergy. On the other hand, landholders whose properties are located in less productive and drier areas would be keen to adopt tree planting for bioenergy. Landholders' sites located in medium productivity areas may not have a strong preference either way. The assumption is that lack of profitable alternatives in drier areas may influence the adoption decision. Above-ground biomass productivity values were obtained for the approximate locations of landholder sites (Velarde 2012), in Microsoft Excel format, from a CSIRO map of biomass productivity for New South Wales (Polglase et al. 2008) in dry tonnes per hectare per year (Figure 11). Three categorical variables of productivity instead of one continuous measure were used in the model because only approximate farm locations were provided by survey respondents, when mapping these approximate locations to the

productivity layer (Polglase et al. 2008), high variability occurred between neighbouring pixels, hence, after discussion with thesis advisers, it was deemed that dummy productivity values (lower, medium and higher productivity) were better suited for modelling.

### c) Hypotheses for landholder preferences on contract attributes

The second research question investigated landholders' preferences about key attributes of contracts for planting trees as energy crops. The choice experiment presented landholders with tradeoffs in order to find their preferences between, for example, a shorter contract but with higher returns, or a higher return contract with no flexibility. The *a priori* expectation is that landholders in general would prefer shorter contracts, higher annual returns, and to have the flexibility to choose the harvesting company. Although this expectation may sound like common sense, it is important to test, before interacting the contract attributes with landholder characteristics.

**Hypothesis 3:** Landholders' preferences do not influence any of the attributes in the choice experiment.

$$ch = f(\alpha - \beta_1 \text{ len} + \beta_2 \text{ ret} + \beta_3 \text{ flex})$$

Where:

ch = choice (1,0)

len = length of contract

ret = return of contract

flex = flexibility of contract

The null hypothesis would then be:

$$H_0: \beta_1 = \beta_2 = \beta_3 = 0$$

The alternative hypothesis is:

$$H_a: \beta_n \neq 0, \text{ where } n=1, 2, 3.$$

In the null hypothesis, the values of  $\beta$  are equal to zero, and the attributes of the contract options have no influence on the choices made. The alternative hypothesis indicates that the coefficients are different from zero. The expectation is to reject the null hypothesis. The values for the choice attributes (length, return, flexibility) are presented in Section 3.4.4. The survey also collected landholder and property characteristics and interacted these with the choice attributes.

**Hypothesis 4:** Landholder and farm characteristics investigated do not influence landholders' preferences for contract attributes in the choice sets.

$$\text{ch} = f(\beta_1 \text{len} + \beta_2 \text{ret} + \beta_3 \text{flex} + \beta_4 \text{L*len} + \beta_5 \text{L*ret} + \beta_6 \text{L*flex} + \beta_7 \text{F*len} + \beta_8 \text{F*ret} + \beta_9 \text{F*flex})$$

Where:

ch = choice (1,0)

len = length of contract

ret = return of contract

flex = flexibility of contract

L = landholder characteristics investigated

F = farm characteristics investigated

The null hypothesis for the j-th effect,  $j=1, \dots, 9$ :

$$H_0: \beta_j = 0$$

and the alternative hypotheses:  $H_a: \beta_j \neq 0$

As in Hypothesis 3, it is expected that the null hypothesis will be rejected, and that at least one of the landholder or farm characteristic investigated will be significant. Further details on how attributes were selected and the levels used for testing are in Section 3.4.4. Hypotheses 3 and 4 were tested using different choice modelling approaches to evaluate which one provides more robust results (see Section 3.5 for the econometric models used, and Chapter 4 for the model results).

Four hypotheses were explored in the quantitative part of the study. These hypotheses tested factors that could influence the adoption of contracts for planting tree energy crops, excluding tree energy crop profitability, which is assumed to be a key adoption factor based on the literature. Qualitative

perceptions or opinions on agroforestry, bioenergy or carbon policies, which may have had an impact on decision making, were documented during the pilot survey. In particular, landholders in the pilot phase had very negative comments about carbon policies. Consequently, any mention of carbon was avoided during the final survey. This pilot finding contradicts the results of a survey (n=352) about the adoption of tree planting for carbon sequestration in neighbouring areas to the Central West New South Wales region (Schirmer & Bull 2011, 2014). The final survey focused on offering landholders a set of contract options to express their preferences and study how contracts for bioenergy should be designed.

Qualitative comments to the survey were noted, in particular, the reasons for non-adoption, and were analysed to better understand these reasons (see Chapter 4). These notes were coded in Microsoft Excel and used throughout the analysis and discussion chapters (Chapter 4 to Chapter 6).

#### **d) Multiple working hypotheses for critical mass**

The third research question about how to build critical mass was partially built on the responses to the first two research questions. Working hypotheses about key pathways for building critical mass that guided this part of the study include:

- Landholders' decisions are crucial to obtain critical mass of biomass to start a bioenergy industry
- Pathways to build critical mass of landholders include policies, market demand and involvement and leadership of local actors
- Trust is needed across all pathways as a factor to secure a sustainable and reliable biomass supply chain.

These *a priori* hypotheses were not statistically tested, rather, the information was gathered through observations, interviews and discussion with landholders, and bioenergy experts, and a more focused literature review on bioenergy adoption factors (Appendix 1) was used in the analysis of these hypotheses in an integrative manner as described in Section 3.5. The results of this integrated analysis are shown in Chapter 5 and discussed in Chapter 6.

### 3.3 Setting and participants

#### 3.3.1 Site selection

The Lachlan and Central West catchments were chosen as focus areas out of four potential sites assessed, to conduct the study (Table 5). These catchments allow accommodating for the sampling mode (surveying landholders at local agricultural events). Their bio-physical characteristics allow for tree energy crops to grow, and local awareness and government and private interest in bioenergy are present. They are also accessible within the resource constraints of this research. Moreover, high quality data on biomass production for the Central West region (that covers most of the Lachlan and Central West catchments) was made available for this thesis. This data is based on prior work by the CSIRO (e.g. Polglase et al. 2008; Rodriguez et al. 2011c; see Appendix 12).

Other regions assessed included the wheat-belt region of Western Australia and the Murrumbidgee catchment in New South Wales. The wheat-belt region satisfies most of the criteria for site selection, in particular, experience in tree planting for bioenergy purposes<sup>11</sup>. However this region presents poor access due to resource and time constraints. The three catchments assessed in New South Wales (Lachlan, Central West and Murrumbidgee) show medium to good accessibility to private transport. The Lachlan catchment complies with most of the criteria specified in Table 5. The Murrumbidgee catchment and Central West catchment also present good prospects as study sites.

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<sup>11</sup> Mallee trees were planted on farms in this region in the early 1990s to reverse soil salinity problems. In 2008, these plantings reached 12,777 hectares. The drivers for adoption of mallee trees on farms include: potential for diversification and local processing, potential for integration into traditional agricultural systems, natural resource management and carbon sequestration (URS Australia Pty Ltd 2009, p. 6). The leaves of mallee trees are used to produce eucalyptus oil. This oil can be used in pharmaceuticals, cleaning products and perfumes (DAFF 2005b).

**Table 5 Assessment of research sites**

Site selection criteria	New South Wales			Western Australia wheat-belt
	Lachlan catchment	Central West catchment	Murrumbidgee catchment	
Annual rainfall at least 300 mm/year <sup>a</sup>	Y	Y	Y	Y
Awareness about bioenergy from biomass in the region	Y	Y	Y, limited	Y
Interest in tree planting for bioenergy purposes	Y	..	..	Y
At least one experience of tree planting for bioenergy purposes	Y	..	..	Y
Active Landcare groups in the region	Y	Y	Y	Y
Data available about economic activities in the area	Y	Y	Y	Y
High quality biomass data available	Y	Y	N	N
Access within budget and driving time constraints <sup>b</sup>	Y	Y	Y, limited	N

**Note:** <sup>a</sup>Australian Government Bureau of Meteorology (2011), <sup>b</sup>not more than eight hours on private transport from Canberra, Y = Yes, N = No, .. = not available.

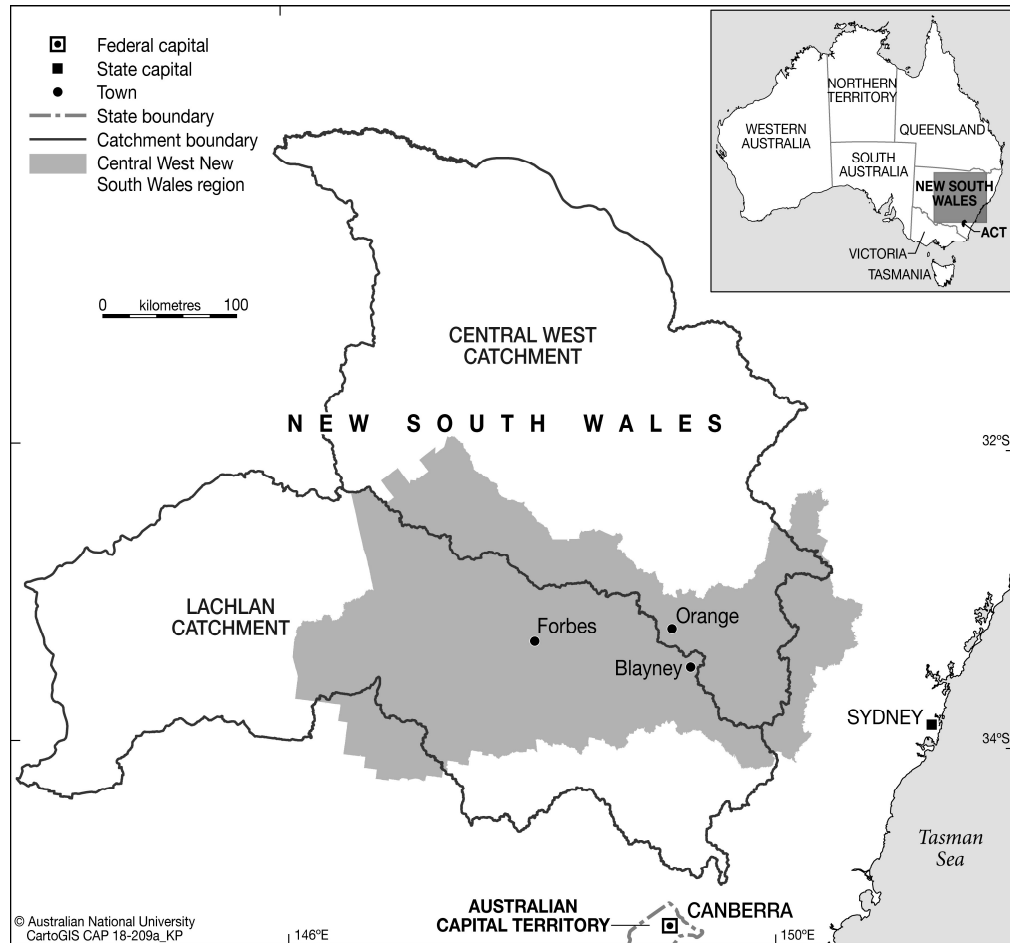
### 3.3.2 Overview of the case study region

#### a) Geographical location

The Central West region of New South Wales is located 250 to 350 km west of Sydney, the capital city of New South Wales (Figure 5). The region lies across two catchments: The Central West and Lachlan catchments (Figure 6 and Figure 7). Although the combined boundaries of these two catchments differ from those

of the Central West region this thesis has the standing assumption that the combined data from both catchments is representative of the Central West region. Landholder information in Australia is reported at the Natural Resource Management (NRM) level, equivalent to the catchment area. This information includes number of agricultural businesses, details about landuse, crops and income from main agricultural commodities. The main regional service centres include Orange in the Central West catchment, and Forbes and Blayney in the Lachlan catchment.

**Figure 5 Map of the Central West New South Wales region**



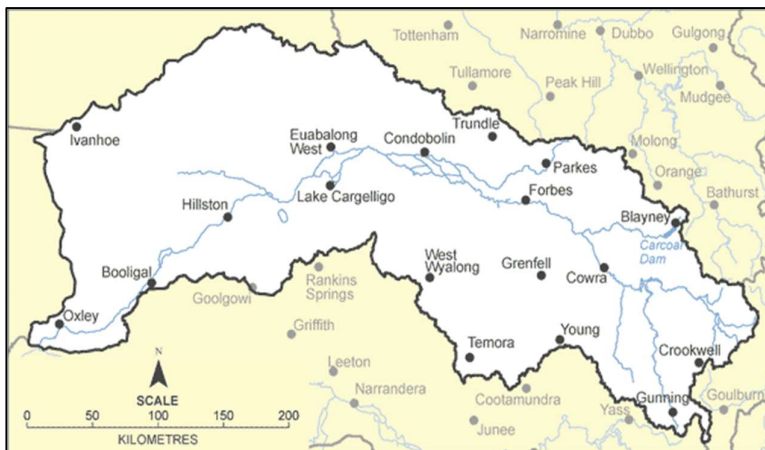
**Source:** Australian National University CartoGIS elaborated with GIS data from Commonwealth of Australia (Murray–Darling Basin Authority) (2012) and CSIRO regional maps.

**Figure 6 Map of the Central West catchment**



**Source:** NSW Office of Water (2015a)

**Figure 7 Map of the Lachlan catchment**



**Source:** NSW Office of Water (2015b)

**b) Socio-economic activities**

Grazing and cropping are the main land uses in the selected catchments (Australian Bureau of Statistics 2011). These catchments have fewer than 0.5 per cent of forestry plantations. Conservation uses of land comprise 3.2 per cent in the Lachlan catchment, whereas this is only 1.3 per cent in the Central West catchment (Table 6). While grazing is the major activity in both catchments, cropping is the second largest activity. Gross margins for livestock in New South Wales vary from AUD 165 per hectare for export cattle destined to the European

market (EU cattle) to AUD 220 per hectare for merino ewe 20 microns<sup>12</sup> (Figure 8). Among the common crops in the region, long fallow wheat provides the highest gross margin value (AUD 389 per hectare), while faba beans production runs at a loss (AUD -5.85 per hectare) (Figure 9). Livestock is usually run as part of a mixed farming system (cropping and livestock), although some farms only work with livestock and other farms that only crop (New South Wales Department of Primary Industries 2012).

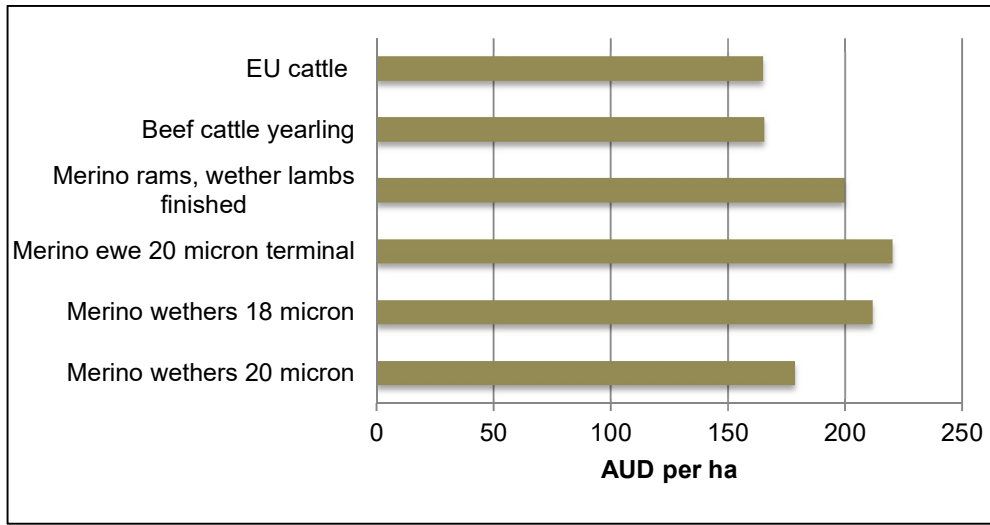
**Table 6 Land use in the Lachlan and Central West catchments**

<b>Land use</b>	<b>Lachlan catchment (% of land)</b>	<b>Central West catchment (% of land)</b>
Crops	27.7	25.5
Grazing – Improved pasture	30.2	34.7
Grazing – Other grazing land	35.7	34.6
Forestry plantation	0.1	0.4
Other agricultural purposes	0.1	0.0
Conservation	3.2	1.3
Other land not used for agricultural purposes	3.0	4.0

**Source:** Australian Bureau of Statistics (2011).

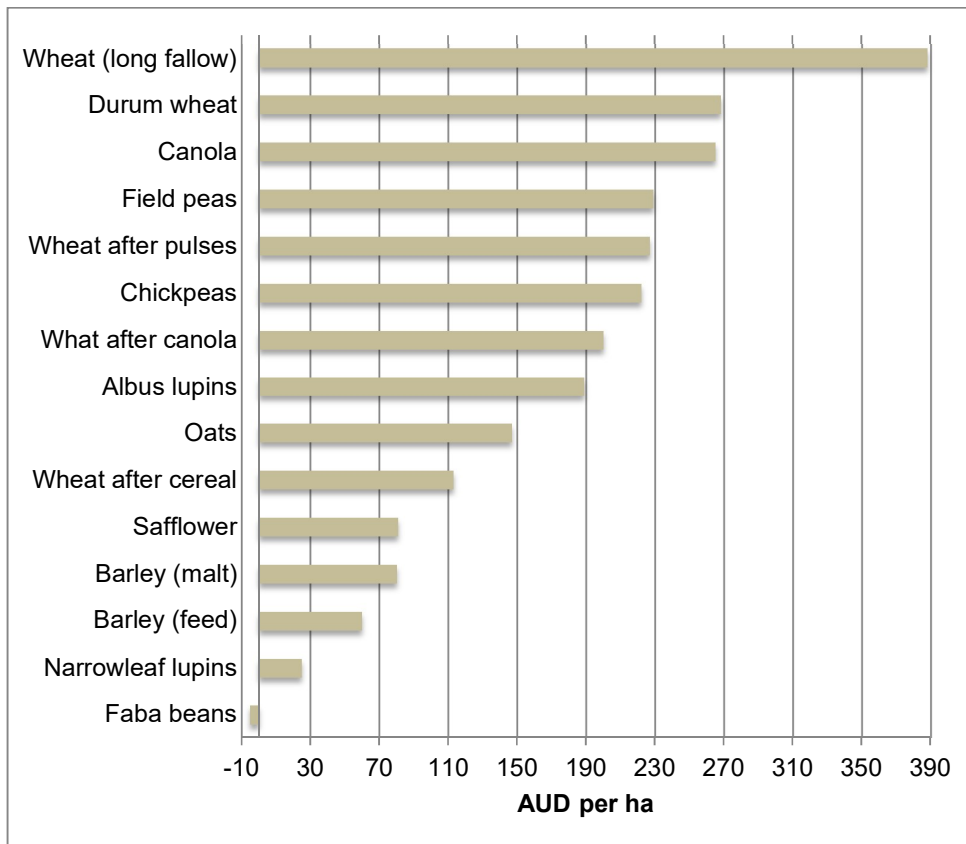
<sup>12</sup> A micron (micrometre) is the measurement used to express the diameter of wool fibre. Twenty to 21 microns is the average fibre diameter of merino wool in New Zealand when wool testing began in 1980s. The current average is 19 and the finest wool is 12 microns (Nicol and Saunders, 2018).

**Figure 8 Gross margins of livestock in New South Wales, 2012**



Source: New South Wales Department of Primary Industries (2014)

**Figure 9 Gross margins of crops in the Central West New South Wales, 2012**



Source: New South Wales Department of Industry and Investment (2012)

### **c) Government support for bioenergy**

Different levels and types of government support for bioenergy were available at the time of conducting this study. Support included research, awareness raising and policies. At the national level, the Australian federal government commissioned several studies to explore the bioenergy potential in the case study region. For example, the Rural Industries Research and Development Corporation (RIRDC) funded the Blue Mountains – Central Tablelands project/University of New South Wales: Bioenergy from native agroforestry (Merson et al. 2011; Baumber et al. 2011; Baumber et al. 2012). The Department of Agriculture, Fisheries and Forestry (DAFF) funded the CSIRO's biomass assessment of Lithgow in Central West New South Wales as part of a larger regional assessment (Rodriguez et al. 2011c). Moreover, Larkin & McMullen (2014) documented the results of a pilot experience on biomass for power generation in the Lachlan Shire. All the studies mentioned showed potential for bioenergy development in the Central Tablelands, the Central West New South Wales region and the Lachlan catchment, respectively.

At the local level, the Lachlan Catchment Management Authority raised awareness about existing trials of native mallee trees for bioenergy at the time of conducting the fieldwork (2011-2012) through a media campaign to publicise the trials, community information booths available at local shows and energy forums, and by organising and conducting series of focus groups, farm visits and field days to introduce these trials to other farmers (Larkin & McMullen 2014). In addition, two local councils in the Lachlan Catchment, Forbes and Parkes, organised various 'Alternative Energy Forums' in 2011 in which I participated (see Table 7).

Relevant national policies with an impact on renewable energy, presented in Chapter 2, include the Mandatory Renewable Energy Target (MRET), the Carbon Farming Initiative and a carbon price mechanism (in place from 1st July 2012 to 1st July 2014).

#### **d) Business models and private interest in biomass production**

Based on my own observations and the literature available for the case study region, two business models currently exist to build a critical mass of mallee tree growers in the Central West region, New South Wales. The first model is based on individuals dealing with one consolidator or intermediary who then deals with a buyer. The second model refers to joint networks of landholders and/or multi-stakeholder groups, who collectively can negotiate agreements with a buyer. Examples of the first model include a pilot biomass production value chain and a carbon offsets company that consolidates dedicated carbon sequestration plantings across Australia.

A real life trial programme exists in order to develop a biomass production value chain in the case study region. It aims to produce biomass for co-firing (i.e. replacing part of the coal used) in a nearby electricity plant. Under this programme, farmers negotiate individually with a ‘local champion’/project developer who acts as the broker of a marketing company to: 1) determine the economic and biophysical feasibility of growing mallee trees for bioenergy production; and 2) set the terms and conditions of growing biomass to be drawn in the supply contract. Once the contract is signed and the biomass grown, the biomass would be harvested. The broker would then sell the biomass to the final user, i.e. the electricity company. Trial farms are located in the Lachlan Catchment (specifically around the towns of Forbes, Parkes and Condobolin). The programme has run since 2010 (Horner 2011). Members of this pilot programme are Delta Electricity<sup>13</sup> (a coal-based NSW State owned electricity company), the NSW Department of Primary Industries and GreenLine Biomass/Aurora Research. By 2011, 10 farmers had participated in the pilot phase (Everett 2011).

The contractual conditions of the above trial are explained by Larkin & McMullen (2014) as follows: Subject to contract, the project developer offers to establish the bioenergy tree crop at no cost to the landholder including a farm audit, seed and seedling propagation, ground preparation, planting and spraying, to monitor and

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<sup>13</sup> Formerly known as Delta Energy.

maintain the trees and to harvest and provide all related logistics and supply chain management. Landholders must provide access to the trees planted (including to contractors and representatives), ownership of the trees to the project developer, inform of any intention to sell the land, tree crop protection including pest, fire, weed and livestock control and tree protection following farm safety regulations. The contract offers an additional revenue stream to the landholders who are to be paid for above ground biomass production and below ground sequestered carbon, and a possibility of collateral benefits, e.g. from windbreaks created by the tree crop. By covering the establishment costs, providing the 'know-how' of supply chain management, opening up a revenue stream, the contract addresses the main barriers to adoption of an energy crop from a landholder perspective and creates certainty in the biomass buyer that supply will be available at amounts and quality required. At the same time, the project developer coordinates across the value chain, from producer to final buyer. The example above illustrates the importance of supply contracts to establish functioning bioenergy systems. It also notes the importance of local champions to build networks and guide supply chain co-ordination (McCormick & Kåberger 2007, p. 451).

In the second example, an Australia carbon consolidator company, CO2 Australia, received expressions of interest from landholders, then scoped the feasibility of planting trees for carbon sequestration on-farm and agrees on terms and conditions with the landholder. The minimum area that CO2 Australia required for scoping landholder farms was 50 ha of available land for planting (CO2 Australia 2012) at the time of conducting the study. Their product is carbon credits, which CO2 Australia consolidates across farms to sell to private companies.

A second business model present in the region at the time of the study was a community organization of oil mallee producers. The idea of planting oil mallee originated in the trials at the Condobolin Agricultural Research Station in 1989, and a group of landholders formed the Lachlan Renewable Energy Alliance (LREA) in 2006. In 2008, a sub-group of LREA formed the company MalleeCondo Pty Ltd. This company explored lower-volume, higher-value

products in the home heating sector (Baumber et al. 2011, p. 269). While the community organisation model may increase the sense of ownership of farmers in the business, compared to individual contractual arrangements as described in the first business model, farmers may have seen this second model as more complex and time consuming because of the specific processes and relationships critical for the success of such collaboration network, such as learning, local capacity building and establishing clear decision-making rules (Head 2008). The fact that this company was deregistered in early 2013 suggests that this model was not feasible under the prevailing circumstances in the period 2008 to 2012. Perhaps more stable energy and carbon policies would have resulted in a different outcome. From a farmers' perspective, the choice of business model, will determine how the critical mass for biomass would be achieved.

### **3.3.3 Research participants**

Three broad group of participants participated in this research. The first broad group consisted of key informants. The second broad group included participants in different events that took place while conducting this research. The third broad group comprised landholders from New South Wales who participated in the landholder surveys (preliminary through to final).

Key informants were selected using purposive sampling and recruited through personal contacts and recommendations from supervisors. Purposive sampling draws participants from relevant categories of interest, rather than on statistical basis (Sharp et al. 2013, p. 1252). Semi-structured interviews were conducted with eight key informants, among them two landholders from the case study region, who provided in depth feedback to the preliminary survey. One of these landholders was part of the pilot bioenergy mallee plantings by Delta Energy and another one was interested in exploring mallee plantings for bioenergy and for carbon. Other key informants included a bioenergy researcher running a project in the case study region, a local government economist working on energy crops in a different region of Australia, a behavioural economist, an anthropologist, a former primary school teacher, and a rural education expert. These informants were selected because of their knowledge of regional areas of New South Wales where

they have worked or lived in, and their ability to provide insights on rural issues and how bioenergy may fit in the bigger picture. In addition to the key informants mentioned above, a group of Australian bioenergy systems experts provided insights to the research design and feedback during 2010-2014. These experts were part of the former Sustainable Biomass Production team at CSIRO. They have expertise in forestry, agronomy and farming systems, ecology, economics, soil science and hydrology, spatial modelling, life-cycle analysis, climate change, policy analysis, process engineering and biotechnology (O'Connell et al. 2013).

The second broad group included attendants to different externally organised events, in which I participated between August 2011 and December 2012. These events included eight field days and agricultural shows, one workshop, and six conferences, fora or expos and one online forum (Table 7). Conversations about this research were held with several attendees to these events. The major conference attended was the annual Bioenergy Australia conference in 2011, the major national bioenergy industry forum. The workshop attended intended to assess the feasibility of developing a regional bioenergy industry involving native agroforestry in the Central Tablelands, New South Wales<sup>14</sup>. This workshop was organised by the University of New South Wales (UNSW), the Blue Mountains World Heritage Institute at the UNSW, and the Future of Australia's Threatened Ecosystems Programme at the University of Sydney, funded by the Department of Agriculture, Fisheries and Forestry (DAFF) and the Rural Industries Research and Development Corporation (RIRDC). Two alternative energy events in the case study region provided further opportunities for discussing this research with participants who are interested in bioenergy. The events attended presented unique opportunities to better grasp farming issues in New South Wales and in rural Australia, particularly related to renewable energy. They also helped me to engage with key stakeholders which provided various opportunities for discussing my research and build networks. The author acknowledges that the views by these

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<sup>14</sup> The Central Tablelands, New South Wales includes the Eastern part of Central West New South Wales.

stakeholders were somewhat biased towards alternative energy across the spectrum, from supporters to opponents and also simply curious individuals with an interest on this topic. The landholder survey however was not conducted at these two events.

The third group comprised landholders surveyed between September and December 2012. Forty one landholders participated in the preliminary and pilot surveys at four geographic locations (Condobolin, Canowindra, Morongla and Bribaree, New South Wales) (see Table 7). One hundred and sixty two landholders participated in the final survey of which 155 responses were considered valid. The final survey was conducted in October 2012 at the Australian National Field Days at Borenore, on the outskirts of the town of Orange, New South Wales. This event is attended by landholders from all over the Central West region, New South Wales and different parts of Australia. A backup survey was conducted after the final survey, in Young, New South Wales. However, its results were not used in the analysis because most of the attendees were unexpectedly not part of the target population (tourists from Queensland rather than local residents).

**Table 7 Local, regional and national events attended**

Type of event	Name	Place	Date
Field days, agricultural shows and festivals	Farmer field days, Delta Electricity and Aurora Research	Condobolin, NSW Tullamore, NSW	29 August 2011 30 August 2011
	Farm field day	Booligal-Hay, NSW	27 May 2012
	Field day <sup>a</sup>	Condobolin, NSW	18 September 2012
	Agricultural show <sup>a</sup>	Canowindra, NSW	22 September 2012
	Agricultural show <sup>b</sup>	Morongla, NSW	30 September 2012
	Agricultural show <sup>b</sup>	Bribaree, NSW	1 October 2012
	Australian National Field Days <sup>c</sup>	Borenore, NSW	16-18 October 2012
	National Cherry Festival	Young, NSW	30 November-2 December 2012
Workshop	Potential for bioenergy and agroforestry in the NSW Central Tablelands, UNSW <sup>d</sup>	Lithgow, NSW	14 November 2011
Conferences /Forum/Expo	Regional conference, Energise Central NSW	Cowra, NSW	5-6 August 2011
	Alternative Energy Expo	Forbes, NSW	3 September 2011
	NSW Landcare Catchment Management Forum	Parkes, NSW	5-7 September 2011
	Annual conference Bioenergy Australia	Sunshine Coast, Queensland	23-25 November 2011
	National conference on Sustainable Rural Communities	Narrabri, NSW	18-19 April 2012
	AgChatOz Live	Canberra, ACT	18 September 2012
Online forum	AgChatOz	Online (via Twitter <sup>TM</sup> )	Observed: July 2012 - July 2013, participated online 14 August 2012

**Notes:** <sup>a</sup>Preliminary survey, <sup>b</sup>Pilot survey, <sup>c</sup>Final survey, <sup>d</sup>Central Tablelands is part of the Central West New South Wales region.

### **3.4 Research tools and procedures for data gathering**

#### **3.4.1 Participant observation and interviews**

The research process followed in this study benefited from qualitative research tools including participant observation and semi-structured interviews. Participant observation was used to start this research. Semi-structured interviews were used to discuss the preliminary landholder survey with key informants and experts.

Participant observation encompasses ‘spending time being, living or working with people or communities in order to understand them’ (Laurier 2010, p. 116). The researcher takes part in the daily activities and interactions of a group of people in both common and uncommon activities (DeWalt & DeWalt 2011). The length of time spent will depend on the objective of the research and the type of study conducted. For example, ethnographers such as Emerson et al. (2001) note the need of a relatively long-term approach for participation. In this research, the purpose of using participant observation was to familiarise myself with the geographical area to better understand the local context, and in particular, to identify how bioenergy fits into the adoption of innovation landscape in the rural setting of the Central West New South Wales, Australia.

The tools used for data collection were field-notes of personal impressions about the events attended. The types of events and fora attended varied from farmer field days, and agricultural shows, to industry conferences and online fora, all were public events except one workshop where I was invited to attend (Table 7). When the event attended required prior registration, the organiser(s) were informed via email or phone of my research and the purpose of attending. Oral informed consent was gained from the people I talked to about my research at these events. Informal conversations on the other hand, do not require informed consent in participant observation. Details on ethics approval for this research are provided in the next section.

In addition to the events attended, I have also been a Student member of the New South Wales Farmers’ Association and the Institute of Foresters Australia during the time of this research, and observed and participated in the online forum

‘AgChatOz’ on Twitter<sup>TM</sup> and a live version (face-to-face), to keep abreast of the most up to date information about agriculture and forestry issues in New South Wales and Australia.

Data gathered through participant observation was coded manually in field notebooks, highlighting relevant keywords, for example, adoption of innovation, farm forestry and trust. Through participant observation, key insights and contacts were obtained and used in further semi-structured interviews that discussed the preliminary surveys. Using participant observation allowed me to: 1) network with regional actors (e.g. Catchment Management Authorities, NSW Farmers’ Association, Landcare groups, farmers, local officials, and researchers in rural issues in Australia); 2) familiarise myself with the policy and geographical context of the research problem; 3) understand field logistical constraints that could affect the sampling modes and research budget; 4) grasp important landholder issues in the case study region and how bioenergy could fit into farming practices and the broader landscape.

Semi-structured interviews were conducted with key informants and used the preliminary survey as the main discussion tool. I personally knew key informants at the time of arranging the interviews, from attending previous events. The informants provided informed consent via email. Then they were emailed the preliminary survey before the interview and agreed to take part in the semi-structured interview. The preliminary survey included questions about adoption factors as found in the literature and factors discussed with bioenergy researchers and stakeholders at the public events as described earlier. The interview included general questions about their involvement with the case study region or bioenergy topic, tree energy crops and adoption of innovation. Interviews typically lasted one to one and a half hours, although some lasted as long as two hours. Interview notes were recorded by hand, focusing on the adequacy of the questions of the preliminary survey. One of the key informants shared their comments in writing before the semi-structured interview. The main outcome of the semi-structured interviews was the pilot survey.

### 3.4.2 Ethical considerations and intellectual property

The ANU Human Research Ethics Committee approved the methods used in this study<sup>15</sup>. No significant issues were found in the field phase as involvement in the research was voluntary and the target research participants were adults. Research participants could pull out at any time and were made aware of this from the beginning of the interactions. Coded databases with landholder surveys were archived so that individual confidential information cannot be identified.

Although the surveys were face-to-face, they were actually anonymous, as no name or address was recorded, only town names and codes for each landholder in the form of enumerator initials and a number, e.g. SV-01.

A Student Agreement<sup>16</sup> that included clauses about Intellectual Property (IP)<sup>17</sup> was signed between myself, the ANU and the CSIRO. Following this agreement, the CSIRO owns all IP generated within this thesis, while I own the copyright. The CSIRO also owns their background IP<sup>18</sup> used mainly in Section 3.5.3, and in Section 5.3. This background IP was produced by CSIRO staff, mainly, but not exclusively, within the scope of the project ‘Assessment of the environmental and economic opportunities and constraints associated with bioenergy production from forest biomass in two prospective regions of Australia’, funded by the Department of Agriculture and Water (formerly DAFF) (Department of Agriculture and Water Resources 2016). Within this project, the CSIRO modelled and generated biomass datasets for the Central West region, New South Wales. This CSIRO project also used former CSIRO background IP (Almeida et al. 2007; Polglase et al. 2008) to model biomass and a transport model developed by Dr Barry May that follows Lambert and Quill (2006). The results of the CSIRO project are available in a report by Rodriguez et al. (2011c) and the methods for biomass assessment information are summarised in Section 3.5.3. The details of

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<sup>15</sup> ANU Human Research Ethics Protocol 2012/418.

<sup>16</sup> The signed agreement is filed at the ANU Crawford School of Public Policy and the CSIRO.

<sup>17</sup> ‘IP’ means any rights in any copyright work (including any work or item created in the future), invention (whether or not patent protection has been sought), design, circuit layout, new plant variety, trademark, know-how or trade secret. (Definition extracted from Student Agreement).

<sup>18</sup> ‘Background IP’ means the IP identified in the details and any IP which is or has been created independently of the Project which is contributed by a party to perform the Project. (Definition extracted from Student Agreement).

all background IP provided by the CSIRO for this research are available in Appendix 12. Below is a list of CSIRO IP used in this thesis:

- Modelled biomass data of *Eucalyptus cladocalyx*, for two scenarios: high stocking five-year rotation average climate (HS5YAC), low stocking 10-year rotation average climate (LS10YAC), extracted for the Orange case study area (a 100 km radius area around the town of Orange, Central West, New South Wales) in DBF format
- Modelled biomass data of softwood biomass (Radiata Pine) for a 100 km radius area around the town of Orange case study area, for the years 2011, 2020 and 2030, in DBF format
- A spreadsheet of softwood feedstock assessment for Central West New South Wales, in Microsoft Excel format. This spreadsheet was used to input the softwood biomass data from the set of DBF files mentioned above for the Orange case study area
- A map of biomass productivity for New South Wales (Polglase et al. 2008) that shows the landholder sites (Velarde 2012), in JPG format.
- Extracted biomass productivity data for landholder sites, in Microsoft Excel format (Polglase et al. 2008)
- A transport model for biofuel/bioenergy generation in Microsoft Excel format. This model was built by Dr Barry May (2011) based on Lambert and Quills (2006). This model was provided by the CSIRO in February 2015 and used to compare transport cost data
- A set of GIS files of a radius of 100 km around the town of Orange, Central West, New South Wales
- A set of GIS files of the Central West, New South Wales boundary
- A set of GIS files of landholder site locations. This set was produced by the CSIRO using data provided by Velarde (2012).

### 3.4.3 Landholder survey

This study used a landholder survey as the main research tool. This section will explain the decision about the sampling mode and the sample size for the landholder survey, the survey design process, from preliminary to final, and the survey instrument.

#### a) Decision about sampling mode

A face-to-face sampling mode was selected. Mail, telephone, online and face-to-face surveys were evaluated as the sampling modes. The selection criteria included the potential for obtaining good quality data and being cost-effective within budget constraints. The first sampling challenge was that a survey frame was not available to the researcher at the time of planning the survey<sup>19</sup>. A survey frame or sampling frame is a database of contacts that can be used to obtain a list of random survey respondents. These contacts can also be obtained from each of the local governments or, alternatively, liaising with them to mail the surveys out. These options were considered to be very time consuming. Online sampling frames were explored by approaching a private marketing company. However, they stated that it is difficult to find farmers in the online environment in Australia (Pureprofile, personal communication)<sup>20</sup>. This statement is supported by evidence from a recent Australia wide survey about agriculture technology (n=662, 82 per cent of them were farmers) (Pengilley 2012). Pengilley (2012) found that while 98 per cent of respondents use email, only 31.9 per cent of them are in the 50-59 years old group. While the average age for the target population of this study (i.e. 56 years old) was within this fraction, the chances of obtaining the required number of respondents was expected to be low.

A second challenge faced was that mail surveys are said to obtain low response rates (Berends 2006; Zikmund et al., 2013). Incentives could have been used to overcome low response rates. However, the use of incentives for participation creates new resource challenges. For example, anecdotal evidence showed that in order to obtain high response rates for email surveys as high as 80 per cent, the incentive has to be very large as well, e.g. a weekend at the Sunshine Coast (Coutts 2012). This high incentive would also result in other challenges such as

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<sup>19</sup> After the final survey was completed, a fellow researcher suggested using phone guides from the local areas. This method was used in research that targets general town dwellers, not specifically landholders/farmers. After reviewing some local phone guides I realised that it is difficult to know the address (i.e. farm location) as most landholders use a P.O. Box.

<sup>20</sup> At the final oral presentation of results of this thesis (June 2014), an expert choice modeler noted the existence of specialized rural panels for farmer online surveys in Australia. This information was not available to the researcher at the time of planning, designing and conducting the study.

getting invalid answers from those respondents who responded to the survey mainly in order to get into the prize draw.

Given these challenges, mail, telephone and online survey options were not considered further as sampling modes. The face-to-face sampling mode was selected. However, given that a sampling frame was unavailable, an alternative was sought as the sampling mode, as explained next.

**b) An innovative approach for landholder sampling**

An innovative approach to survey farmers was designed as the sampling mode; a face-to-face survey in an informal social setting familiar to landholders, such as agricultural events. This sampling mode would not only increase the response rate but also add a social dimension to the research. The social dimension refers to the researcher and enumerators interacting directly with landholders and being able to take notes on reactions, comments, or any other relevant information that could inform this study. However, potential biases of this sampling mode are acknowledged such as interviewer bias and peer pressure. Interviewer bias was mitigated through training as explained next. Peer pressure refers to landholders' being influenced by their peers. This bias was mitigated by interviewing the landholders individually whenever possible.

The agricultural events used to collect data are held only once or twice a year on the outskirts of most regional towns in New South Wales, increasing the chances of landholders attending. In order to obtain the needed number of landholder surveys and reduce the chances of interviewer bias, volunteer enumerators<sup>21</sup> were trained and participated in six surveys, from the preliminary to the final and a backup survey (Table 7). Training of enumerators was done mainly in face-to-face meetings held usually one or two weeks before each event. A dry-run of the survey was done before the final survey, rehearsing different responses, dealing

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<sup>21</sup> Twelve volunteer enumerators, mostly postgraduate students were recruited. Half of them participated in the pilot surveys and half of them participated in the final survey. Enumerators were students at the Australian National University, University of New South Wales at the Australian Defence Force Academy, University of Western Sydney, and Charles Sturt University.

with rejection and general survey protocol procedures (e.g. how to identify themselves, hand in the information sheet, thank the respondent).

### **c) Sample size**

It is important to note the difference between a theoretical sample size for estimating adoption factors, based on the number of individual landholders, and choice-based sampling for the choice experiment embedded within the landholder survey. A theoretical sample size was first estimated for the Central West New South Wales region considering a random sample of landholders at 95 per cent confidence level (Table 8). Data for the Lachlan catchment and Central West catchments were used to calculate the number of landholders in the Central West region.

The number of agricultural businesses in the Lachlan and Central West catchment was obtained from the Australian Bureau of Statistics (2011) and used as a proxy for the number of landholder in each catchment. However, not all landholders run an agricultural business. Some ‘hobby farmers’ or ‘lifestyle’ landholders may have been left out of this statistic and they are also not reported in the official statistics as such, so it is difficult to estimate their number. This lack of information is recognised as a limitation in the estimation of landholders. Nevertheless, the number of agricultural businesses provided a good starting point.

Two variables were explored to compare the expected proportion of individuals who would be willing to plant trees as bioenergy crops and to estimate the theoretical sample size: Landcare membership and experience planting or sowing trees or shrubs. The reason for choosing these variables is that landholders who are Landcare members already plant shrubs or trees and therefore could be interested in planting trees for bioenergy. Second, landholders who have had experience planting trees or shrubs may also be willing to plant trees as bioenergy crop as they already understand this activity.

When the proportion of Landcare members (Table 8, row 3) is used as an indicator of potential landholders who would consider planting trees as bioenergy

crops, the minimum sample size in the Central West would be 65 individuals or 195 choices, if they were presented with three choices. On the other hand, if the proportion of individuals who have experience planting trees is used, then the sample size is 54 individuals or 162 choices.

**Table 8 Theoretical sample size parameters**

Row	Parameter	Lachlan catchment (A)	Central West catchment (B)	Central West region (A+B)
1	Number of agricultural businesses <sup>a</sup>	5,228	5,405	10,633
2	Member of Landcare group <sup>a,b</sup>	1,203	970	2,173
3	Proportion of Landcare members	0.23	0.1795	0.2043
4	Sample size (number of individuals) <sup>c,d</sup>	..	..	65
5	Sample size (number of choices) <sup>c,d</sup>	..	..	195
6	Planted or sown trees and shrubs <sup>a</sup>	972	759	1,731
7	Proportion of landholders who have planted or sown trees and shrubs	0.1859	0.14	0.16
8	Sample size (number of individuals) <sup>c,e</sup>	..	..	54
9	Sample size (number of choices) <sup>c,e</sup>	..	..	162

**Note:** <sup>b</sup> Relative standard error of 10 to less than 25% and should be used with caution; <sup>c</sup> Sample size at 95% confidence level, standard error 5%; <sup>d</sup> Proportion used: 0.2043; <sup>e</sup> Proportion used: 0.16.  
**Source:** <sup>a</sup> Australian Bureau of Statistics (2011); n calculations: National Statistical Service sample calculator (National Statistical Service 2012).

Having calculated the theoretical sample size, I then investigated choice-based sampling and how it is done in reality. Here, rules of thumb tend to be used

instead of statistical power. The first rule of thumb found was that the best strategy for sampling is obtaining 50 respondents, choosing each alternative presented (Hensher et al. 2005, p. 194). The second rule of thumb found was  $N \geq 50 + 8m$ , where  $N$  is the sample size and  $m$  is the number of factors in the model. This rule of thumb delivers a power of 0.8 or more for a multinomial regression with a medium effect size (Green 1991). Three factors were analysed in the choice sets: contract length, annual return and flexibility to choose the harvesting company, therefore, the calculation for this rule of thumb is  $50 + 8(3) = 74$ . A third rule of thumb for a 'medium-sized partial correlation between  $y$  and a predictor holding all other predictors constant' (Green 1991, p. 558) is  $N \geq (104 + m)$ . In this study,  $N \geq 107$ .

In the final sample, 155 valid responses were obtained in the survey. The sample size was therefore satisfactory, taking into consideration both the theoretical size and the rules of thumb used in choice-based sampling, as described above.

#### **d) Landholder preliminary survey**

A preliminary landholder survey was prepared based on the literature review and discussed with different audiences. First, it was discussed with an internal audience of thesis advisers, choice modelling experts and the ANU statistical unit. Second, it was discussed with seven key informants including landholders and rural experts, using semi-structured interviews (see Sections 3.3.3 and 3.4.1). In addition to the adoption factors, these landholder preliminary surveys explored the attributes and levels of contracts for planting trees as energy crops and led to building the pilot survey.

#### **e) Pilot survey**

The pilot survey was tested with 41 farmers in the study area at two agricultural shows in the rural towns of Morongla and Bribaree, in the Lachlan catchment, New South Wales. In the pilot survey, landholders were provided first with a scenario for tree planting for bioenergy and then asked if they would be willing to plant or not. Only those landholders who responded that they would be willing to plant had a look at the contract options. Twelve contract options were presented in six rounds of choices.

Following the pilot study, the wording and order of questions was changed in the final survey so that more landholders could look at the contract options first before deciding if they would plant or not. It was also clear that presenting six choices to a respondent was too burdensome and therefore I decided to present only three choices in the final survey.

Policy changes such as the merging of local agencies were announced in between the pilot and final surveys so a question that included different government agencies as individual organisations was modified to read “others”. Given the feedback of the pilot survey, some questions were modified, discarded or replaced, as detailed in Table 3. In addition to these changes, the feedback from the pilot survey was used to refine the values of the different attribute levels. The final list of attributes and levels used in the face-to-face surveys is shown in (Section 3.4.4).

The list of final factors or independent variables collected in the landholder survey is shown in Table 4, indicating the type of variable and the expected sign in the regression models. For those who expressed willingness to plant, further contract characteristics were explored including type of agreement, and layout and species preference outside the choice experiment.

#### **f) Final landholder survey**

The final landholder survey (Appendix 3) was conducted face-to-face with landholders attending the National Agricultural Field Days in Borenore, next to the town of Orange, Central West New South Wales from 16 to 18 October 2012. A random sampling method was used. Enumerators who were distributed evenly across the different street sites randomly approached passers by.

A total number of 573 people were approached, 280 of which were landholders from New South Wales (target population), and 163 of them answered the survey, reaching a response rate of 58 per cent. The estimated response rate was calculated as the proportion between answered surveys, by the number of approached landholders in the target group. Eight surveys were not used because

they were incomplete. Therefore, 155 surveys were considered valid and used in the modelling stage.

An information sheet was handed to the landholders at the beginning of the survey (Appendix 4). The landholder survey included five parts. The first part asked about the landholder farming experience, farming or land management goals, their property (size and unproductive area) and type of farming conducted. The second part asked about experience planting trees on their property, and what extension and layout (scattered, strips of trees, blocks of trees of less than one hectare and more than one hectare) they preferred. The third part introduced the choice experiment. For those landholders who chose to plant, the fourth part asked about specific preferences for planted trees for bioenergy. The fifth and last part asked about demographic characteristics.

In the choice experiment, landholders were asked their opinion about contracts for planting trees as energy crops under the key assumptions presented earlier in this chapter (Section 3.2.3-a.5). The scenario assumptions relate to an existing market, responsibility of the buyer for establishment costs and harvesting costs, decision of the farmer on layout and that a neighbour has signed a contract. The contracts introduced have three attributes:

- Length of the contract in years
- Return in AUD per acre per year
- If the contract is flexible and the landholder can choose the harvesting company ('Yes') or if the landholder has to accept the default company ('No').

Using showcards, landholders were shown three choice sets (one at a time) with three options each, where options A and B were bundles of the above attributes, and option C represented the *status quo* (i.e. no contract) (Table 9). The levels of each attribute and the experimental design are explained in Section 3.4.4. Six types of questionnaires were used in the survey (Appendix 6) based on the experimental design (Appendix 5).

**Table 9 Example choice set in a showcard**

<b>Attribute</b>	<b>A</b>	<b>B</b>	<b>C</b>
Length of contract (years)	5	15	
Annual return (\$/acre)	53.00	76.00	Neither A nor B = No additional income (\$0)
Flexibility to choose harvesting company	No	Yes	
I would prefer this option	[ ]	[ ]	[ ]

For those landholders who chose either of the options A or B, they were asked about their preferences for planting trees for bioenergy: the area allocated, the preferred layout (belts, blocks or a combination of both) and species, and if they would like to negotiate the agreement individually or as a group with higher negotiation power.

For those landholders who chose all options C or *status quo*, the survey asked about the reasons for this choice. Among the options were: a) interested but none of contracts looked interesting, b) need a real life example and market in place before giving an opinion, c) need more information e.g. about returns and risks, and d) other. Further, landholders were asked if they would change their minds. Answer options included ‘nothing will make me change my mind’, 50, 100 or 200 per cent higher financial returns than current land use, an expressed financial need, and other reasons.

The last part of the survey asked about demographic characteristics, including geographical location (nearest town), membership in agricultural related organisations, highest level of education, estimated property value, if the landholder had a mortgage, age and any final comment on the survey.

#### **3.4.4 Choice model to analyse contract attributes**

The choice modelling method was used to elicit preferences for selected attributes of hypothetical contracts for planting trees as bioenergy crops. This method is very powerful and has the potential to reveal the close to real preferences of landholders. Showing landholders different contract options and levels of contract attributes, and the option of not choosing any contract, provided an estimate of the demand for bioenergy contracts among the respondents and therefore the basis for an estimation of critical mass to supply to a bioenergy production plant. The theoretical basis of these choice models is random utility theory, explained in Chapter 2.

In Australia, the application of choice modelling to natural resource management has been mainly related to payments for environmental services (Ivanova & Rolfe 2011; Kragt & Bennett 2011; Scheufele & Bennett 2011; Rolfe & Brouwer 2012; Windle & Rolfe 2013). The method has been used less intensively to analyse potential adoption of agricultural innovations, e.g. Windle and Rolfe (2005). Choice modelling includes attribute selection, experimental design and choice model analysis. The latter will be explained under the data analysis section.

##### **a) Choice attribute selection**

Choice models are built based on the responses to choice sets, which in turn comprise a small set of attributes with different levels. The selection of attributes to include in the choice sets is usually done first through literature review followed by expert opinion and/or focus group. The latter allows for including diverse views in a relatively short period of time. Expert opinion was sought to obtain feedback on the selection of attributes by interviewing landholders previously met during the preliminary phase, as well as discussions with current and former local government staff who work with farmers and researchers with experience in the study area and/or Australian agricultural issues. Using this one-on-one approach also allowed for deeper understanding and detailed feedback on the choice set itself and the research design and overall survey tool. Following semi-structured interviews and a subsequent pilot survey, contract attributes were

prioritized and reduced to three in the final survey. These attributes are: length of contract, annual return and flexibility to choose the harvesting company (Table 10).

**Table 10 Attributes and levels used in the choice experiment**

<b>Attribute</b>	<b>Levels and coding</b>	<b>Variable name</b>
Length of contract (years)	5, 15, 25	Len
Annual return (AUD per ha per annum) <sup>a,b</sup>	74, 131, 188	Ret
Flexibility to choose the harvesting company	Yes (1) No (-1) <sup>c</sup>	Flex

**Note:** <sup>a</sup> Values used in the survey: AUD 30, 53, 76 per acre, respectively; <sup>b</sup> Values in hectares are rounded; <sup>c</sup> Accept default company in the contract.

#### **a.1) Contract length**

The initial levels explored in the pilot survey for length of contract included 5, 15, 25 and 100 years. While 25 years corresponds to the harvesting cycle for wood plantations, the other periods were chosen with a focus on co-benefits of carbon sequestration. At the time of doing the survey, 100 years was the maximum potential relinquishment period for an eligible carbon offset project, and five years the minimum period for reporting carbon credits as per the Carbon Farming Initiative Act 201 (Commonwealth of Australia 2011a). Fifteen years was proposed as an intermediate period between five and 25 years. These periods were discussed in feedback sessions with bioenergy experts at the CSIRO and in interviews with local experts. The 100 years option was removed from the choice sets as per feedback from the pilot survey.

#### **a.2) Annual returns**

Annual returns that were explored were based on the potential annual average lease value of the property in the region and what could be considered a ‘fair rent’. There are several methods to estimate this fair rent and one of them is a percentage of market property value. In New South Wales these rates are stable and range between five and nine per cent (NSW Department of Primary Industries 2007). Estimations for land rent at five per cent for different localities for the

Central West, New South Wales indicate that the lowest fair annual rent would be AUD 73 per hectare per annum and the highest AUD 777 per hectare per annum, while the median of AUD 186 per hectare per annum (Appendix 7). The values of AUD 74, 131 and 188 per hectare per annum used in the survey reflect five per cent of the lowest to the median rural property value. Note that acres were used in the survey instead of hectares to describe farm size and annual returns because this was the unit that landholders preferred to use in the preliminary and pilot surveys to describe their farms<sup>22</sup>.

### **a.3) Flexibility to choose the harvesting company**

This variable had only two levels; if the landholder would accept the default company in the contract or if they would have a say in choosing the harvesting company.

### **b) Experimental design**

There are several options to conduct the experimental design for a choice experiment. First, a full factorial design is when all possible treatment combinations are enumerated. Fractional factorial design allows for reducing the number of treatment combinations. Other more sophisticated design methods such as the d-efficient design need previous information of the survey population, such as their preferences for bioenergy tree crops, which was not available before this survey.

The experimental design for the choice sets in the landholder survey was generated, using the software CycDesign<sup>23</sup>. This software produces optimal or near-optimal experimental factorial designs. Based on the numbers of factors explored (three levels of contract length, three levels of returns and two levels for flexibility), the 18 possible combinations were randomised into nine blocks of size two because only two combinations could be compared at a time. A block is an

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<sup>22</sup> Interestingly though, landholders used hectares to describe tree plantings.

<sup>23</sup> CycDesign is available from VSN International: <https://www.vsn.co.uk>, recommended and supported by the ANU Statistical unit. CycDesign was used instead of the specialised choice model software generator Ngene, because the researcher did not have access to Ngene at the time of planning the survey. Ngene is available from: <http://www.choice-metrics.com/features.html>

experimental design term that corresponds to a two-option choice. In this case, these are options A and B (see Table 9). Note that option C is not included in the design since it is literally a non-option where all attributes of a contract are zero. Adding the non-option in the questionnaire should not affect the overall design.

The most efficient design was found for detecting differences between the levels of attributes, using two replicates. This means that there are two separate randomisations of the 18 combinations into nine blocks of size two. The nine blocks from each replicate were divided into three groups, with each group corresponding to a set of three choices for a questionnaire. Thus, there are six different questionnaires, three for each replicate. Once produced, the design was reviewed for consistency (Appendix 5). The experimental design used in the final survey included six questionnaire types (Appendix 6).

### **3.5 Data analysis**

#### **3.5.1 Statistical analysis of adoption**

Within the available adoption studies, two distinct types were identified; qualitative and quantitative studies. Qualitative studies focus on perceptions, preferences and barriers to adoption of agricultural innovation (Pannell et al. 2006). Quantitative empirical studies of adoption have used different methods, among them, logistic distribution function (logit), inverse cumulative distribution function (probit), censored regression models (tobit), and multinomial models (Feder et al. 1985; Feder & Umali 1993; Mercer 2004; Moser & Barrett 2006; Knowler & Bradshaw 2007). While most of these empirical studies are *ex-post* analyses, this thesis explores *ex-ante* adoption or potential adoption.

The extent of potential adoption in this thesis is determined by expressing the area to plant trees for bioenergy. Potential adoption was analysed in this research, first, using a continuous econometric model (tobit) that investigated the planting area found in the survey responses as the dependent variable, and second, using a discrete model (logistic regression) for an adoption area of 50 or more hectares. Two main hypotheses were investigated, using the tobit and logistic regressions:

**Hypothesis 1:** Landholder and farm characteristics investigated do not determine the likelihood of planting or the area of planting

**Hypothesis 2:** There is no difference in the willingness to plant trees as energy crops among those landholders whose properties are located in areas with lower biomass productivity values and those landholders whose properties are located in areas with higher biomass productivity values

Landholders' preferences about bioenergy tree crops contracts expressed in different choice sets were used to build choice models. The best model was interacted with the landholder and farm characteristics to find if these characteristics influenced preferences on specific contract attributes. The next two quantitative hypotheses tested were:

**Hypothesis 3:** Landholders' preferences do not influence any of the attributes in the choice experiment

**Hypothesis 4:** Landholder and farm characteristics investigated do not influence landholders' preferences for contract attributes in the choice sets.

#### a) Tobit model

In the first part of the analysis, potential adoption is defined as the logarithm of the area that the landholder nominated for tree planting plus a constant. The values for planting areas are zero or any positive value. Therefore, this variable is a censored continuous variable. While logit and probit regression models are commonly used in the agricultural adoption literature, they examine adoption as a discrete decision, which could lead to unnecessary loss of information when more detailed information such as potential planting area is available (Choudhury & Goswami 2013). Tobit regression models are more suitable for analysing the intensity of adoption (Lin 1991; Adesina 1996; Moser & Barrett 2006; Mazvimavi & Twomlow 2009). These models have been recently applied in the study of the adoption of bioenergy crops (Jensen et al. 2007; Qualls et al. 2012; Choudhury & Goswami 2013).

The first step in the tobit regression was to transform the planting area to a logarithmic scale due to the high variation of values found in the sample<sup>24</sup>. After this transformation, all socio-demographic variables were evaluated in the model and the resulting models compared using their AIC values and McFadden pseudo-R squared as will be further explained in Section 3.5.2 Choice modelling. In order to interpret the results, it is important to note that in a tobit model, the coefficients indicate the effect of change in a given independent variable on the expected value of the latent variable (in this case, the logarithm of planting area), keeping the rest of the variables constant.

#### **b) Logistic regression**

In the second part of the analysis, the dependent variable analysed is a binary variable, ‘willingness to plant 50 hectares or more of trees as bioenergy crops’. Fifty hectares is the minimum area required by the first carbon plantation company to have a carbon farming<sup>25</sup> methodology approved in Australia (CO2 Australia 2012). This area was chosen as a benchmark area given the gap in literature about a minimum area of tree planting for bioenergy.

### **3.5.2 Choice modelling**

#### **a) Multinomial Logit**

As explained in Chapter 2, random utility theory is the basis of choice modelling. The first step into modelling the choices made by landholders was to estimate a multinomial logit (MNL) model (Hensher & Greene 2003). This step helps in selecting candidate attributes before embarking on more complex modelling and ensures that parameters signals and significance make sense (Louviere 2000, cited in Hensher & Greene 2003). In the MNL, the choice probabilities of each alternative are a function of the systematic portion of the utility of all the

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<sup>24</sup> One unit was added to the potential planting area, so that an original decision of not planting was transformed to 1 and  $\log(1)=0$ . In this way, non-adopters would have a value of zero as the dependant variable.

<sup>25</sup> Carbon farming refers to the policy ‘Carbon Farming Initiative’ (CFI) that aims to capture carbon and reduce emissions on farms. One of the main farm activities under CFI is tree planting.

alternatives. In this study, a MNL was generated, using NLOGIT 5.0<sup>26</sup>. This model evaluated the coefficients of the contract attributes: length of contract, annual returns, and flexibility and a constant for the *status quo* option.

The MNL models assume that the error terms are independently and identically distributed (IID), and that preferences across respondents are homogeneous (de Bekker-Grob et al. 2012). These assumptions are restrictive to describe human behaviour (de Bekker-Grob et al. 2012). The equivalent behavioural assumption to IID is the independence of irrelevant alternatives (IIA) (Hensher et al. 2005, p. 518). By this property, including an irrelevant alternative in a choice set has no impact on the probability of a particular alternative being selected by the respondent (Hanley et al. 2001). If the IIA assumption does not hold, then more complex statistical models should be used (Hanley et al. 2001).

#### **b) Random parameter logit models**

More complex modelling relaxes some assumptions of the MNL model. Mainly, that the error component in the model is IID extreme value type I. In real life the error can be correlated within alternatives and this assumption is therefore restrictive (Hensher & Greene 2003). A mixed logit or Random Parameters logit (RPL) allows for this relaxation. RPL models take into account preference heterogeneity<sup>27</sup>, both observed and unobserved, across survey respondents. They also relax the IIA assumption because this assumption tends to be violated when an opt-out alternative is introduced (Kontoleon 2003). In the choice experiment used in this survey, the opt-out alternative is the option C (see sample choice set in Table 9).

The RPL econometric models used simulations with 1,000 Halton draws based on expert suggestions to produce comparable results across different NLOGIT versions (D Hensher 2014, pers. comm., 6 February).

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<sup>26</sup> NLOGIT 5.0 Student version.

<sup>27</sup> Also known as heterogeneity in means.

### c) Model selection

The best econometric choice models explored in this thesis were chosen based on the Akaike Information Criterion (AIC) and McFadden pseudo-R squared. The AIC is widely used for comparing models with different numbers of explanatory variables (Tutz 2012). The AIC has two terms; the first term represents the lack of fit and the second term represents the model complexity:

$$AIC = -2 \log (ML_z) + 2p_z.$$

In this equation,  $\log (ML_z)$  is the natural logarithm of the maximized likelihood function for model  $z$ .  $p_z$  is the number of free parameters in the model (Myung 2000, p.196). The model with the lower value of AIC would be the best model to fit the data among a series of models because this criterion penalizes models with more parameters (Myung 2000). The McFadden pseudo-R squared is an indicator of goodness of fit of a particular model. If this indicator is between 0.20 to 0.40, the rule of thumb among practitioners is that the model fits the data (El-Osta et al. 2008).

After the adoption factors and preferences for contracts for planting trees as bioenergy crops were investigated, the biomass in the case study region was assessed, as explained next.

#### 3.5.3 Biomass assessment

Woody biomass in the Orange case study region (Figure 16) was investigated, including softwood biomass currently available in the area and potential new hardwood biomass plantings. The biomass assessment contributes to answering the third research question of this thesis: What are the potential pathways to build a critical mass of tree growers for bioenergy?. The case study area for the biomass assessment included a radius of 100 km around a random point on the outskirts of the town of Orange, New South Wales. This point represents the location where a second generation bioenergy plant could be established. The main outputs of the biomass assessment include biomass productivity summary tables, biomass supply cost curves and break even analysis, and the results are presented in Chapter 5. The assessment builds largely on the work of Rodriguez et al. (2011c)

at the CSIRO who modelled woody biomass for the Central West New South Wales region.

**a) Biomass productivity assessment**

The CSIRO modelled and provided softwood biomass productivity data for the Orange case study region for the years 2011, 2020 and 2030, including thinnings at years 16, 24 and 30, every 5 km. These data were obtained from the biomass assessment in Rodriguez et al. (2011c) for the Central West New South Wales. The data in Rodriguez et al. (2011c), was modeled by Auro Almeida, Debbie Crawford and Tom Jovanovic. Details on the data are provided in Appendix 12. CSIRO also provided a layer of total annual potential biomass productivity data for *Eucalyptus cladocalyx* (see Appendix 12 and Section 3.4.2) from which data was extracted using ArcGIS Desktop 10, every 5 km<sup>28</sup>. These secondary data were further processed by the researcher in Microsoft Excel to build up summary tables following the formats provided by the CSIRO.

The assessment of softwood availability in the case study region considered the three scenarios conceptualised, developed and modelled by the CSIRO for the Central West New South Wales<sup>29</sup> (Rodriguez et al. 2011c). Although softwood (*Radiata* pine) exists in the region, it is only used for timber production; hence Rodriguez et al. (2011c) introduced the following potential softwood biomass availability scenarios:

- Scenario 1, the most pessimistic, considers that only harvest residues are available for bioenergy
- Scenario 2 considers that harvest residues plus 50 per cent of pulp logs and all sawmill residues are available

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<sup>28</sup> All secondary data extracted by Debbie Crawford at CSIRO – December 2013 and March 2014 (Appendix 12).

<sup>29</sup> The methods to obtain the biomass model outputs provided by the CSIRO and detailed in Appendix 12 are described in detail in Rodriguez et al. (2011c): Section 4.8.3. The assumptions for the estimations of the softwood biomass outputs used are described in Rodriguez et al. (2011c): Table 4.12.

- Scenario 3, the most optimistic, considers that 100 per cent of harvest residue, 100 per cent of pulp logs, and all sawmill residues are available. Sawmill residues include bark, chips, sawdust and shavings.

Hardwood biomass availability scenarios on the other hand, were conceptualised differently by Rodriguez et al. (2011c) because no hardwood plantations exist on a significant scale in the case study region. Rodriguez et al. (2011c) modelled several hardwood species in Central West New South Wales with different combinations of stocking ratio (low stocking ratio refers to 1,500 trees per hectare and high stocking ratio refers to 2,500 trees per hectare), rotation lengths (5 and 10 years), and climatic parameters (average climate for the period 1970 to 2000 and current monthly climate for the period 1999 to 2009) using a forest-based process model (Almeida et al. 2007; Polglase et al. 2008). They concluded that *Eucalyptus cladocalyx* is the most suited species for the region. Two of the *E. cladocalyx* biomass scenarios provided the highest productivity for the Central West New South Wales and were further explored in this thesis:

- High stocking five-year rotation average climate (HS5YAC)
- Low stocking 10-year rotation average climate (LS10YAC).

The hardwood biomass productivity layer provided by the CSIRO included new hardwood biomass plantations up to 100 per cent of the potential available area which excludes existing plantations, conservation areas, irrigated areas or intensive use of land and water bodies (see Rodriguez et al. 2011c, p. 68). The hardwood biomass availability scenarios used plausible landholder adoption assumptions based on the landholder survey: 2.5, 5, and 10 per cent (Rodriguez et al. 2011c assumed a 10 per cent adoption rate).

#### **b) Biomass supply curve**

The biomass supply cost curves show the delivered cost of different sources of biomass at the bioenergy processing plant. Biomass supply curves were built using the step-by-step method described by Ashton et al. (2008) and Langholtz et al. (2007) using Microsoft Excel (see Figure 17 and Figure 19). Biomass production cost data and transport costs were obtained from Rodriguez et al. (2011c) and inflated to the first quarter of 2014 using the Australian Consumer

Price Index inflation calculator (Australian Bureau of Statistics 2014) (see Appendix 11). The transport costs obtained were compared to a transport model provided by the CSIRO (May 2011) which builds on Lambert and Quill (2006)<sup>30</sup>. While in Rodriguez et al. (2011c), the biomass supply curve includes both existing softwood and hypothetical hardwood plantings<sup>31</sup>, this thesis first explores the existing softwood biomass in the Orange case study area and then a hypothetical biomass cost supply curve that includes both softwood and hardwood biomass. Therefore, it is easier to analyse how many new hardwood plantings would be needed to supply a bioenergy plant in the case study region.

### c) Break even analysis

Break even point is the ‘starting point from which the production of biomass becomes profitable’ (Escobar et al. 2009). Following Rodriguez et al. (2011c), the break even analysis includes four steps. The first step is to explore the retail petrol pump price in Australia (AUD per litre) for different oil prices (USD per barrel) (Appendix 13 and Table 20). The second step is to calculate the production cost of ethanol ( $E_p$ ) for different costs of biomass, as follows:

$$E_p = B + K + O$$

Where:

$B$  = biomass cost

$K$  = capital cost

$O$  = operational cost

The third step is to calculate the ethanol price at the pump, defined by the formula:

$$E_{pp} = E_p + D + GST + X + M$$

Where:

$E_{pp}$  = ethanol price at the pump

$E_p$  = ethanol production cost

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<sup>30</sup> This MS Excel transport model was provided in February 2015, hence used only to verify results.

<sup>31</sup> Dr Luis Rodriguez (CSIRO), Dr Gabriela Scheufele and Professor Jeff Bennett (ANU) provided feedback on the biomass supply cost curves. Dr Luis Rodriguez provided feedback on the break even analysis.

$D$  = distribution cost

$GST$  = General Services Tax = 10% \* [ $E_p$  +  $D$ ]

$X$  = ethanol excise

$M$  = retail margin = 5% \*  $E_{pp}$

The final step is to estimate the biomass cost (AUD per tonne) to produce bio-ethanol at a price that equals the petrol pump price for a given oil price (USD per barrel), taking into account that the ethanol pump price is equivalent to 1.46 times the petrol pump price after adjusting for energy content<sup>32</sup>, as shown in the formula:

$$E_qRPP = E_{pp} * 1.46$$

Where:

$E_qRPP$  = Ethanol price equivalent to retail petrol pump price

The break even graph was created in Microsoft Excel comparing different biomass cost at the plant gate with oil prices after adjusting for energy content (see Section 5.3.2 for the results of the break even analysis).

#### **d) Sensitivity analysis**

To account for uncertainty in the cost estimates of second-generation biomass, the sensitivity analysis varied the price of oil by  $\pm 50$  per cent, keeping everything else constant, and also considered variations of  $\pm 60$  per cent in the cost of biomass at the farm gate, keeping everything else constant and estimated the oil price to break even under these conditions.

#### **3.5.4 Ethanol Policy scenarios**

In May 2014, the Australian government announced changes to the Ethanol Production Grants Programme (Australian Government 2014). Effectively, from July 2016, the excise on ethanol is AUD 0.025 per litre and will increase by AUD 0.025 for five years until it reaches AUD 0.125 per litre. The impacts of this

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<sup>32</sup> The energy content of petrol is 34.2 MJ per L and for ethanol it is only 23.4 MJ per L (Commonwealth of Australia 2009). The conversion factor is estimated as follows: 34.2 MJ per L / 23.4 MJ per L = 1.46.

policy change on the ethanol price and cost of biomass at break even point, including an estimate of total biomass available at this break even point, keeping all other variables equal, were analysed (Table 25).

### **3.5.5 Estimation of landholder critical mass**

Primary data collected in the landholder survey (Chapter 4) was used in combination with the biomass assessment explained in Section 3.5.3 to estimate the number of landholders who would produce enough biomass to supply the hypothetical bioethanol plant in the case study and the potential area needed for new hardwood plantings. The estimation considers the most pessimistic scenario of softwood biomass availability explained earlier in this chapter. The average farm area was estimated from the landholder survey, but focusing only on those landholders who would plant 50 or more hectares. For comparative purposes, the results are divided into landholders who would plant 50 or more hectares and those landholders who would plant 100 or more hectares.

### **3.5.6 Integrated analysis to analyse building critical mass pathways**

Interpreting, linking and integrating quantitative and qualitative data and analysis has been recognised as a challenge (Bryman 2007; Bazeley 2010). This challenge involves at least three aspects: the meaning of integrated analysis, the writing up of integrated results, and the challenge of integrating disciplines. Bryman (2007, p. 21) argues that ‘there is considerable uncertainty concerning what it means to integrate findings in mixed methods’. Bazeley’s (2010) definition of ‘integration’ was used in this research:

Integration can be said to occur to the extent that different data elements and various strategies for analysis of those elements are combined throughout a study in such a way as to become interdependent in reaching a common theoretical or research goal, thereby producing findings that are greater than the sum of the parts. (p. 432)

It is also important for research to recognise that the outcome of integrated research can be unpredictable (Bryman 2006) and that conclusions can be invalid or weakened if all the information available is not considered, regardless of the

model of integrated analyses used (Bazeley 2012).

The second challenge posed by applying integration is writing up the integrated results. In this respect, the lack of well-known exemplars of mixed methods research means that best practice guidelines for writing up integrated findings are not readily available (Bryman 2007). As a consequence, mixed methods researchers sometimes end up writing their findings for different audiences (Bryman 2007, p. 12). Some academic journals tend to emphasise either quantitative or qualitative research and this emphasis would inhibit integration (Bryman 2007). Therefore, unless the topic of research is inherently integrated, defaulting to either qualitative or quantitative research is easier in order to publish in most academic journals. Moreover, finding academic journals that publish integrated research has been recognised as problematic (O'Connell et al. 2013, p. 298).

The third challenge of integrated analysis is disciplinary integration. Holbrook (2013, p. 1867) provides a useful definition of interdisciplinarity as follows: 'the integration of two or more disciplines focused on a common (and, it is sometimes insisted, a complex) problem'. Rotmans and van Asselt (1996, p. 327) further emphasise that integration brings 'together various knowledge domains in order to synthesize these pieces of information into insights that cannot be derived from a single disciplinary analysis'. O'Connell et al. (2013) argue that research on bioenergy requires a high level of integration, in particular, if the full bioenergy value chain is considered from production to retail and combustion (p. 288). Waste management, economics, process engineering, chemistry, carbon accounting and policy are some of the knowledge areas required in a full value chain bioenergy assessment (O'Connell et al. 2013). This thesis investigates planting trees as bioenergy crops with a focus on feedstock production up to the bioenergy plant gate. Therefore, the research cuts across the bio-physical, socio-economic, technology and policy spectrum.

To conclude, there is no formula about how to do integrated analyses. The process followed to conceptualise the pathways to build critical mass in this research is sequential, and the answer to one research question becomes the starting point for

answering the next question. The rationale for integration includes complementarity of methods to inform, illustrate and clarify the results, development and expansion to improve the understanding of a complex problem. Table 2 shows the questions and tools, using mixed methods and integrated analysis to put the pieces of the puzzle together. Integrated analysis in this research is applied in particular in Chapter 5, which combines the results of the survey and biomass supply curve, the learnings from participant observation, qualitative comments on the survey and learnings from the literature, to propose pathways that could build critical mass of tree energy crop growers.

### **3.6 Limitations/caveats of methodology and available information**

Time, resources and access constraints have played a major role in the choice of methodological approach in this study. One of the anticipated limitations of the study was to obtain access to research participants, mainly landholders. Without direct contacts in the area and linkages to institutions that could provide entry points, I spent the initial part of the research building appropriate networks and understanding rural issues in the area. However, despite these efforts, the only groups that were keen to participate in the research were those who traditionally participate and are probably overrepresented in rural studies, e.g. Landcare groups.

A different approach was needed to obtain a more balanced view of the issues through the surveys. This approach resulted in the chosen sampling mode, of attending externally organised agricultural shows in the study region. While this approach is innovative in nature (not reported in the adoption literature), it requires careful logistical planning and training of enumerators.

Another caveat of the methodology refers to the survey tool. While showing landholders with different choice sets would provide statistically efficient results, there may be a risk that learning (Savage & Waldman 2008; Scheufele & Bennett 2012) would result in using strategic responses. This means that landholders may adapt their responses according to what they first saw. To address this caveat, the enumerators were asked to show and verbalize the options one by one, so that the

respondent could only see one set of options each time. Landholders were not allowed to change their responses after they had made a decision. This caveat responds to behavioural economics principles explored in Chapter 2.

Relevant landholder information is only officially reported at the catchment level in Australia. The assumption held throughout this research is that the combination of the Lachlan catchment and Central West catchment is representative of the Central New South Wales region (Figure 10). However, this data only includes agricultural businesses and not hobby or lifestyle farmers who are also landholders. Given regional statistical limitations, the study also assumed that the number of agricultural businesses in Central West New South Wales is the best estimation of the number of landholders in the region.

Further, the literature recognises the challenges of integrating quantitative results with qualitative data when implementing a mixed-methods approach. This research also faced these challenges and most of the reported results in Chapter 4 are quantitative. The qualitative evidence was used to design the research, increase understanding of the local context, support statements and inform discussions in Chapter 5 and Chapter 6. Given time and resource constraints of this study, however, a second iteration of interactions with the participants to discuss the results presented in Chapter 4 was not feasible.

### **3.7 Conclusions**

This chapter has presented the factors investigated, the hypotheses formulated and the research design to answer three research questions: the first about factors influencing adoption of planting trees as energy crops, the second about contract attribute preferences, and the third about potential pathways to build critical mass of bioenergy tree growers. The hypotheses were mapped to the research questions and to the results chapters (Table 11).

A major research decision covered in this chapter was the choice of case study area. The Lachlan and Central West catchments were selected as the focus area because of four reasons; their bio-physical characteristics allow for tree energy

crops to grow, there is awareness about bioenergy in these catchments, the accessibility to the research sites is within the resource constraints of this research, and finally high quality biomass data was available for this study. The sampling mode decision is explained in detail in this chapter and resulted in a novel approach that can be used in forthcoming *ex-ante* adoption studies.

This chapter also described a mixed methods approach. Qualitative methods such as semi-structured interviews were used to discuss the pilot survey with key informants and experts. Participant observation was used across the study but mainly in the initial stages to understand the context and issues. Quantitative data gathering tools included a landholder survey and a choice model (embedded in the landholder survey). The choice modelling method was chosen because of its power to reflect real-world landholder decisions, where trade-offs are made. The biomass assessment supported the estimation of the potential number of adopters. Integrated analysis aimed to bring together the learnings from the literature review, the results of the landholder survey, the semi-structured interviews and participant observation. The next chapter provides detail about the results of the landholder survey.

**Table 11 Summary of research questions and hypotheses formulated**

<b>Research questions</b>	<b>Hypotheses</b>
<b>Hypotheses assessed using mainly quantitative methods</b>	
1. What factors underlie landholders' willingness to plant bioenergy tree crops?  See Chapter 4 and Chapter 6	Null hypotheses (quantitative)  <b>Hypothesis 1:</b> Landholder and farm characteristics investigated do not determine the willingness of planting trees as energy crops or the area of planting  <b>Hypothesis 2:</b> There is no difference in the willingness to plant trees as energy crops among those landholders whose properties are located in areas with lower biomass productivity values and those landholders whose properties are located in areas with higher biomass productivity values
2. What are the landholders' preferences in the design of contracts for planting trees as energy crops?  See Chapter 4 and Chapter 6	Null hypotheses (quantitative)  <b>Hypothesis 3:</b> Landholders' preferences do not influence any of the attributes in the choice experiment  <b>Hypothesis 4:</b> Landholder and farm characteristics investigated do not influence landholders' preferences for contract attributes in the choice sets
<b>Hypotheses assessed using mixed methods</b>	
3. What are the potential pathways to build a critical mass of tree growers for bioenergy?  See Chapter 5 and Chapter 6	Working hypotheses (quantitative) There is enough biomass available to supply an hypothetical bioenergy plant in the case study area  Working hypotheses (qualitative) Landholders' decisions are crucial to obtain critical mass of biomass to start a bioenergy industry  Pathways to build critical mass of landholders include policies, market demand and involvement and leadership of local actors  Trust is needed across all pathways as a factor to secure a sustainable and reliable biomass supply chain

## Chapter 4

### Factors influencing the potential adoption of trees as energy crops

#### 4.1 Introduction

This chapter presents the factors influencing the potential adoption of planting trees as energy crops in Central West New South Wales and it presents landholders' preferences in the design of contracts for planting trees as energy crops. The data collected in the landholder survey are both quantitative and qualitative. The quantitative results comprise responses to the questions from a face-to-face survey, while the qualitative results include the landholders' comments to this survey. Section 4.2 describes the survey sub-population that took part in the face-to-face survey. Section 4.3 presents the sample descriptive statistics that includes both continuous and categorical variables. Section 4.4 summarises the results of two econometric models, tobit and logit, for two different dependent variables. The tobit model was used to analyse the intensity of potential adoption. The logit model was used to analyse the willingness to plant 50 hectares or more of trees as energy crops. Section 4.5 explores preferences for contracts to plant tree energy crops, using choice models. The hypotheses presented in Chapter 3 are tested in Section 4.6, using the results of the tobit, logit and choice models. The study caveats and limitations are discussed in Section 4.7. Section 4.8 discusses the methodological lessons learnt by the author. The chapter concludes in Section 4.9.

#### 4.2 Survey sub-population

The population of this study are landholders in the Central West region of New South Wales, as described in Chapter 3. The sub-population for the survey is the group of landholders from New South Wales attending the Australian National

Field Days in Borenore, New South Wales, from 16<sup>th</sup> to 18<sup>th</sup> October 2012. This event specifically targets landholders in central, western and southern New South Wales and has run for 62 years (Australian National Field Days 2013a). The field days are the largest and best-established annual agricultural event in the Central West region. The majority of the 2012 field day visitors stated that this is the only field day they attend in the year and more than two thirds of them aimed to purchase or enquire about purchasing a product or service at the event (Australian National Field Days 2013b).

Since descriptive statistics of this sub-population are not publicly available, the Central West and Lachlan natural resource management (NRM) regions were used as reference areas for comparison of socio-demographic and farming information in this thesis. These two NRM regions are located across the Central West region as shown in Figure 10. Statistics related to agriculture and land management in Australia are officially recorded by NRM region. Data from these two NRM regions are therefore an approximation of the Central West region population. The majority of landholders in the survey have their farms spread across the two NRM regions and most of them are within the Central West region. Hence, the assumption maintained throughout this thesis is that the sub-population represents the population. In Chapter 5, the analysis of biomass production corresponds to the Central West region.

### **4.3 Sample descriptive statistics**

One hundred and fifty five surveys were used in the analysis. The discarded surveys were not used because they were incomplete. The reasons for incomplete surveys include: 1) Landholder had visual impairment (could not see the options offered), 2) Landholder was interrupted halfway and could not complete the survey, 3) One of the volunteer interviewers decided to skip questions instead of following the logic in which the questionnaire was designed. The sampling mode and method were described in Chapter 3. The survey collected information relating to two types of variables; continuous and categorical, as explained next.

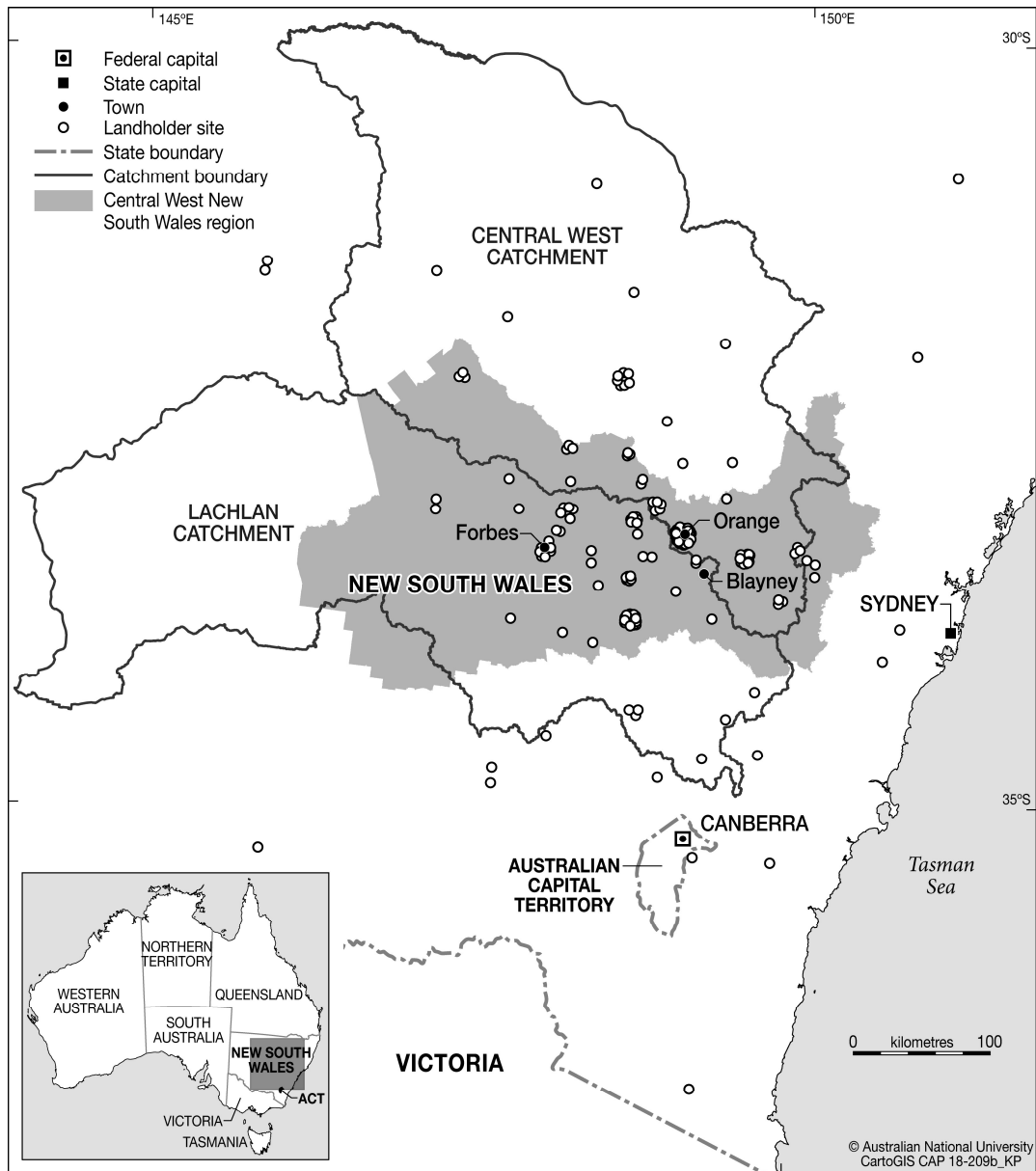
#### 4.3.1 Continuous variables

The data for the continuous variables collected in this study are: landholder age and farming experience, property size, amount of unproductive land perceived by the landholder<sup>33</sup>, property value, amount of area where the landholder would plant trees as energy crops. Two variables were derived from the survey: percentage of nominated planting area and percentage of unproductive land. Above-ground productivity data were obtained from secondary sources (see Table 12).

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<sup>33</sup> As described in Chapter 3: Unproductive land in the survey is defined as land that a landholder does not derive income from.

**Figure 10 Landholders' properties approximate locations**



**Source:** Australian National University CartoGIS elaborated with GIS data from Commonwealth of Australia (Murray–Darling Basin Authority) (2012), CSIRO regional maps, and landholder sites by Velarde (2012).

**Table 12 Descriptive statistics for continuous variables (n=155)**

<b>Variable</b>	<b>Code Name</b>	<b>Mean</b>	<b>Standard deviation</b>	<b>Skewness</b>	<b>Kurtosis<sup>e</sup></b>	<b>Min</b>	<b>Max</b>	<b>Missing cases<sup>f</sup></b>
Age (years) <sup>a</sup>	AGE1	53.23	13.56	-0.57	2.96	18	87	4
Farming experience (years)	EXP	28.92	16.70	0.14	2.11	0	75	0
Farm size (acres)	SIZ	2,972.46	6,234.57	4.77	31.72	4.5	52,000	0
Unproductive area (acres)	UNP	460.44	2,979.81	11.48	138.37	0	36,400	0
Proportion of unproductive area <sup>b</sup>	UNPP	0.14	0.21	2.31	8.69	0	1	0
Property value (\$/acre) <sup>a</sup>	VALAC1	10,476.77	50,109.96	9.12	94.23	15.38	555,556	18
Area to plant for bioenergy <sup>d</sup> (acres)	PLANTB	308.96	2,011.63	11.65	141.53	0	24,710.54	0
Above ground productivity (t/ha/year) <sup>g</sup>	PROD	8.39	1.99	0.45	4.02	3.57	14.41	4

**Notes:** <sup>a</sup>Missing values imputed with mean; <sup>b</sup>UNPP = UNP/SIZ; <sup>c</sup>Number of organisations in which the landholder is a member; <sup>d</sup>Zero if no response; <sup>e</sup>In a normal distribution, kurtosis = 3.00; kurtosis > 3.00 is a leptokurtic distribution, kurtosis < 3.00 is a platykurtic distribution; <sup>f</sup>Missing cases in raw dataset, imputations for modelling as indicated in a; <sup>g</sup>Data obtained from an overlay of Polglase et al. (2008) and landholder sites by Velarde (2012).

### a) Landholder characteristics

Landholder age and landholder experience are likely correlated factors. The mean landholder age in the sample was 53 (Table 13) which is three years older than the median age of farmers in the period 2011-12 in Australia (Australian Bureau of Statistics 2013b). T-tests for mean differences revealed that the sample respondents' age are statistically significant different from the mean landholder age of the Central West ( $t=-3.5509$ ,  $p\text{-value}=0.0005$ ) and from the mean landholder age of the Lachlan region ( $t = -2.4494$ ,  $p\text{-value} = 0.0154$ ) at the five per cent level. In the sample, age is moderately negatively skewed<sup>34</sup> but with a kurtosis<sup>35</sup> close to a normal distribution (Bulmer 1979).

In the sample, the mean landholder farming experience was 28.92 years. T-tests revealed that the differences between the sample and the Central West NRM region landholder population ( $t = -0.88105$ ,  $p\text{-value} = 0.3797$ ) and the Lachlan NRM region landholder population ( $t = -1.701$ ,  $p\text{-value} = 0.09096$ ) with respect to years of farming experience are not statistically significant at the five per cent level. The distribution of landholder farming experience is approximately symmetrical but platykurtic, this is, less concentrated about the mean than a normal distribution. Six landholders (3.8 per cent of the sample) reported that their farming experience was 'all my life' or the same number for age and farming experience. For these landholders, farming experience was estimated by subtracting 12 years from their reported age. While the involvement of rural children in farming activities starts at an early age, even while attending school, their farm work responsibilities increase as they grow up. All of the landholders who responded about their education (98 per cent) indicated they had primary school which finishes approximately at 12 years old, hence this number was used instead of the legal school leaving age of 15 years for New South Wales in 2010.

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<sup>34</sup> Bulmer (1979) suggested the following guidelines for interpreting skewedness: Highly skewed:  $> 1$  less or  $< -1$ , moderately skewed: between 0.5 and 1 or -0.5 and -1, low skew: Between 0.5 and -0.5, no skew: Zero or approximately zero.

<sup>35</sup> In a normal distribution, kurtosis = 3.00; kurtosis  $> 3.00$  is a leptokurtic distribution, where the tails of the distribution are large. If kurtosis  $< 3.00$ , it is a platykurtic distribution, with a lower peak but shorter tails.

**Table 13 Landholder and holding characteristics in the Central West and Lachlan NRM regions, 2011-12 and the sample (n=155)**

	NRM region		
	Central West	Lachlan	Sample
Total area of holding (ha)	7,417,424	6,886,407	186,449
Number of agricultural businesses	5,694.00	5,356.87	155
Average size of holding (ha) <sup>a</sup>	1,302.67	1,285.63	1,202.9
Unproductive land (%) <sup>b</sup>	14.17	5.47	14.0
Landholder age (years)	57.10	55.90	53.23
Landholder farming experience (years)	30.10	31.20	28.92
Landcare member (%)	14.34	17.10	20.6

**Note:** <sup>a</sup>Estimated by dividing the total size of holding by number of agricultural businesses in each region; <sup>b</sup>Estimated by subtracting the area of grazing, agriculture, forestry and other productive uses from the total area of holdings.

**Source:** Australian Bureau of Statistics (2013b); Landholder survey.

#### **b) Property characteristics**

The average property size in the sample is 1,202.9 ha (2,972 acres), 7.66 per cent smaller than the average farm size in the Central West NRM region and 6.43 smaller than the average farm size in the Lachlan NRM region (Australian Bureau of Statistics 2013a) (Table 13). T-tests revealed that the property size in the sample and the regions are not significantly different from the Central West ( $t = -0.49223$ ,  $p\text{-value} = 0.6233$ ) or the Lachlan region ( $t = -0.40814$ ,  $p\text{-value} = 0.6837$ ) at the five per cent level.

The distribution of the variable property size is positively skewed, this means that there are many low scores in the distribution. The extent of unproductive land and the percentage of unproductive land are also positively skewed. Both variables have a leptokurtic distribution, this is, the values are more concentrated about the mean when compared to a normal distribution.

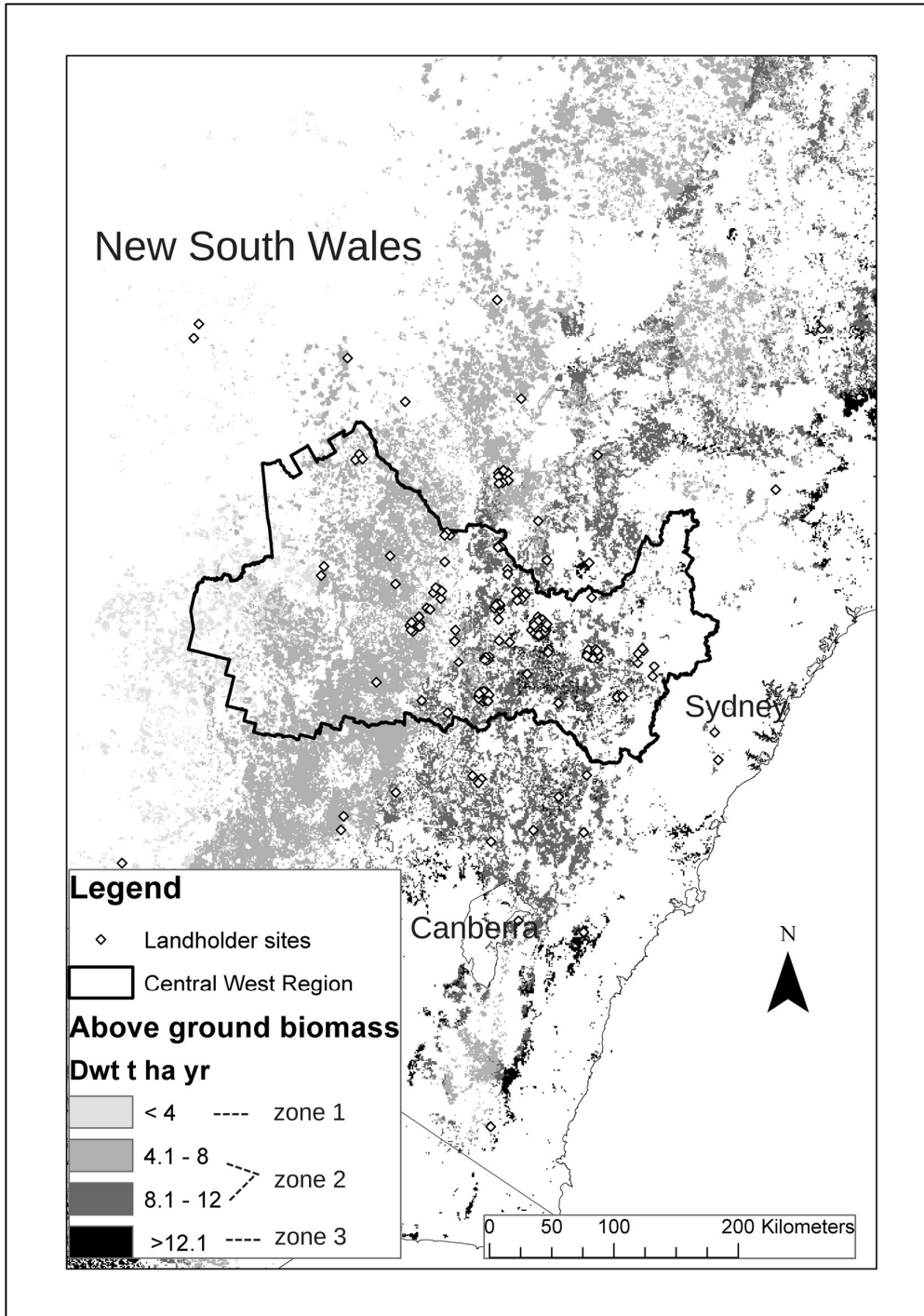
Land productivity was studied using two indicators. The first is related to the economic aspects of productivity and the second is related to the biophysical aspects. In the survey, unproductive land is defined as: ‘you are not obtaining any

income from the land'. Baseline comparative statistics of unproductive land indicate that the percentage of unproductive land is higher in the Central West (14.17 per cent) than in the Lachlan NRM region (5.47 per cent). The average percentage of unproductive land in the sample is 14 per cent and is comparable to the value found for the Central West NRM region but almost three times the proportion found in the Lachlan NRM region. To illustrate the concept of unproductive land from an economic perspective, a grazier would rarely indicate having any unproductive land unless this area is designated for the protection of creeks or for other conservation purposes. On the other hand, hobby farmers would say that all their land was unproductive (Landholders No. 64, No. 67 and No. 89). Thirteen of the 155 landholders (eight per cent) said that 50 per cent or more of their farm land was unproductive (Table 12).

The second productivity indicator used in the analysis was secondary data of above-ground biomass (dry tonnes per ha per year) for agriculture and grazing areas (Polglase et al. 2008) (Figure 11). These data were used to classify the properties in three zones; zone 1 or lower productivity, zone 2 or medium productivity, and zone 3 or higher productivity. These variables were used as dummies in the modelling stage (see details in Section 4.2.2).

The variable with the most missing values in the survey was property value. Landholders were asked to provide an estimate of their property value, either by indicating the total value or value per acre in Australian Dollars. All responses were transformed to value per acre to compare them. While some landholders expressed a lack of knowledge about their land value, others explicitly expressed they were not willing to provide this information. The distribution of the variable land value is positively skewed and leptokurtic, which means that this distribution is more concentrated around the mean and there is a high probability of extreme values. This variable was intended to be a proxy of income, however, since more than 11 per cent of the landholders chose not to answer this question or answered 'don't know', this variable was not used at the modelling stage.

**Figure 11 Above ground biomass productivity in the study area**



**Note:** Dwt = dry weight

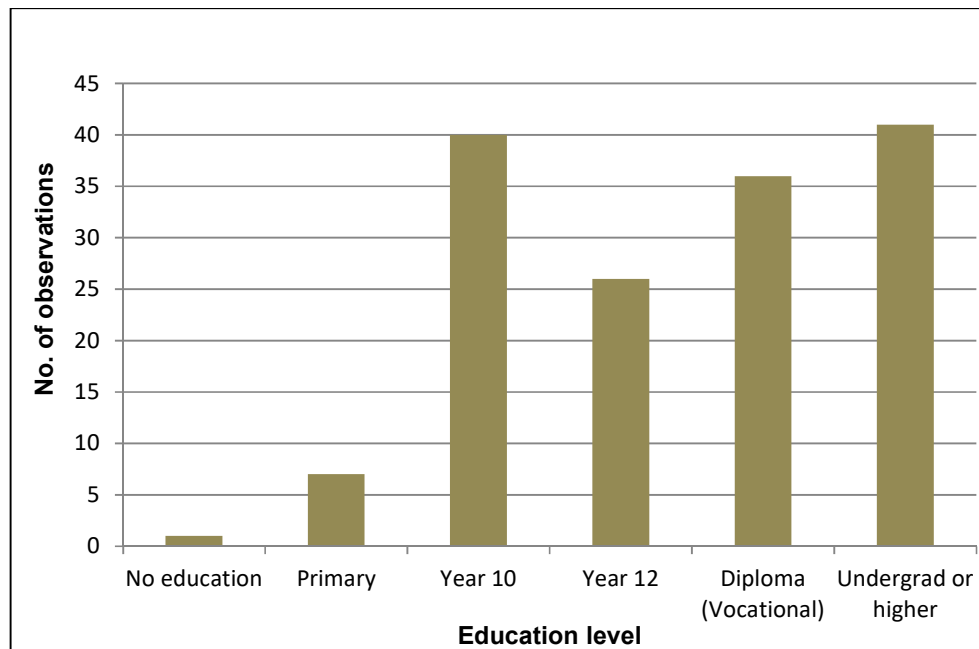
**Source:** CSIRO elaborated with Polglase et al. (2008) with landholder site data from Velarde (2012).

### 4.3.2 Categorical variables

#### a) Landholder characteristics

The first categorical variables explored in the survey were the landholders' highest level of education, the types of organisations in which landholders were members and landholders' lifestyle. The aim of the education variable was to understand the critical point where a landholder would be most likely to adopt planting trees as energy crops. In Australia, the education system allows for vocational education as part of secondary studies or even without having finished secondary studies. Therefore, it is difficult to distinguish the influence of different levels of education. In the sample, most landholders had secondary or higher education, whereas only one landholder indicated not having any formal education (Figure 12). Tertiary education (undergraduate or higher) was used as an effect coded variable in the modelling stage in Section 4.3, where variable EDU (tertiary education) = +1 if the landholder had tertiary education and -1 if not.

**Figure 12 Highest level of education obtained**



**Source:** Author's estimation based on landholder survey.

The second categorical variable is which organisations the landholder is a member. While many landholders in the survey were part of an organisation, more than half of them were independent (50 per cent, n=77). Obtaining the views of independent landholders was a notable achievement of this study because survey respondents are usually contacted through organisations (see Chapter 3), which could bias their responses. Since half the landholders in the sample identified themselves as independent, the survey results may reflect the average landholder's view in the region.

The organisations mentioned in the survey deal directly with land management and farming issues. The New South Wales Farmers Association is the largest association in the State with 5,495 members at the end of 2012 (NSW Farmers Association 2013). Thirty five per cent of the landholders in the sample were members of this organisation. A second renowned landholder and volunteer organisation mentioned in the survey is Landcare, as is explained next. Other reported organisations in the survey were catchment management authorities and specific industry associations, such as grazing and horticulture associations.

Landcare is the only organisation mentioned in this survey that is explicitly included in the agricultural census (Commonwealth of Australia 2012). Landcare membership in the sample was 20.6 per cent (n=32 individuals), higher than the 2011-2012 census data which indicates that Landcare membership declined to 17 per cent in the Lachlan NRM region and 14 per cent in the Central West NRM region (Table 13). This volunteer organisation has self-reported 1,400 members in the Lachlan NRM region and more than 1,000 members in the Central West NRM region (NSW Department of Primary Industries & Landcare New South Wales 2011).

The response to the question 'Are you a member of any of these organisations?: 1) NSW Farmers' Association, 2) Landcare group, 3) Other (please specify), 4) None of the above.' was used to derive the quantitative variable total number of organisations in which the landholder was a member. Information about the total number of organisations of which a landholder is a member is not available in the census and therefore there is no baseline with which to compare the results. While

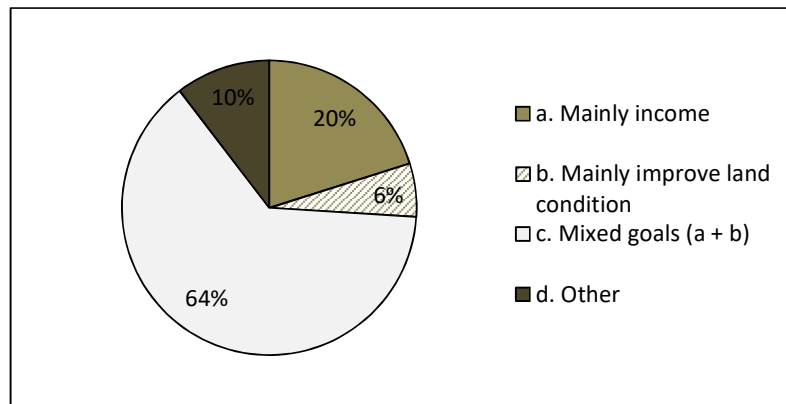
50 per cent of landholders (n=77) were not affiliated to any organisation, 29 per cent was affiliated to one organisation (n=45), 15 per cent to two organisations (n=24), and 3 per cent to three organisations (n=4). This variable was used as a proxy for trust and social capital as explained in Chapter 3.

Landholder lifestyle (hobby farmer) was derived from the question about farming type (see next section). Only 14 hobby farmers participated in the survey. These farmers usually use their property as a retirement place and are not interested in farming for generating income.

### b) Property management and experience in planting trees

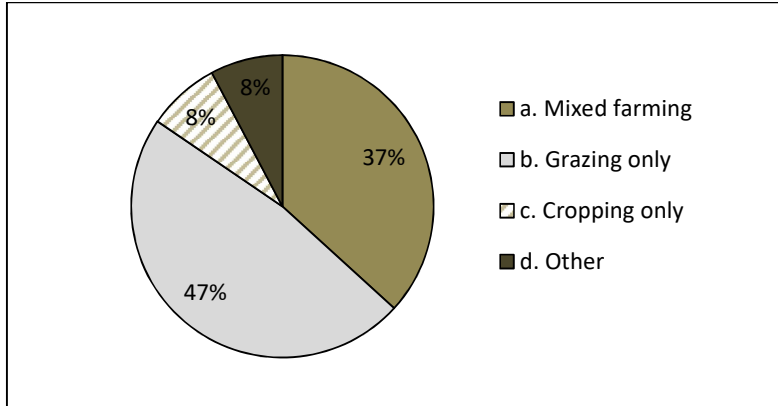
The next categorical variables explored in this study focus on farm management. These variables are main farming or land management goal, type of farming, and number of trees planted on the property. The majority of landholders in the sample have a dual farming goal by combining income generation and improving the condition of the land, whereas only 20 per cent mentioned income as their main goal (Figure 13). Forty seven per cent of landholders were graziers only and 37 per cent had mixed farming systems. Cropping only farmers accounted for only 7 per cent of landholders in the sample (Figure 14).

**Figure 13 Land management goal**



**Source:** Author's estimation based on landholder survey.

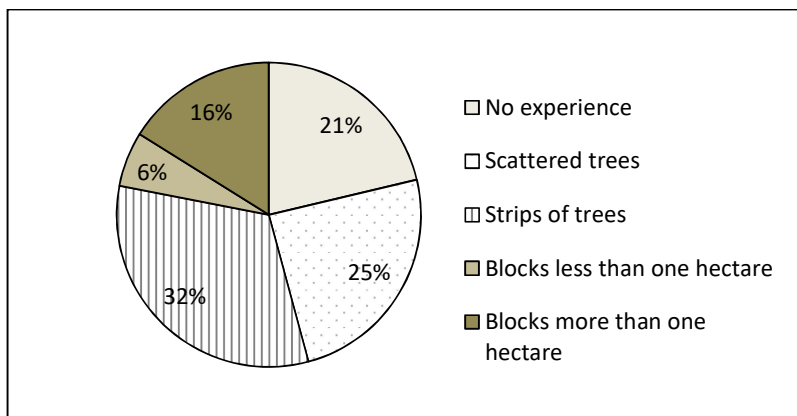
**Figure 14 Farming type**



**Source:** Author's estimation based on landholder survey.

Twenty one per cent of landholders did not have any experience in planting trees, whereas 32 per cent had experience in planting strips, and 22 per cent had experience in planting blocks of trees (Figure 15). The rest (25 per cent) had experience in planting scattered trees only. The survey asked about landholder's experience in planting trees, from scattered trees to blocks of trees. Experience in planting blocks of trees of less than one hectare and more than one hectare were combined and used as an effect coded variable in the analysis (variable BLOCK). This effect coded variable was included in the econometric models built in Section 4.3, where BLOCK (landholder has experience planting blocks) = +1 if the landholder had experience or -1 if not.

**Figure 15 Experience in planting trees**



**Source:** Author's estimation based on landholder survey.

Finally, the study included a dummy location variable that would allow identifying geographical and productivity differences on a broad scale. Dry, lower productivity areas were represented by farms in zone 1 (n=9), medium productive farms were in zone 2 (n=121), and more productive farms were located in zone 3 (n=21). Four landholders did not provide their location but were allocated to zone 2, which is the region where the large majority of farms were located.

#### **4.4 Factors relating to potential adoption of planting trees as energy crops**

Two hypotheses were investigated about the potential adoption of planting trees as energy crops using landholder responses to the survey (n=155):

**Hypothesis 1:** Landholder and farm characteristics investigated do not determine the willingness of planting trees as energy crops or the area of planting.

**Hypothesis 2:** There is no difference in the willingness to plant trees as energy crops among those landholders whose properties are located in areas with lower biomass productivity values and those landholders whose properties are located in areas with higher biomass productivity values.

Landholders were asked how much area they would consider allocating to planting trees as energy crops. The answer varied from zero (or no planting) to some positive value constrained by the size of their property. In the first part of the analysis, the dependent variable is defined as the logarithm of the area that the landholder nominated for tree planting, plus a constant (the constant used was 1). The dependent variable was analysed using a left censored tobit model. In the second part of the analysis, the dependent variable was defined as willingness to plant 50 hectares or more of trees as energy crops. This latter variable was analysed using a logit model of adoption.

Only 33 landholders (21.29 per cent) were willing to plant 50 or more hectares. A subset of only eight landholders would consider planting 400 or more hectares. Notably, one of these landholders was willing to plant 10,000 hectares of his

property if others would plant. This point will be expanded in the discussion about building critical mass (see Chapter 5).

#### **4.4.1 Tobit model for intensity of potential adoption**

A tobit model was estimated for the dependent variable logarithm of planting area, plus a constant, using R, an open source statistical analysis software (The R Foundation, 2014) (Appendix 8). The independent variables analysed were all socio-demographic and property management variables (see data code sheet in Appendix 9). The results of the tobit model show that the statistically significant factors of the extent of the potential planting area are: the proportion of unproductive land, the number of organisations in which the landholder is a member, the landholder's lifestyle, and the landholder's farm location and age-squared. The first two variables have positive coefficients and lifestyle variable and age-squared have negative coefficients. Undergraduate education and experience in planting blocks of trees are not significant in the tobit model (Table 14).

Statistical significance is not a reason to exclude variables from a model (Hyndman 2011; Grace-Martin 2012; Flom 2013). Reasons for including non-significant variables in a model are: 1) these variables are expected controls, e.g. education, 2) these variables have theoretical bases to be included, e.g. experience in planting trees (see Section 3.2.3), and 3) these variables are included in specific hypotheses to test, e.g. Hypothesis 2 in this thesis which refers to farm productivity.

**Table 14 Tobit model results, n=155**

Variable	Estimate	Standard error	t value	Pr(>t)
(Intercept)	0.514	0.358	1.438	0.150
UNPP	2.068	0.584	3.539	0.000 ****
AQ1	0.494	0.130	3.784	0.000 ****
AGESQ	-0.000	0.000	-1.685	0.092 *
BLOCK <sup>a</sup>	0.191	0.128	1.490	0.136
EDU <sup>a</sup>	0.056	0.119	0.470	0.638
HOBB <sup>a</sup>	-0.442	0.209	-2.115	0.034 **
z <sub>3</sub> <sup>b</sup>	0.562	0.324	1.737	0.082 *
z <sub>1</sub> <sup>b</sup>	0.467	0.445	1.042	0.297
logSigma	0.210	0.074	2.857	0.004 ***
Log-likelihood	-220.339	Degrees of freedom	10	

**Notes:** \* Statistically significant at 10 per cent level; \*\* Statistically significant at 5 per cent level; \*\*\* Statistically significant at 1 per cent level; \*\*\*\* Statistically significant at 0.1 per cent level;

<sup>a</sup>Effect coded, <sup>b</sup>Dummy coded. UNPP = Perceived proportion of unproductive land, AQ1 = Number of organisations in which the landholder is a member, AGESQ = Age-squared, BLOCK = +1 if landholders has experience planting blocks of trees, - 1 if not; EDU = +1, has university education, -1 if not; HOBB = +1 If the landholder is a lifestyle or hobby farmer, -1 if not; Landholder location: z<sub>3</sub> (higher productivity) or z<sub>1</sub>. (lower productivity)

#### a) Land productivity

The perceived proportion of unproductive land (variable UNPP) resulted in a key factor influencing potential adoption of trees as energy crops (p=0.0004). As any new agricultural or forestry activity, planting trees as energy crops would compete with other resources on the farm such as time, water, soil and fertilizers.

Therefore, it is expected that landholders who perceive having large areas of unproductive land would be interested in planting trees for bioenergy. However, the survey data also show some exceptions where land that is considered unproductive was also considered unsuitable for tree planting, for example, areas that the landholder had set apart for conservation purposes (Landholder No. 9).

In the tobit model, landholders in higher productivity areas, zone 3 ( $p=0.082$ ), would be more likely to adopt trees as energy crops. Note that these results include the whole sample, where the planting area of trees as energy crops varies considerably, from 0.66 hectares (1.65 acres) to 1,000 hectares (24,710 acres).

#### **b) Membership in organisations**

Contrary to initial expectations, being a Landcare member alone was not a factor influencing potential adoption. Note that Landcare membership was proposed as a proxy of trust in the planning stages of the analysis (Chapter 3). A second variable was used instead: number of organisations in which the landholder is a member (variable AQ1). This variable is statistically significant in the tobit model ( $p=0.0001$ ). In the sample, while 50 per cent of landholders were independent, 29 per cent were members of only one organisation and 18 per cent were members of at least two organisations. The organisations mentioned include a production organisation (e.g. the NSW Farmers Association), and a volunteer land management organisation (mainly Landcare). The higher the number of organisations in which the landholder was a member, the more likely he/she was to adopt trees as energy crops.

Being connected to an agency or local networks of farmers or watershed groups are amongst key factors in the adoption of best management farming practices (Baumgart-Getz et al. 2012). Specifically, it was hypothesised that Landcare membership would positively influence adoption, however, this was not the case. Given the lack of variability of organisations mentioned in the survey (most landholders were members of NSW Farmers' Association for example), another variable was tested, this is, number of organisations in which the landholder is a member. The intuition behind this variable is that the more connected to different organisations a landholder is, the most likely to adopt.

#### **c) Experience in planting blocks of trees**

Based on the results of influencing adoption factors (Section 3.2.3), it was expected that experience in planting trees would have an influence on the dependent variable, logarithm of planting area plus a constant. However the variable experience in planting blocks of trees (variable BLOCK) did not show

statistically significant results in the tobit model. If the results were significant and the coefficient positive, then experience in planting blocks of trees would have had a positive influence on the extent of the dependent variable, if the coefficient was significant and negative, then not having experience in planting blocks of trees would influence adoption.

#### **d) Landholder lifestyle**

Hobby farmers (variable HOBB) were less likely to be interested in planting trees as energy crops. This is understandable as some of them have acquired their properties as a retirement strategy (Landholders No.72, 119) or expressed that he would not like to see the trees cut, even if they are replanted afterwards (Landholder No.114). Note that hobby farmers represent only 9 per cent of the sample (n=14).

To conclude, in the tobit model, the variables, proportion of unproductive land, farm location, number of organisations in which a landholder is a member, exert statistically significant influence over the extent of the potential planting area, while being a hobby farmer discourages potential adoption. The negative and significant age-squared coefficient in the tobit model means that as people get older, the effect of age-squared on adoption is lower. Tertiary education and experience in planting blocks of trees were not statistically significant in the tobit model (Table 14).

In the sample, 70 per cent of landholders said they would plant some area, whilst only 21 per cent of them would be willing to plant 50 hectares or more (approximately 123.55 acres). A logit regression model was used to explore reasons for planting 50 hectares or more as explained in the next section. The hypotheses tested with the results of the tobit and logit models are evaluated in Section 4.5.

#### **4.4.2 Logit model for landholders who would be willing to plant 50 or more hectares**

After assessing the extent of potential adoption with the tobit model, I focused the analysis on applying an industry perspective of a minimum planting area of 50

hectares as explained in Section 3.5.1. This section uses a logit model to investigate factors that influence the potential adoption of a minimum of 50 hectares of trees as energy crops. This model was estimated using R software (Appendix 8).

In the logit model the dependent variable is binary and refers to the potential adoption of tree planting for bioenergy in 50 hectares or more (variable PL50H). The logit model shows that the proportion of unproductive land, the number of organisations in which the landholder is a member, experience in planting blocks of trees, and location positively influence the potential adoption of trees as energy crops of at least 50 hectares while age-squared has a negative influence (Table 15). The models first included all variables and model selection followed a backward selection approach where variables are discarded one by one based on indicators of the results of the model, mainly using the lowest Akaike Information Criterion (AIC).

**Table 15 Logit model for PL50H, n=127**

Variable	Estimate	Standard Error	z value	Pr(> z )
(Intercept)	-1.733	0.670	-2.586	0.009 ***
UNPP	5.374	1.748	3.074	0.002 ***
AQ1	1.070	0.302	3.539	0.000 ****
AGESQ	-0.0003	0.000	-1.718	0.086 *
BLOCK <sup>a</sup>	0.513	0.274	1.868	0.062 *
EDU <sup>a</sup>	0.135	0.269	0.501	0.616
Z <sub>3</sub> <sup>b</sup>	2.002	0.781	2.562	0.010 **
Z <sub>1</sub> <sup>b</sup>	1.686	0.807	2.090	0.036 **

**Notes:** \* Statistically significant 10 per cent level; \*\* Statistically significant at 5 per cent level; \*\*\* Statistically significant at 1 per cent level; \*\*\*\* Statistically significant at 0.1 per cent level; <sup>a</sup>Effect coded; <sup>b</sup>Dummy coded. UNPP = Perceived proportion of unproductive land, AQ1 = Number of organisations in which the landholder is a member, AGESQ = Age-squared, BLOCK = Landholder has experience planting blocks of trees (+1), does not (-1); EDU = Has university education (+1), does not (-1); Landholder location: z<sub>1</sub> (low productivity) or z<sub>3</sub> (higher productivity).

#### **a) Land productivity**

The proportion of unproductive land (variable UNPP) exerts a statistically significant influence on the adoption of trees for bioenergy ( $p=0.002$ ) in the logit model, with the same caveats mentioned earlier (i.e. land considered unproductive was also considered unsuitable for tree planting as is set apart for conservation). Similar to the tobit model, the logit model shows a location effect. This effect is positive and statistically significant for both zone 1 (lower productivity,  $p=0.036$ ) and zone 3 (higher productivity) ( $p=0.0181$ ).

#### **b) Landholder characteristics**

Experience in planting blocks of trees was also statistically significant at 5 per cent level ( $p=0.061$ ), and positively influences the adoption decision of planting more than 50 hectares. The number of organisations in which the landholder is a member (variable AQ1) is statistically significant in the logit model ( $p<0.000$ ). As per the tobit model, the more connected to different organisations the landholder is, the more likely he/she is to adopt trees as energy crops. Age-squared negatively influence the decision of planting 50 or more hectares as energy crops ( $p=0.086$ ).

#### **c) Outliers**

Three landholders indicated that they would be willing to plant 100 per cent of their farms with energy crops (Landholder No 9, 73 and 89). Landholder No 89 expressed that all of their land was unproductive, whereas Landholder No 9 and Landholder No 73 expressed that 20 and 13 per cent of their land was unproductive, respectively. This may be a reason for their willingness to switch to energy crops. Changing all current land use to tree energy crops would affect farm production. Guidelines about the proportion of energy tree crops in farms are needed to avoid potential land use conflict of traditional vs. non-traditional land uses (Williams 2011). These guidelines would also prevent potential opposition from the public that could affect future bioenergy projects, as discussed in Section 2.3.1b Removal of barriers to adoption. If this percentage is capped, for example, at 20 per cent of farm size, 22 of the 33 landholders who said they would plant 50 or more hectares fall within this limit. We do not know if these landholders

would be willing to participate even if the area allocated to tree planting was less than what they had initially expressed.

To conclude, the results of the tobit and logit models demonstrate that landholders' farm productivity is a key factor in their decision making about adoption. The larger the unproductive area they perceive on their farm, the higher their willingness to adopt. Landholder connectedness is also a key influencing adoption factor. Landholder experience in planting blocks of trees exerts significant and positive influence on adoption in the logit model (Table 15). Age was statistically significant only in the tobit model (Table 14) and would negatively influence adoption. Tertiary education was not a statistically significant factor in any of the models. The statistically significant variables found in these models are analysed with the different contract attributes to find landholder preferences in the analysis of contract choices in the next section.

#### **4.5 Landholders' preferences about contracts for planting trees as energy crops: Choice model results**

Landholders' preferences about tree energy contracts were investigated through choice models. The best model was interacted with landholder and farm characteristics to determine if these characteristics influenced preferences on specific contract attributes. This section explores the next two quantitative hypotheses:

**Hypothesis 3:** Landholders' preferences do not influence any of the attributes in the choice experiment

**Hypothesis 4:** Landholder and farm characteristics investigated do not influence landholders' preferences for contract attributes in the choice sets.

In this section, landholders' preferences about tree planting contract attributes are explored. All landholders are included in the analysis, potential adopters and potential non-adopters. As explained in Chapter 3, each landholder was provided with three choice sets with three choices each. Each choice set was formed by

options A, B and C (status quo) (Table 9). Several choice models were used to analyse the results; multinomial logit (MNL), random parameter logit (RPL), and error component models. The number of observations (choices) in the choice models was 465 because each of the 155 landholders was presented with three choice sets. The experimental design is available in Appendix 5 and explained in Section 3.4.4.

#### 4.5.1 Multinomial Logit

The first step to model the choices made by landholders is to estimate a multinomial logit (MNL) model (Hensher & Greene 2003) (see Chapter 3). In this study, the MNL model evaluated only the coefficients for contract attributes: length of contract, profitability, and flexibility and a constant for the *status quo* option. The results correspond to *a priori* expectations about the sign of the coefficients. On average, landholders prefer contracts that are short, have higher returns and offer flexibility. All attribute coefficients are statistically significant and different from zero ( $p < 0.0001$ ) (Table 16). As indicated by the log-likelihood function, comparing the model with an intercept only model, the model was significant (Log-likelihood function -439.84).

**Table 16 Results of a multinomial logit (MNL) model, n=465 choices**

Attribute	Coefficient	p-value	Standard error	95% Confidence Interval	
Length (LEN)	-0.0843 <sup>a</sup>	<0.0001	0.0096	-0.1031	-0.0655
Return (RET)	0.0208 <sup>a</sup>	<0.0001	0.0040	0.0129	0.0287
Flexibility (FLEX)	0.4222 <sup>a</sup>	<0.0001	0.0696	0.2859	0.5585
Constant (CON)	0.13690	0.5878	0.2526	-0.3581	0.6319
<b>Goodness of fit indicators</b>			<b>Model specifications</b>		
Log likelihood function (LL)	-439.8419		Number of observations (N)	465	
AIC normalized (AIC/N)	1.909				

**Note:** <sup>a</sup> Statistically significant at 1 per cent level.

#### 4.5.2 Random Parameter Logit

To produce the RPL model, different contract attribute distributions were tested; normal, uniform and triangular (see model specifications in Appendix 10). Note that since normal distributions allow the attribute sign to be positive or negative, this may lead to counter-intuitive results, such as a negative coefficient on the *return* attribute in the choice model (Kragt & Bennett 2011). The assumptions of uniform distribution for the *flexibility* attribute and triangular distribution for the *return* attribute, which restrict the distribution to positive values only, resulted in a better model fit than the MNL model (Table 17). The distribution used for the *length* variable was normal. The RPL model shows statistically significant standard deviations at 1 per cent for the three contract attributes explored.

The variables – experience planting blocks, landholder’s age, proportion of unproductive land, location (variables  $Z_2$  and  $Z_3$ ), and number of organisations in which a landholder is a member– were interacted with the RPL model in Table 17 to find if there is a significant influence of these variables on the contract attributes. These interactions resulted in significant coefficients for the interaction terms of FLEX x BLOCK (-0.32691,  $p=0.0336$ ) and RET x UNPP (+0.12864,  $p=0.0110$ ) (Table 18). This means that landholders who have experience in planting blocks of trees would have a lower preference for flexible contracts than landholders who don’t have experience in planting blocks of trees, i.e. they are less likely to need a flexible contract.

Non-significant interactions were kept in the RPL model with interactions (Table 18) because they are included in specific hypothesis to test (Flom 2013; Grace-Martin 2012), specifically, hypothesis 4 which refers to the influence of landholder and farm characteristics on preferences for contract attributes in the choice sets.

The interaction term of the constant and the number of organisations in which the landholder was a member (CON x AQ1) is also statistically significant. This result suggests that confounding factors exist and were not captured by the variables analysed. From a contract ‘organiser’s perspective’ (Oliver & Marwell 2001), the results imply that the contracts offered should target landholders with

experience planting blocks so that they accept the harvesting company proposed in the contract, which reduces transaction costs for the organiser. Other models such as the error components model were explored but the results were not better than the RPL model, therefore, only the RPL results are presented in this thesis.

#### **4.5.3 Other contract attributes**

For those landholders who expressed willingness to plant (n=109), their preferences about species, layout and type of agreement were recorded. Eucalyptus was the most preferred species mentioned (51 per cent), followed by 'natives' (9 per cent). Although Eucalyptus are native to Australia, when landholders mentioned 'natives' they referred to smaller trees with many branches native to New South Wales or the local area, e.g. the mallee tree. Twenty four per cent did not have a preference. Only four landholders preferred Radiata pine and three landholders preferred other pine. Five preferred other species including non-natives, deciduous, maples, a mix of species, but excluding Radiata pine.

There was no clear preference for layout of the new plantings. Belts, blocks and a combination of these received similar preferences (34, 33 and 32 per cent respectively), among those who would plant and responded to this question (n=106). Only one landholder expressed a preference for a random layout.

Landholders also preferred to negotiate the agreement individually (n=63) instead of as a group with higher negotiation power (n=43). These preferences are used in the discussion of critical mass in Chapter 5.

The results from the tobit, logit and choice models that were used to test the hypotheses outlined in Chapter 3, are explained next.

**Table 17 Random parameters logit, n=465 choices**

<b>Variables</b>	<b>Coefficient</b>	<b>p-value</b>	<b>Standard error</b>
Length (LEN)	-0.1959 <sup>a</sup>	< 0.0001	0.0365
Return (RET)	0.0365 <sup>a</sup>	< 0.0001	0.0084
Flexibility (FLEX)	0.6910 <sup>a</sup>	< 0.0001	0.1558
Constant (CON)	-1.2603 <sup>b</sup>	< 0.0484	0.6385
<b>Distances of RPS. Standard Deviations or limits of triangular</b>			
NsLEN	0.1665 <sup>a</sup>	< 0.0001	
TsRET	0.0365 <sup>a</sup>	< 0.0001	
UsFLEX	1.0819 <sup>b</sup>	< 0.0071	
NsCON	4.9115 <sup>a</sup>	< 0.0001	
<b>Goodness of fit indicators</b>		<b>Model specifications</b>	
AIC normalized (AIC/N)	1.564	Number of observations (N)	465
Log likelihood function (LL)	-356.6323	Halton draws	1,000
McFadden Pseudo R-squared	0.3019		

**Notes:** <sup>a</sup> Statistically significant at 1 per cent level; <sup>b</sup> Statistically significant at 5 per cent level.

**Table 18 Random parameters logit (RPL) with interactions**

<b>Attribute</b>	<b>Coefficient</b>	<b>p-value</b>	<b>Standard error</b>	<b>95% Confidence Interval</b>	
<b>Random parameters in utility functions</b>					
Length (LEN)	-0.1509 <sup>a</sup>	0.0018	0.0483	-0.2456	-0.0561
Return (RET)	0.0288 <sup>b</sup>	0.0109	0.0113	0.0066	0.0511
Flexibility (FLEX)	0.6763 <sup>a</sup>	0.0051	0.2416	0.2027	1.1499
Constant (CON)	-0.0543	0.9595	1.0712	-2.1539	2.0452
<b>Heterogeneity in mean, Parameter value</b>					
LEN:UNPP	-0.1813	0.1905	0.1385	-0.4526	0.0901
LEN:BLOCK	0.0366	0.1853	0.0276	-0.0176	0.0908
LEN:AQ1	-0.0271	0.3561	0.0292	-0.0848	0.0305
RET:UNPP	0.1286 <sup>b</sup>	0.0110	0.0506	0.0294	0.2279
RET:BLOCK	-0.0022	0.7746	0.0076	-0.0170	0.0129
RET:AQ1	-0.0079	0.2978	0.0076	-0.0228	0.0070
FLEX:UNPP	-0.2856	0.6707	0.6716	-1.6019	1.0307
FLEX:BLOCK	-0.3269 <sup>b</sup>	0.0336	0.1538	-0.6284	-0.0254
FLEX:AQ1	-0.0885	0.5658	0.1540	-0.3903	0.2134
CON:UNPP	1.5301	0.6449	3.3205	-4.9779	8.0382
CON:BLOCK	-0.1339	0.8613	0.7661	-1.6355	1.3677
CON:AQ1	-2.1123 <sup>a</sup>	0.0100	0.8197	-3.7188	-0.5057
<b>Distances of RPS. Standard Deviations or limits of triangular</b>					
Ns LEN	0.1789 <sup>a</sup>	<0.0001			
Ts RET	0.0288 <sup>a</sup>	0.0109			
Us FLEX	1.0330 <sup>b</sup>	0.0167			
Ns CON	5.1235 <sup>a</sup>	<0.0001			
<b>Goodness of fit indicators</b>			<b>Model parameters</b>		
AIC normalized (AIC/N)	1.559		No. of observations	465	
Log likelihood function	-343.3956		Halton draws	1,000	
McFadden Pseudo R-squared	0.32780				

**Notes:** <sup>a</sup> Statistically significant at 1 per cent level; <sup>b</sup> Statistically significant at 5 per cent level. Ns=Normal distribution, Ts=Triangular distribution, Us=Uniform distribution.

## 4.6 Testing quantitative hypotheses

This section revisits the null hypotheses of this thesis and explains why they should be rejected or not.

**Hypothesis 1:** Landholder and farm characteristics investigated do not determine the willingness of planting trees as energy crops or the area of planting.

**Hypothesis 1a:** Landholder and farm characteristics investigated do not determine the extent of area of planting of trees for bioenergy (tested with tobit model)

**Hypothesis 1b:** Landholder and farm characteristics investigated do not determine the likelihood of planting 50 hectares or more of trees for bioenergy (tested with logit model)

**Hypothesis 1c:** Being a Landcare member does not influence the decision on the extent of adoption (tested with tobit and logit models).

In both the tobit and logit models, landholder characteristics exert a statistically significant influence on the decision of the extent of potential planting area (tobit model), and the decision to plant 50 hectares or more (logit model). Based on the results of the tobit model (Table 14), the null hypothesis 1a is rejected because the proportion of unproductive land, the number of organisations in which the landholder is a member, landholder age and landholder's lifestyle, determine the extent of planting trees for bioenergy.

The decision to plant 50 hectares or more analysed with a logit model was positively influenced by the proportion of unproductive land, the number of organisations in which the landholder is a member, experience in planting blocks of trees and location in lower productivity and higher productivity areas, while age-squared negatively influences potential adoption (Table 15).

Based on the results of the logit model, hypothesis 1b is also rejected. On the other hand, there is not enough evidence to reject hypothesis 1c. Landcare membership alone was not a statistically significant factor that influenced willingness to adopt, using either the tobit or logit models.

**Hypothesis 2:** There is no difference in willingness to plant trees as energy crops among those landholders whose properties are located in areas with lower biomass productivity values and those landholders whose properties are located in areas with higher biomass productivity values.

The tobit model provides evidence to reject this hypothesis. Landholders in high productivity areas (located in zone 3) were interested in planting. The coefficient is statistically significant at 10 per cent level (Table 14). In the logit model, where the dependent variable was a binary variable for planting 50 or more hectares, the farm location effect was also positive and statistically significant at 5 per cent level for both lower and higher productivity areas (zone 1 and zone 3) (Table 15).

**Hypothesis 3:** Landholders' preferences do not influence any of the attributes in the choice experiment.

Based on the results of the different choice models, MNL (Table 16), and two RPL models (Table 17 and Table 18), this hypothesis is rejected. Preferences for all contract attributes were statistically significant, different from zero, at 1 per cent level and with the expected signs. This means, landholders prefer shorter contracts, higher returns and flexibility to choose the tree harvesting company. If the contract attributes were not significant, further interactions of these variables with any other variable would not be significant.

**Hypothesis 4:** Landholder and farm characteristics investigated do not influence landholders' preferences for contract attributes in the choice sets.

Based on the results of the RPL model with interactions (Table 18) this hypothesis is rejected. Two interactions between contract attributes and landholder and farm characteristics were statistically significant. In particular, those landholders with

experience in planting blocks of trees would be likely to accept less flexible contracts, this is, they would accept the harvesting company specified by default in the contract. Second, those landholders with a higher proportion of unproductive areas would prefer higher returns. These results are statistically significant at the 5 per cent level.

The interactions between socio-demographic characteristics and the contract attributes were not significant in the RPL model with interactions, therefore, there is not enough evidence to reject the hypothesis for the rest of the independent variables. Hence, preference for the contract attributes were not significantly different between landholders with different characteristics.

#### **4.7 Study caveats and limitations**

To best of my knowledge, this study is the first attempt to research contract preferences for bioenergy in Australia using choice models. However, several caveats apply.

##### **Survey questionnaire design and information available to the respondent may influence the adoption decision**

The order of questions and length of the survey aimed to be as efficient and credible as possible to landholders. The variables investigated in the survey were limited to tangible and measurable information for most of the survey. Instead of asking in the first instance if the landholder would be willing to plant trees as bioenergy crops, the landholder was offered contract options to choose from and then asked if, based on the options, he/she would plant or not. If the responses to the choices were all negative, follow up questions explored the reasons not to plant.

When comparing the results of the pilot study with the final study, we observe a difference in the total number of potential adopters, 20 per cent vs. 70 per cent potential adoption (planting any area, regardless of how small). In the pilot, the question about planting area was asked before the choice experiment. This

difference seems to indicate that seeing the contracts had an influence on landholders' responses. Moreover, landholders in the survey expressed their decision in the absence of potentially critical information. They did not have information about growth rates that correspond to the different harvest periods proposed in the contracts (e.g. 5 years vs. 10 years) or a visual prompt on how the plantations would look on their own farms. We do not know if these factors could have affected the responses obtained.

### **Results are only a snapshot within a rapidly changing policy environment**

This survey is a snapshot of circumstances at a certain point in time and place. A rapidly changing policy environment and biophysical circumstances could motivate different answers, even a few months later. For example, the Ministry of Primary Industries announced in early October 2012—in between the pilot and final survey—that a new land management agency called 'Local Land Services' was to be created from early 2014 (Hodgkinson 2012). This new agency merged different local government agencies that deal with agricultural production, biosecurity, natural resource management and emergency management. Notably, the Catchment Management Authority falls under this new agency. Thus, I reviewed the set of answer options about landholder membership so that only those organisations not directly affected by this change were explicitly mentioned in the final survey. Therefore the options for organisations in the final survey were: New South Wales Farmers Association, Landcare and other. It is worth noting however that landholders had the option to choose 'other' as a response and to provide the name of the organisation. Some landholders mentioned the Catchment Management Authority in their responses.

### **Income data is a sensitive issue, in particular for face-to-face surveys**

Income data were also difficult to obtain in the pre-pilot survey and was replaced with a question about land value in the pilot and final survey. Moreover, in the final survey 11.6 per cent of the respondents (n=18) either did not know the land value or chose not to answer. Expert knowledge suggested that it would be difficult to obtain accurate income information (S Whitten 2012, pers. comm., 13 September). This knowledge was corroborated with the different income options

expressed in the pre-pilot phase. For example, income before or after tax, last year's income (very productive because of the wettest period on record: 2010-2011) (National Climate Centre & Bureau of Meteorology 2012), average income (very low because of a previous long term drought), and source of income (on farm vs. off farm). Every landholder had a different income figure in mind and it was very difficult to agree on an ideal income parameter or set of parameters and how to standardise this information.

#### **Interviewer biases may occur**

Other potential bias include interviewer bias and if there was a difference in landholder responses to each interviewer. While most landholders interviewed (98 per cent) were white males, interviewees were mostly females and from different ethnicities. To test if there was a significant difference, the initial analysis introduced the variable interviewer as independent variable but found it was not significant. From a qualitative perspective, however, it is noted that one interviewer received more detailed comments than the rest of the interviewers, potentially because of the location of the interview, which took place at the field day grounds, next to the rest area. Interviewer bias was mitigated through training.

#### **Choice experiment caveats**

Regarding the choice analysis, loss of balance could be a potential caveat. Although every possible effort was made to have a balanced representation of the six questionnaire types by randomly assigning them to interviewers, interviewers' efficiency (number of surveys completed per day) was different which led to having more questionnaires of a certain type completed. Therefore, the sample could be unbalanced.

Another potential caveat of the survey is hypothetical bias. This bias is understood as the inconsistency between hypothetical and real choices (Hensher 2010; Fifer et al. 2014). This bias is a concern for stated preference studies. The magnitude of the hypothetical value seems to be a primary factor explaining this bias (Murphy et al. 2005). Hypothetical bias was addressed using scenarios that are plausible and financial returns that were equivalent to a fair rent in the region, as explained in Chapter 3 (see Appendix 7).

Peer pressure is another possible caveat of a face-to-face choice model survey. This bias was mitigated by interviewing the landholders individually whenever possible.

#### **4.8 Personal learnings about methods**

The following are two key major personal learnings that will impact on how I do research in the future. Experienced researchers are familiar with these lessons, however, it is important to recognise that learning is a key part of the research process.

##### **Trade-offs exist between the amount and depth of information of a mail out survey vs. a face-to-face survey**

As explained in Chapter 3, mail out surveys have a very low response rate, tend to be long and generate survey fatigue. On the other hand, face-to-face surveys tend to obtain higher response rates (58 per cent in this study) and have the potential to obtain more details about the reasons for different responses (e.g. qualitative comments to the survey). However, face-to-face surveys also require the enumerators to be adequately trained.

Face-to-face surveys held at events organised by landholders themselves, although more convenient to the landholder, have to be brief, no more than 10 to 15 minutes and therefore, the survey tool needs to be as parsimonious as possible. Therefore potential tradeoffs exist between the total number and depth of questions asked.

##### **If resources are available, hiring professional enumerators is preferable**

Hiring professional enumerators was initially explored but it would have resulted in a prohibitive cost per survey. The alternative option, training volunteer students as enumerators, while providing an opportunity to discuss the research in a collegial environment, resulted in different depth in recording the qualitative comments to the survey and some incomplete surveys. Therefore, involving volunteers needs to be weighted against the goals of future studies.

Despite these limitations, the survey provided results within the expected signs in most of the econometric models. However, levels of significance were affected when moving from the simple models to the more complex ones. On the other hand, the survey managed to capture the views of independent landholders that are not traditionally targeted in surveys.

## 4.9 Conclusions

The results of the landholder survey are comparable with assumptions of adoption rates found in desk studies of 10 per cent of available land (Rodriguez et al. 2011c). While the sample may be representative of only the sub-population, i.e. those landholders from New South Wales attending the Australian National Field Days, the average potential planting area was 10.39 per cent across the sample. If only potential adopters were considered, the average increased to 14.61 per cent of their land. If only adopters of 50 hectares or more were considered, then the average decreased to 9.72 per cent across the sample and 18.90 per cent of their land.

In terms of the number of adopters, 70 per cent of the sample would consider planting trees as energy crops. Thirty per cent of the sample would consider planting 50 hectares or more. This latter finding seems to be in conflict with adoption theory, where innovators are usually 2.5 per cent of the potential adopters, while early adopters represent 13.5 per cent.

### **Highly connected landholders with higher levels of unproductive land would be more willing to adopt tree energy crops**

The results of the tobit model identified the adoption factors that positively influence the potential extent of planting area, in addition to financial returns which were assumed to be a factor influencing adoption across all models. These factors are: the proportion of unproductive land in landholder's property, the number of organisations in which the landholder is a member, and landholder's farm location. On the other hand, age-squared would negatively influence adoption.

### **Planting programmes of 50 hectares or more should target landholders with experience in planting blocks**

In the logit model of adoption where the dependent variable is willingness to plant trees for bioenergy on 50 hectares or more, the potential positive adoption factors identified are: proportion of unproductive land, number of organisations in which the landholder is a member, experience in planting blocks of trees and farm location in zones 1 and zone 3 (Table 15).

### **Contract design is important to adoption**

After identifying the potential adoption factors using tobit and logit models, these factors were used in the analysis of choices related to tree planting contract attributes. Because each landholder answered three choices, the sample size of the choice model was n=465 choices. Different models were run from basic simple multinomial models to more complex random parameters logit models using 1,000 Halton draws. The results of these models (multinomial and random parameters logit) found that in general, landholders prefer shorter contracts, higher returns and flexibility to choose the tree harvesting company.

When the random parameters logit model was interacted with the landholder and farm characteristics, only two of these interactions revealed significant heterogeneity. First, those landholders with experience in planting blocks of trees would be likely to accept a less flexible contract, i.e. to accept the harvesting company specified by default in the contract. Second, those landholders with a higher proportion of unproductive areas would prefer higher returns. Preferences for contract attributes were not influenced by landholder and farm characteristics.

The contribution of this chapter is the identification of factors that would influence the adoption of bioenergy tree crops in the case study area. Two factors positively influenced adoption across all models: area of unproductive land and number of organisations in which the landholder is a member. Preferences for shorter and flexible contracts with higher returns were statistically significant in all choice models explored. When interacting the contract attributes with

landholder and farm characteristics, experience in planting blocks and the proportion of unproductive land resulted in positive adoption factors.

This chapter has answered two of the three research questions in this thesis:

- What factors underlie landholders' willingness to plant bioenergy tree crops?
- What are the landholders' preferences in the design of contracts for planting these trees?

In the next chapter, the issue of critical mass for a biomass energy industry in the case study area will be analysed.

## Chapter 5

### Building critical mass for a bioenergy industry

#### 5.1 Introduction

This chapter addresses the issue of building critical mass using the landholders' preferences explored in Chapter 4. It starts by discussing the concept of critical mass and its relevance to the context of tree biomass for bioenergy (Section 5.2). Current and potential biomass supply curves for the case study area are presented and used to estimate a break even point for the production of biomass under different oil prices (Section 5.3) and ethanol policy scenarios (Section 5.4).

While the concept of critical mass refers to the biofuel system, which requires a critical mass of actors (e.g. landholders, brokers, bioenergy developers), policy forces and market forces, the focus of this study is critical mass of tree growers for bioenergy. A case study of bioenergy application is explored as an exemplar to estimate biomass volume and costs (Section 5.5).

The last section of this chapter explores pathways to build a critical mass of biomass growers. Joint discussion of the results chapters (Chapters 4 and 5) is presented in Chapter 6.

#### 5.2 Critical mass

The issue of building critical mass has not been directly addressed within the bioenergy literature to the best of my knowledge. This issue is complex, multidisciplinary and concerns multiple stakeholders. The importance of building critical mass is a tacit issue about technology adoption and is taken as a given in the literature. Only a handful of studies do mention the importance of building critical mass in the scientific literature, for example, on research collaboration in biotechnology (Peter 2004) and in materials science (Nature 2003). However

these studies fall short in explaining what the potential mechanisms to build this critical mass could be.

Game theorist Thomas C. Schelling (2006) and sociologist Mark Granovetter (1978) were the early contributors to the concept of critical mass in the social sciences. Schelling (2006) uses the term 'critical mass' as shorthand for a critical number, critical density or critical ratio 'involved in some activity that is self-sustaining once the measure of that activity passes a certain minimum level' (p. 95). He also notes that there is not a single model of critical mass but rather the concept could be applied to a family of models in different areas, such as voting, epidemiology and neighbourhood social structure.

Schelling (2006) also indicates that in the social sciences, this critical number or critical ratio might vary among individuals. For example, in the context of this thesis, some landholders may decide to plant trees for bioenergy if a neighbour has done so already, whereas other landholders would need to see more landholders that have planted trees for bioenergy before they do it themselves. Others may also decide not to plant.

The number or ratio of people that is 'enough' is called a 'threshold' by Granovetter (1978). He defined the concept of 'threshold' as 'the number or proportion of others who must make one decision before a given actor does; this is the point where net benefits begin to exceed net costs for that particular actor' (Granovetter 1978, p. 1420).

The concepts of critical mass and threshold are pivotal to understanding the theory of diffusion of innovations postulated by Everett Rogers. Rogers (2003) indicated that critical mass happens when 'enough individuals in a system have adopted an innovation so that the innovation's further rate of adoption becomes self-sustaining' (p. 343). Innovators and early adopters are therefore the first members of this critical mass.

It is worth noting that other authors have proposed a 'theory of the critical mass' but specifically applied it to the generation of public goods (Oliver et al. 1985).

Surprisingly, these authors did not refer to the former conceptual work of Rogers (2003), Schelling (2006) or Granovetter (1978) in their theory. Oliver and Marwell (2001) came up with a similar concept where critical mass is mostly understood as ‘the problem of getting enough people organised to contribute that some or much more of the collective good could be provided’ (p. 299). A review of the use of this ‘theory of the critical mass’ by Oliver and Marwell (2001) found that the literature had interpreted the critical mass concept closer to a threshold model or ‘getting enough cooperators up to a tipping point where everybody cooperates’ (p. 299). This finding is in line with the original conceptual work on thresholds developed by Granovetter (1978). More recently, Axsen and Kurani (2012) defined critical mass in a public good context as ‘a group with high interest and access to resources that is willing to actively induce widespread uptake of a prosocietal product or practice’ (p. 322).

The issue of critical mass has been explored in the study of social dynamics, in particular, critical mass related to collective action for the supply of public goods (Oliver & Marwell 2001), gender politics (Bratton 2005), adoption of telecommunication technology (Markus 1987), social media (Shen et al. 2013) and the adoption of pro environmental behaviour (Axsen & Kurani 2012). Understanding the adoption of both new technologies and new behaviours is pivotal for this chapter (see Chapter 2 for an overview of adoption and innovation diffusion theory). One of the most comprehensive works that contrasts different research perspectives of social interactions and their influence on new behaviours is probably that of Axsen and Kurani (2012). Their work includes an analysis of critical mass where they argue that critical mass creates the conditions to facilitate the uptake of new technologies or behaviours. Hence, in the context of this thesis, critical mass can be understood as the subset of landholders, brokers, policy makers and other actors rather than only early adopters. The scope of their review is however broader than the scope of this chapter. They focus primarily on social networks, whereas this thesis focuses on individual decisions on adoption rates and species preferences that influence the amount of biomass economically available.

Even though this chapter does not explain a step-wise process for how to build critical mass, it recognises that the ‘how’ depends on each individual situation and context, and proposes pathways to achieve critical mass that can be adapted accordingly. The pathways explored are based on a qualitative assessment of the information presented and available case studies from other regions, and the quantitative results of Section 5.3 in this chapter. In the context of this thesis, critical mass of landholders refers to how many landholders would produce enough hardwood biomass to supply a hypothetical bio-ethanol plant which is used as an example of biomass production volume and costs.

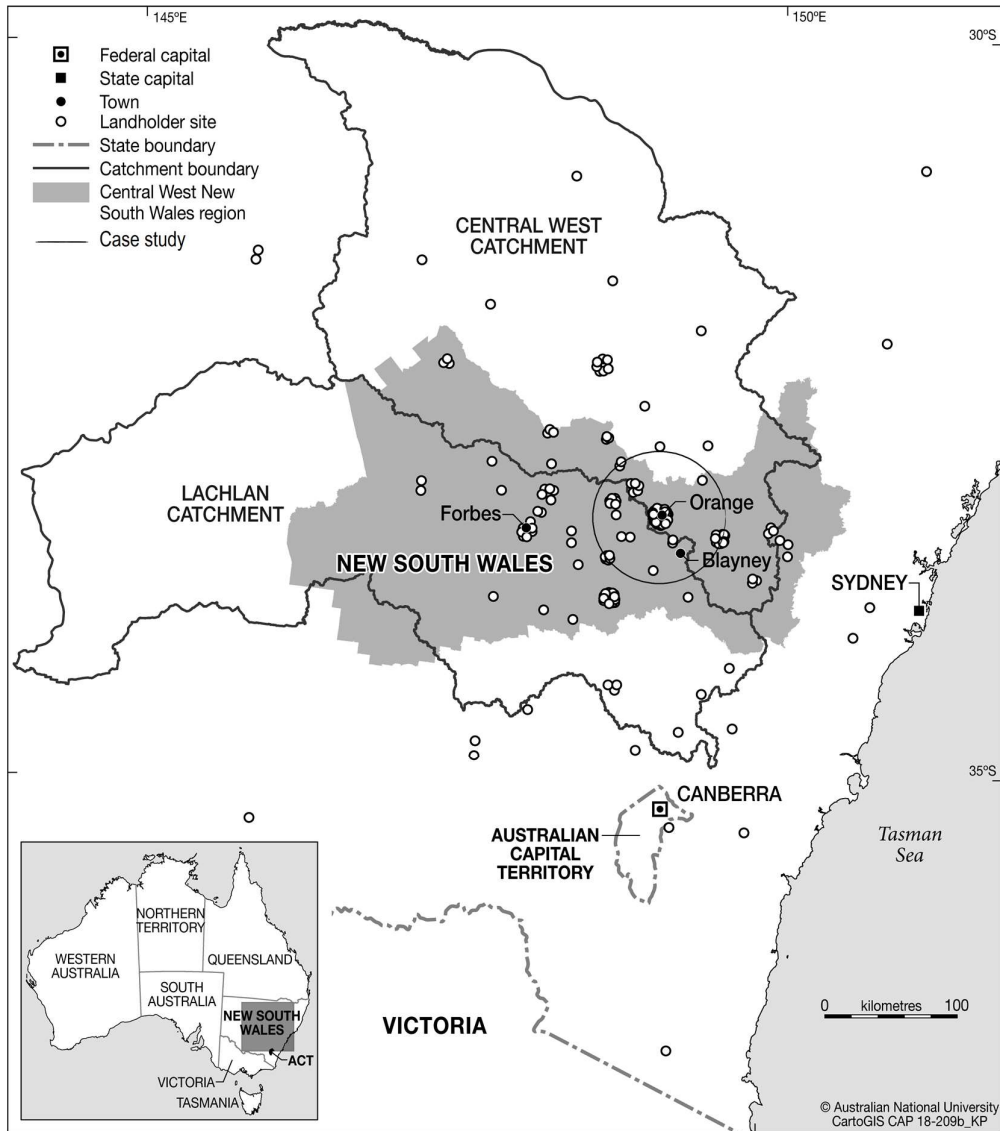
This chapter uses informed assumptions about landholders’ preferences obtained through primary data collection in this thesis (see Chapter 4) and background IP provided by the CSIRO, including: secondary biomass data from existing softwood plantations and potential new hardwood plantations in the case study region, transport and biomass production cost data updated from the CSIRO (Rodriguez et al. 2011c), and a transport model (May 2011 based on Lambert & Quill 2006) used as reference in the quantitative assessment (see Appendix 11 and Appendix 12). The methods used to produce the results in this section (Biomass assessment) are described in detail in Chapter 3, Section 3.5.3.

This chapter focuses on building the critical mass of a ‘latent product’, a bioenergy tree crop, which has both private and public goods aspects (see Chapter 2, Section 2.2.3). Following S&T Consultants Inc (2007), this chapter uses the case of supplying a hypothetical 68 ML second-generation bio-ethanol plant. The minimum annual supply of biomass needed for this second-generation bio-ethanol plant is 210 kilo tonnes (kt) per year<sup>36</sup>. This biomass could be sourced from existing softwood plantations and potential hardwood plantings as explained next. The biomass assessed corresponds to an area of 100 km radius around the town of Orange in Central West New South Wales, Australia (Figure 16).

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<sup>36</sup> This reference plant capacity of 68 ML and has a conversion efficiency of 325 L ethanol per tonne of biomass (S&T consultants 2007, cited in Rodriguez et al. 2011b, 2011c). This plant would require 209.23 kt of dry weight biomass a year, rounded to 210 kt for biomass estimations. This reference plant would be located on the outskirts of the town of Orange, New South Wales.

**Figure 16 Map of the case study area for the biomass cost analysis**



**Note:** The biomass cost analysis is based on an area of 100 km radius from the outskirts of Orange, within the Central West region New South Wales (circle).

**Source:** Australian National University CartoGIS elaborated with GIS data from Commonwealth of Australia (Murray–Darling Basin Authority) (2012), CSIRO regional maps, and landholder sites by Velarde (2012).

### 5.3 Biomass assessment

Previous research by the CSIRO assessed environmental and economic opportunities for bioenergy in two regions in Australia<sup>37</sup>, including the Central West New South Wales, as explained in Chapter 3 (Section 3.5.3). The assessment by Rodriguez et al. (2011b) included modelling of existing softwood biomass and of new hardwood woody biomass plantings around the nearby town of Wallerawang in the Central West region. Rodriguez et al. (2011c) concluded that new plantations of mallee tree biomass would not be enough to supply the power station in the town of Wallerawang with co-firing<sup>38</sup>. Second, the estimated cost of biomass would not justify its production. Rather, ethanol production, which requires less biomass than co-firing<sup>39</sup>, may represent a feasible near term option (Rodriguez et al. 2011c). Therefore, this section explores woody biomass for ethanol production.

The analytical methods and secondary data used for this section were earlier explained in Chapter 3, Section 3.5.3. The results outlined in this section build largely on the work by Rodriguez et al. (2011c) who provided biomass datasets, biomass production cost data and transport cost data and models. At the same time, some minor updates were made, including updating the biomass and transport costs to April 2014. Also, building a biomass supply curve with only existing softwood was added to the analysis in addition to the hypothetical supply curve that includes new hardwood plantations as shown in Rodriguez et al. (2011c).

A standard second-generation bio-ethanol plant of 68 ML per year would require a minimum supply of 210 kilo tonnes (kt) of biomass per year (S&T Consultants Inc 2007). The supply curve examines current biomass available as well as new

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<sup>37</sup> Work funded by the Department of Agriculture and Water Resources, formerly known as the Department of Agriculture, Fisheries and Forestry (1998-2013). The Department has funded several bioenergy assessment projects (Department of Agriculture and Water Resources 2016).

<sup>38</sup> Co-firing refers to replacing 20 per cent of coal with woody biomass to produce power.

<sup>39</sup> In Rodriguez et al. 2011c, a 68 ML bioethanol plant was assessed for the Gippsland region in Victoria. This plant would require 210 kilo tonnes of biomass.

plantings for a hypothetical 68 ML bio-ethanol plant. This biomass could be sourced from existing softwood plantations and potential hardwood plantings from an area of 100 km radius from the outskirts of the town of Orange in the Central West New South Wales region (Figure 16). A critical mass of landholders means a sufficient number of landholders who would plant new hardwood so that deficits between the needed 210 kt and the most pessimistic scenario of softwood availability in the case study area can be covered. The most pessimistic scenario of softwood availability is chosen to provide a conservative figure. Therefore, in the context of this chapter, reaching critical mass means getting enough landholders planting hardwood on their farms so that there is enough biomass to supply a hypothetical bio-ethanol plant.

The first step in the analysis of critical mass is to estimate the current and potential biomass feedstocks in the case study area. The method to produce the supply curves was described in Chapter 3 (Langholtz et al. 2007; Ashton et al. 2008). Biomass availability data was estimated based on softwood (radiata pine) and hardwood (eucalyptus) productivity maps from the Central West New South Wales region provided by the CSIRO (see Appendix 12 for metadata of the biomass databases).

### **5.3.1 Softwood biomass supply cost curve**

Softwood biomass feedstock available in the case study area were summarised from data of existing softwood plantations modelled and provided by the CSIRO. The models excluded harvested logs, which have a direct use in the forestry industry, and considered three softwood biomass supply scenarios for the years 2020 and 2030, within a radius of 100 km from a 68 ML hypothetical bio-ethanol plant (Table 19). The scenarios of softwood availability were developed by the CSIRO for the Central West region and introduced in Chapter 3, Section 3.5.3.

The secondary data for the Orange case study area indicate that, from a biophysical perspective, there would be enough biomass available from current softwood plantations to supply a hypothetical 68 ML bio-ethanol plant under Scenarios 2 and 3 (Table 19). On the other hand, the most pessimistic softwood

biomass supply scenario (Scenario 1) would need new hardwood plantings to achieve the minimum 210 kt of biomass required by the hypothetical bio-ethanol plant.

**Table 19 Three scenarios of softwood biomass supply - Orange case study area**

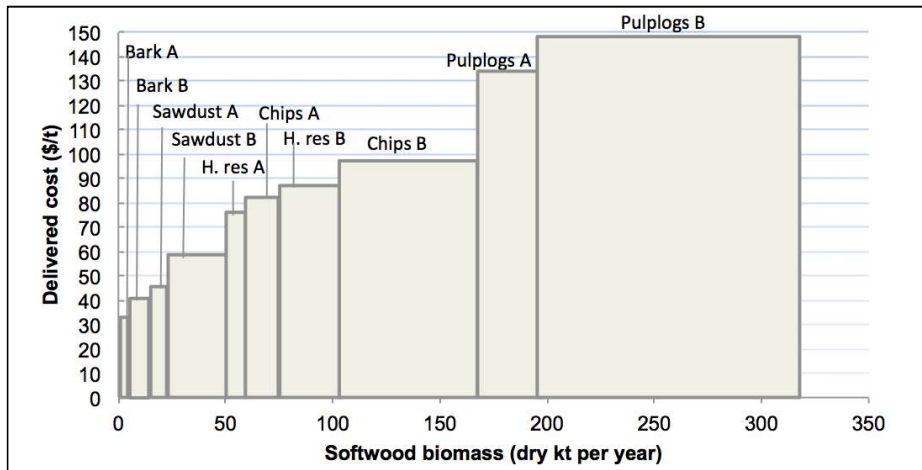
<b>Year</b>	<b>Scenario 1 Harvest residue only  (kt)</b>	<b>Scenario 2 Harvest residue + 50% pulp logs + sawmill residue  (kt)</b>	<b>Scenario 3 Harvest residue + 100% pulp logs + sawmill residue  (kt)</b>
2020	37.86	249.61	326.50
2030	43.28	286.94	367.03

**Source:** Based on CSIRO data from 2011 (see Appendix 12a for details: Softwood existing plantings).

Next, the amount of softwood biomass available in the case study area in 2020 at a cost that would justify processing it at the bio-ethanol plant was estimated. This analysis required first building a biomass supply cost curve (Figure 17). This curve shows the amount of softwood biomass in the horizontal axis and the delivered cost or plant gate cost of producing this biomass (AUD per tonne) in the vertical axis. The delivered cost includes biomass farm gate cost and transport costs to the bio-ethanol plant gate (Appendix 11a). In 2020, the biomass feedstocks with lower plant gate costs are bark, and sawdust and shavings up to 100 km from the hypothetical bio-ethanol plant (AUD 31.67 to AUD 59.13 per tonne) (Appendix 11b), The most expensive biomass feedstocks are pulp logs (AUD 133.59 to AUD 148.90 per tonne) (Rodriguez et al. 2011c). Note that pulp logs alone within a radius of 100 km of the hypothetical plant constitute 47 per cent of the total softwood biomass in the area in 2020.

In order to determine if there would be sufficient softwood biomass at a cost that would justify processing it at the bio-ethanol plant in the case study area, the biomass delivered cost (plant gate cost) obtained in the supply curve (Figure 17) were compared to the ethanol prices, as explained next.

**Figure 17 Softwood biomass supply cost curve (existing plantations) - Orange case study in 2020**



**Note:** A= 0-50 km radius, B= 50-100 km radius; H.res = harvest residues.

**Source:** Elaborated with CSIRO biomass data from 2011 (see Appendix 12a: Softwood existing plantings) and CSIRO biomass production and transport data updated to the first quarter of 2014.

### 5.3.2 Break even analysis: Biomass and ethanol price

It is important to understand how the cost of biomass affects the production cost of ethanol and how different ethanol pump prices compare to oil prices in order to find the biomass cost that would break even with a given oil price. Australia is a petrol price-taker country, and uses the price of unleaded petrol in Singapore<sup>40</sup> as its pricing benchmark (Australian Institute of Petroleum 2014a). The Singapore price of unleaded petrol in turn uses the TAPIS<sup>41</sup> oil price as its pricing benchmark. The steps in this section follow Rodriguez et al. (2011c), while the oil price data and exchange rate data are updated to April 2014.

The first step in the analysis is to explore the retail petrol pump price in Australia (AUD per litre) for different TAPIS oil prices (USD per barrel). Appendix 13 shows calculations of the unleaded petrol pump price at different TAPIS oil prices taking as base case the value of USD 115.13 per barrel, and sensitivity estimations, from -75% to +100% of this oil price, corresponding to 0.854 AUD per litre and 2.375 AUD per litre of retail petrol pump price (RPP), respectively.

<sup>40</sup> The unleaded petrol in Singapore is known as MOPS95.

<sup>41</sup> TAPIS oil is the Malaysian crude oil.

The estimations for the oil price of USD 115.13 per barrel (April 2014) are shown in Table 20.

**Table 20 Estimation of unleaded petrol retail pump price (RPP) based on TAPIS oil price (April 2014)<sup>e</sup>**

Item	Unleaded petrol	Unit	Value	Formula
A	Oil price per barrel TAPIS <sup>a</sup>	USD/barrel	115.13	
B	Exchange rate <sup>b</sup>	USD/AUD	0.9648	
C	Volume conversion	L/barrel	159.00	
D	Oil price per litre TAPIS <sup>c</sup>	AUD/L	0.7505	
E	Refining cost petrol Singapore <sup>d</sup>	AUD/L	0.0685	
F	Petrol price per litre Singapore <sup>a</sup>	AUD/L	0.819	F = D+E
G	Australian fuel excise	AUD/L	0.38143	
H	Wholesale margins and other costs <sup>c</sup>	AUD/L	0.05	
I	Importing costs to land fuel <sup>c</sup>	AUD/L	0.05	
J	Australian GST (10%) <sup>c</sup>	AUD/L	0.13	J = 0.1 * (F+G+H+I)
K	Terminal Gate Price (TGP)	AUD/L	1.430	K = F+G+H+I+J
L	Retailer cost and margin (5% of RPP) <sup>c</sup>	AUD/L	0.08	L = 0.05 * M
M	Retail Petrol Pump Price (RPP) <sup>c</sup>	AUD/L	1.506	M = K/0.95

**Source:** <sup>a</sup>Australian Institute of Petroleum (2014b): Weekly petrol prices report (April 2014).

<sup>b</sup>Australia Taxation Office (2014); <sup>c</sup>Australian Institute of Petroleum (2014a); <sup>d</sup>Estimated as the average difference between MOPS95 and TAPIS oil, based on weekly estimates of April 2014;

<sup>e</sup>Cost items relationships obtained from Rodriguez et al. 2011c, Table 5-3 and re-parametised for April 2014.

The second step is to calculate the production cost of ethanol for different costs of biomass (see Section 3.4.3). The cost of ethanol production assumes a capital cost of AUD 0.34 per litre and an operational cost of AUD 0.25 per litre<sup>42</sup>. In the case study region, the estimated biomass feedstock costs range between 31.67 and AUD 148.90 per tonne<sup>43</sup> in 2020 (see Section 5.3.1). To estimate the biomass cost

<sup>42</sup> Based on Rodriguez et al. (2011c) capital cost of AUD 0.32 per litre and operation cost of AUD 0.23 per litre inflated to the first quarter of 2014.

<sup>43</sup> Based on Rodriguez et al. (2011c), costs inflated to the first quarter of 2014.

into AUD per litre, the biomass cost (AUD per tonne) was transformed using a conversion factor of 325 litres per tonne of biomass<sup>44</sup>. After this conversion, the ethanol production cost was calculated for different biomass feedstocks and costs (Appendix 14). The cost of biomass is one of the key factors influencing the production cost of ethanol (14 per cent to 44 per cent of  $E_p$ ). The production cost of ethanol ( $E_p$ ) from softwood biomass ranges from AUD 0.69 per litre to AUD 1.05 per litre (Appendix 14).

The third step is to calculate the ethanol price at the pump. The estimated ethanol price at the pump varied from AUD 0.94 per litre to AUD 1.36 per litre (Appendix 14).

The final step is to estimate the biomass cost (AUD per tonne) to produce bio-ethanol at a price that equals the petrol pump price for a given oil price (USD per barrel), taking into account that the ethanol pump price is equivalent to 1.46 times the petrol pump price after adjusting for energy content. At the oil price of USD 115.13 per barrel<sup>45</sup>, the retail petrol pump price is about AUD 1.506 per litre (Table 20). The EqRPP (Ethanol price equivalent to retail petrol pump price)<sup>46</sup> varies from AUD 1.37 to AUD 1.98 per litre for the different softwood feedstocks studied and softwood biomass plant gate cost varies from AUD 31.7 to AUD 148.9 per tonne (Appendix 14).

Ethanol production breaks even with petrol using softwood biomass with a plant gate cost of about AUD 57 per tonne (Figure 18). At this biomass plant gate cost, only approximately 22.21 kt per year comprising bark up to 100 km and sawdust and shavings up to 50 km from the bio-ethanol plant might be economically used for ethanol production. This amount is only about 10.6 per cent of the 210 kt

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<sup>44</sup> This conversion factor of 325 L per tonne of biomass corresponds to a reference plant capacity of 68 ML (S&T consultants 2007, cited in Rodriguez et al. 2011b, 2011c).

<sup>45</sup> TAPIS oil price as of April 2014.

<sup>46</sup> EqRPP (Ethanol price equivalent to retail petrol pump price) =  $E_{pp} * 1.46$

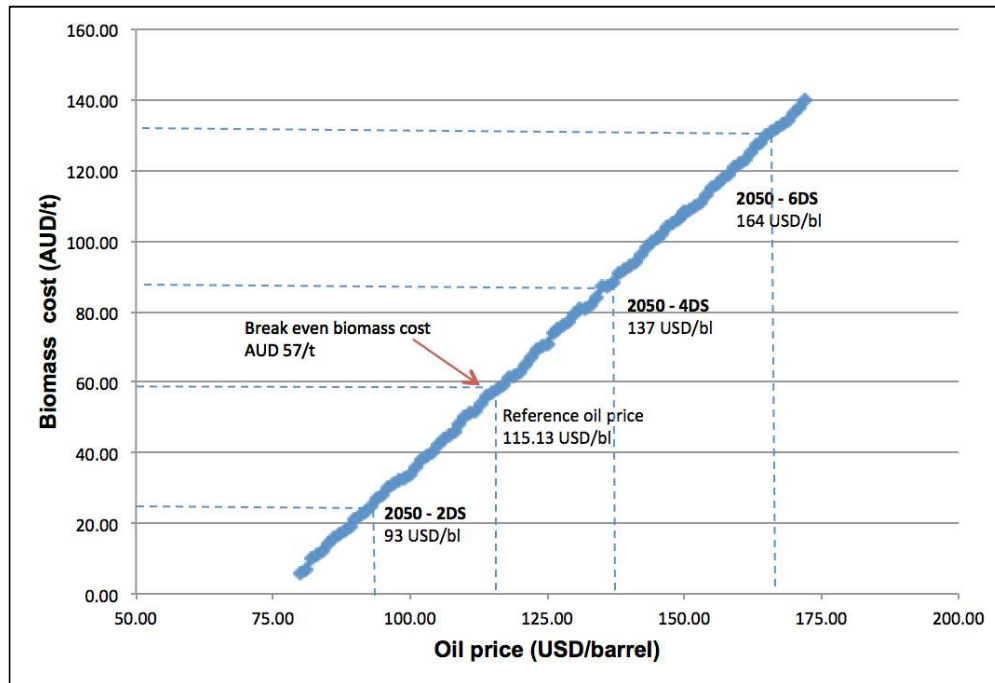
$E_{pp}$  = Ethanol price at the pump =  $E_p + D + GST + X + M$

$E_p$  = Ethanol production cost,  $D$  = distribution cost,  $GST = 10 \% * (E_p + D)$ ,  $X$  = ethanol excise,  $M$  = retail margin = 5%.

needed by the bio-ethanol plant. Alternative feedstocks would therefore be needed to cover the gap of 187.79 kt of biomass.

In the last couple of years (2015-2016), the oil price has dropped to about one third of the April 2014 oil price used as the reference in this study. Figure 18 shows that biomass would need to be gifted or subsidised to be economically viable at an oil price USD 75 per barrel or less. The volatile nature of the oil price directly impacts the uncertainty surrounding biofuel and bioenergy investments in general. Any estimation in such a changing environment needs to be constantly revisited. However, this thesis uses the break even analysis as an illustration of the conditions at a certain point in time. Figure 18 also shows the projected 2050 oil prices by the International Energy Agency (2016) in a two degree, four degree and six degree Celsius climate change scenario. While the four degree Celsius scenario is considered ambitious, the six degree scenario is business as usual. At a two degree Celsius scenario, petrol price is projected to be USD 93 per barrel in 2050 (OECD/IEA 2016a). The projections for 2020 fluctuate between USD 77 to USD 83 per barrel for 2020 and USD 87 to USD 107 per barrel in 2025, depending on the climate change scenario (OECD/IEA 2016a).

**Figure 18 Biomass plant gate cost to equal petrol pump prices after adjusting for energy content vs oil price**



**Note:** 2DS, 4DS, 6DS correspond to 2, 4 and 6 degree Celsius global warming scenarios. 2DS = reductions by almost 60% by 2050 (compared with 2013), 4DS = takes into account recent pledges by countries to limit emissions, 6DS = business as usual, CO<sub>2</sub> emissions grow by 60% from 2013 to 2050.

**Source:** Author estimations; 2050 oil prices: OECD/IEA (2016a).

### 5.3.3 Hardwood and softwood biomass supply cost curves

Additional biomass will be needed at a production cost that would justify processing this biomass to produce bio-ethanol. This section introduces hardwood plantings as a potential biomass source to cover this gap (187.79 kt). The species assessed for new hardwood plantings was selected based on the landholders' preferences identified through the landholder survey (Eucalyptus or native species) (see Chapter 4), the levels of biomass productivity (dry tonne per hectare) and the availability of modelled biomass data. Based on these criteria, secondary biomass productivity data from *E. cladocalyx*, a moderately fast growing species (McMahon et al. 2010), was used to explore the new hardwood plantings biomass (see Appendix 12 for a description of the spatial data used). These data were modelled by the CSIRO (Rodriguez et al. 2011c) using a forest-based process model (Almeida et al. 2007; Polglase et al. 2008).

Two rotation cycles were explored: harvesting rotations of five years and high stocking rates of 2,500 stems/ha, and rotations of 10 years and low stocking rates of 1,500 stems/ha (Appendix 12). Although landholders preferred shorter five-year rotations, the 10-year rotation cycle produces more biomass. Hence, both the five year and 10-year rotations are presented for comparative purposes (Table 21 and Table 22, respectively).

Three adoption levels were investigated based on the potential area planted with hardwood: 10 per cent as per the average potentially planted area of total farm area across the sample (Chapter 4), a medium adoption level of 5 per cent and an early adoption level of 2.5 per cent. These calculations aimed to identify the amount of biomass potentially available and closer to the biomass needs noted above (187.89 kt). Note that the current production of new hardwood plantings in a nearby region west of the case study area is at its pilot stage and there are no local or regional plans for planting trees for bioenergy in place. Consequently, it is reasonable to assume that the average adoption rate of 10 per cent of total farm area across the sample would be at the high end of the adoption of trees as energy crops. Hence, the analysis focuses on exploring an early adoption level of 2.5 per cent of available land by 2020 for further biomass calculations.

**Table 21 Hardwood biomass potentially available (kt per year) from a 5-year *E. cladocalyx* rotation**

Distance	Adoption level (based on area planted)		
	2.5%	5%	10%
0-50 km	119.06	238.13	476.26
50-100 km	198.51	397.02	794.04
Total	317.57	635.15	1,270.30

**Source:** CSIRO *E. cladocalyx* biomass productivity layers (Appendix 12) modelled in 2011; Appendix 15.

**Table 22 Hardwood biomass potentially available (kt per year) from a 10-year *E. cladocalyx* rotation**

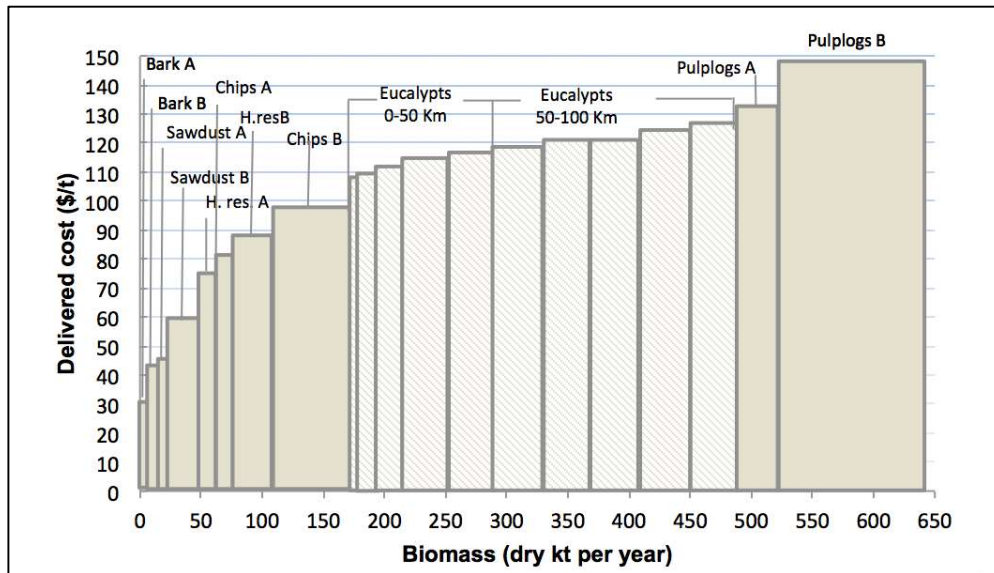
Distance	Adoption level (based on area planted)		
	2.5%	5%	10%
0-50 km	130.33	260.55	521.31
50-100 km	223.67	447.35	894.69
0-100 km	354.00	708.00	1,416.00

**Source:** CSIRO *E. cladocalyx* biomass productivity layers (Appendix 12) modelled in 2011.

The estimations of the potential amount of biomass from *E. cladocalyx* under a five-year rotation cycle at an adoption rate of 2.5 per cent show that 119.06 kt of biomass could be produced in the first 0-50 km buffer area (Table 21; Appendix 15), whereas the difference of 68.83 kt needed to reach 187.89 kt could be produced in the 50-100 km buffer. Under a 10-year rotation, 130.33 kt could be produced in the 0-50 km buffer whereas the difference of 57.56 kt could be produced in the 50-100 km buffer (Table 22). The 10-year rotation produces larger amounts of biomass per harvest, however landholders did not favour this longer rotation period. This point is explored further in the conclusions of this chapter.

The potential supply curve was then built for 2020, indicating the total delivered cost of biomass at the bioenergy plant gate for both softwood and hardwood biomass (Figure 19). New hardwood plantings included in this supply cost curve assume an initial adoption rate of 2.5 per cent of farmland by 2020 and five-year harvest rotations. *E. cladocalyx* in this potential supply could produce a total of about 317 kt of biomass every year within a 100 km radius from the town of Orange, at a biomass plant gate cost that varies between AUD 109.83 and AUD 126.72 per dry tonne (Figure 19).

**Figure 19 Potential supply cost curve of woody biomass feedstocks for the Orange case study region for 2020, 2.5% adoption rate**



**Note:** A= 0-50 km radius, B= 50-100 km radius; H.res = harvest residues.

As noted earlier, the break even biomass cost is AUD 57 per dry tonne (for an oil price of USD 115.13 per barrel). None of the new hardwood plantings are economically available at the reference oil price. *E. cladocalyx* plantings within the first 10 km radius cost AUD 109.83 per dry tonne at the plant gate and would need an oil price of at least USD 152 per barrel to produce ethanol to break even with the price of petrol. To be able to use all of *E. cladocalyx* within the case study area up to a plant gate cost of USD 126.72 per tonne, would require an oil price of at least USD 163 per barrel. These oil prices fall under the projected 2050 oil prices by the International Energy Agency (2016) in a four degree and six degree Celsius climate change scenario (Figure 18).

### 5.3.4 Sensitivity analysis and benchmark comparison

Cost estimates of second-generation biomass are extremely uncertain. To account for this uncertainty, the sensitivity analysis varied the price of oil by  $\pm 50$  per cent, keeping everything else constant (Table 23). A low price oil scenario of USD 57.57 per barrel decreases retail petrol pump prices to about AUD 1.07 per litre. This reduction in petrol prices makes ethanol competitive only if the biomass is subsidised at AUD 27 per tonne at the plant gate (i.e. delivered cost). At higher oil

prices, more biomass could be economically used for ethanol, if the price of oil increases to USD 172.69 per barrel, biomass up to AUD 140 per dry tonne could be available at the break even point (Table 23). This means 519 kt of biomass per year, comprising sawmill residues, harvest residues, all *E. cladocalyx* and softwood pulp logs up to a 50 km radius (Figure 19).

**Table 23 Oil price sensitivity analysis, keeping everything else constant**

<b>Variation in oil price</b>	<b>Oil price (USD per barrel)</b>	<b>Retail petrol pump price (AUD per L)</b>	<b>Break even biomass delivered cost* (AUD per dry t)</b>
+50%	172.69	1.940	140
0%	115.13	1.506	57
-50%	57.57	1.071	-27

**Note:** Base oil price as of April 2014 = USD 115.13 per barrel; \*Delivered cost = biomass at farm gate + transport cost.

Biomass costs have been recognised as a significant proportion of total production. Together with conversion efficiencies these two factors were found to be the most uncertain among different production factors in a national biomass cost assessment for Australia (Brinsmead et al. 2014). Following Brinsmead et al. (2014), the sensitivity analysis also considered variations of  $\pm 60$  per cent on the cost of biomass at the farm gate keeping everything else constant. A 60 per cent reduction in the farm gate price of *E. cladocalyx* resulted in biomass plant gate costs in the range of AUD 53.44 to AUD 70.33 per dry tonne, which in turn resulted in AUD 1.48 to AUD 1.57 per litre of ethanol equivalent to the petrol pump price (Table 24; Appendix 16). To break even, oil price of USD 112 to USD 124 per barrel would be required (Figure 18).

On the other hand, a 60 per cent increase in the farm gate cost of *E. cladocalyx* resulted in biomass plant gate costs in the range of approximately AUD 166 to AUD 183 per tonne that in turn resulted in a price of AUD 2.07 to AUD 2.16 per litre of ethanol equivalent to petrol pump price (Table 24; Appendix 16). To break even, oil price of USD 190 to USD 202 per barrel would be required (Figure 18).

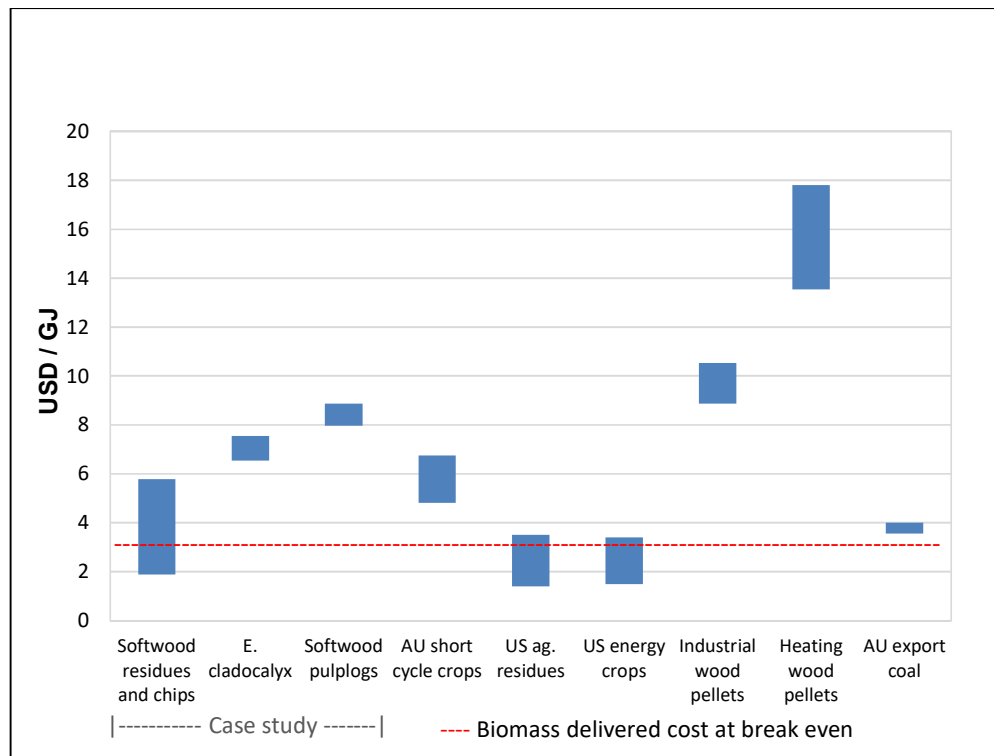
**Table 24 Biomass cost sensitivity analysis, keeping everything else constant**

<b>Variation in biomass farm gate cost*</b>	<b>Biomass delivered cost** (AUD per t)</b>	<b>Ethanol equivalent to petrol pump price (AUD per L)</b>	<b>Oil price and break even point (USD per barrel)</b>
+60%	166.22 – 183.11	2.07 – 2.16	190 – 202
0%	109.83 – 126.72	1.78 – 1.87	152 – 163
-60%	53.44 – 70.33	1.48 – 1.57	112 – 124

**Note:** \*Biomass farm gate cost (*E. cladocalyx*)=AUD 93.99 per dry t; \*\*At the plant gate, includes the cost of biomass and transport for *E. cladocalyx*, 0 – 100 Km.

The results of the case study were compared with set of benchmark energy prices in USD/GJ. There is some overlap of the case study delivered biomass cost for softwood residues and chips with Australian short cycle crops, United States agricultural residues and energy crops (Figure 20). The cost of delivered biomass new hardwood plantings (*E. cladocalyx*) is less than the cost of softwood pulplogs and both, industrial and heating, wood pellets. The delivered biomass cost at break even (3.39 USD/GJ) is also slightly lower than the price of Australian export coal (3.56-4.00 USD/GJ) (Figure 20; Appendix 17).

**Figure 20 Comparison of case study results with Australian, US and international benchmarks**



**Source:** Elaborated with data from BREE (2014), ITP Power (2015), IRENA (2015), Strauss (2017), Strauss (2018) and this thesis.

## 5.4 Ethanol Policy scenarios

In May 2014, the Australian government announced the cancellation of the Ethanol Production Grants Programme from 30 June 2015 (Australian Government 2014). This programme provided a grant of AUD 0.38413 per litre of ethanol produced locally, effectively cancelling out the fuel excise of AUD 0.38413 per litre. The new ethanol excise policy proposes to adopt a zero fuel excise for the financial year 2015-2016. Effectively, there will be no change in practical terms in the first year of this policy, and from 1<sup>st</sup> July 2016, the excise on ethanol will be AUD 0.025 per litre which will increase by AUD 0.025 for five years until it reaches AUD 0.125 per litre. At an oil price of USD 115.13 per barrel, this policy implies that the break even cost of biomass will vary from AUD

49.70 per tonne in 2016-2017 to AUD 20.25 per tonne in 2020-2021, reducing the amount of biomass available at a cost that breaks-even with the retail petrol pump price. An overview of the impact of this new ethanol excise policy on the ethanol price and cost of biomass at break even point, including an estimate of the total biomass available at this break even point, keeping all other variables equal is shown in Table 25.

The impact of the new ethanol excise policy is a gradual decrease in the required biomass cost at break even point for a given oil price, making ethanol production using biomass less and less economically attractive up to the point where only about 3,000 tonnes of softwood bark could be available at the break even point with a petrol pump price of AUD 1.506 per litre (or oil price of USD 115.13 per barrel).

This new ethanol excise policy presents a challenge for the future of planting trees for bioenergy purposes. However, there are many uncertainties related to the ethanol price, mainly, the oil price and biomass farm gate costs. The pathways to build critical mass need to consider these uncertainties as a given.

**Table 25 Influence of new ethanol excise policy on the price of ethanol and biomass availability in the case study area**

Financial year	Ethanol excise (AUD per L)	Range of ethanol price equivalent to RPP <sup>a,b</sup> (AUD per L)	Break even biomass cost <sup>c</sup> (AUD per t)	Biomass available at break even cost <sup>d</sup> (t)
2015-16	0.000	1.78-1.86	57.20	~25,000
2016-17	0.025	1.82-1.90	49.70	~22,200
2017-18	0.050	1.86-1.94	42.30	~14,000
2018-19	0.075	1.89-1.98	35.00	~ 3,000
2019-20	0.100	1.93-2.02	27.70	0
2020-21	0.125	1.97-2.06	20.25	0

**Notes:** <sup>a</sup>RPP: Retail petrol pump price; <sup>b</sup>Price range for biomass of *E. cladocalyx* only; <sup>c</sup>If oil price equals USD 115.13 per barrel or RPP of AUD 1.506 per litre; <sup>d</sup>Includes softwood and hardwood.

## 5.5 Landholder critical mass

The number of landholders who could produce enough hardwood biomass to supply a hypothetical 68 ML bio-ethanol plant in the case study area is estimated. From a biophysical perspective, softwood biomass, excluding pulp logs accounts for 172.7 kt of biomass in 2020, which is only 37.3 kt of what would be needed from new plantings. However, the break even analysis showed that only 22 kt of softwood biomass is available at an oil price of USD 115.13 per barrel, leaving a 188 kt gap that would need to be covered by alternative sources of biomass. If the oil price reaches USD 153 per barrel, keeping everything else constant, then *E. cladocalyx* up to 30 km from the plant and all softwood biomass except pulp logs up to 100 km could be used. This high oil price is contemplated in the 2050 oil price projection of the International Energy Agency (2016) under a ‘business-as-usual’ scenario. The question becomes, under favourable conditions, how many landholders could produce at least 188 kt of biomass annually.

Based on the survey results, landholders who would plant trees as energy crops in areas of 50 or more hectares on their farms would use an average area of 376 hectares, excluding a large outlier, or 781 hectares, if including the outlier. For those landholders who would plant 100 or more hectares on their farm, they would use 502 hectares on average, excluding the outlier, or 1,065 hectares including the outlier<sup>47</sup>. Based on this average, the area and number of landholders who could produce more than 188 kt was estimated. Depending on the adoption rate, critical mass could be achieved by 37 to 57 landholders (Table 26). By mid 2014, 11 trial sites for mallee plantings for bioenergy in Central West New South Wales were established. These trials can help reduce the uncertainty surrounding biomass growing through learning. Learning is claimed as a method to reduce uncertainty about the long-term profitability of a crop (Abadi Ghadim & Pannell 1999); this occurs in the bioenergy industry at various levels and takes different forms, for example, pilot trials with bioenergy growers and pilot trials in biofuel refineries. Trials in the case study region (Horner 2011) may help increase confidence in the bioenergy crop. On the technology side, technology learning curves have been applied to regional bioenergy analysis that can reduce costs in the long term (Hayward et al. 2015).

**Table 26 Critical mass of landholders**

	Adoption rate (area based) <sup>c</sup>		
	2.5%	5%	10%
Biomass (kt)	196	197	194
Area (has)	21,602	20,730	18,534
Distance (km)	65-70	40-45	25-30
No of landholders needed (50+ ha) <sup>a</sup>	57	55	49
No of landholders needed (100+ ha) <sup>b</sup>	43	41	37

**Note:** <sup>a</sup>Planting on average 376 hectares; <sup>b</sup>Planting on average 502 hectares; <sup>c</sup>Area and biomass data extracted from CSIRO GIS biomass productivity layers for *E. cladocalyx* (Appendix 12).

<sup>47</sup> This landholder said he would plant all of his area with trees for biofuels: 24,711 hectares.

The next section builds on the review of successful cases of woody bioenergy development reviewed in Chapter 2, landholders' comments to the survey, the results of the analysis of biomass supply curves above and my own understanding of the bioenergy critical mass issue.

## **5.6 Integrated analysis: Building critical mass**

Regardless of different oil price and biomass cost scenarios, certain conditions, as discussed in Chapter 2, were identified to establish a successful bioenergy supply chain. The initial working hypotheses for building critical mass presented in Chapter 3 considered three aspects: policy, markets and the role of actors (e.g. landholders/growers, brokers and buyers/consumers). This section discusses potential pathways to build a critical mass of tree growers for bioenergy development in regional Australia, taking lessons from the case study and the literature. The proposed pathways integrate knowledge obtained through: the literature reviewed (Chapter 2), the landholder survey (Chapter 4), the biomass supply curve and break even analysis (Chapter 5), and discussions with other researchers and industry experts.

The starting point for all pathways should be an identified opportunity for bioenergy production in a future market. This opportunity would preferably respond to the demand side, e.g., power companies requiring bioenergy. The opportunity could also respond to the supply side, e.g., high levels of unutilised mill residue in a region.

Moreover, the farm gate<sup>48</sup> price for biomass is the same regardless of the market that it enters (e.g. pulpwood, biomass for electricity production, biomass for biofuels for transport, etc.). The existence of a strong market is an important factor of willingness to adopt a bioenergy crop (Brown et al. 2016) and other factors such as risk aversion play an important role in adoption of biofuel crops

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<sup>48</sup> Farm gate is a basic price with the “farm gate” as the pricing point, that is, the price of the product available at the farm, excluding any separately billed transport or delivery charge. (OECD 2005).

(Caldas et al. 2014). Globally, wood biomass markets include: fuel, industrial roundwood, pellets, sawnwood, panels, veneer, plywood, particle and fibreboard, pulp (FAO 2017), and bioenergy markets for heat, power, and transport (IEA 2016). In New South Wales, sawlogs and sawn timber are the main wood markets, while pulplogs wood residues are used to make newsprint and cardboard, fibreboard, particleboard and reconstituted wood panels (Timber NSW 2017). In a similar vein to wood markets, a market with many customer profiles (i.e. many biofuel production plants or projects) is desirable for the development of a ‘critical mass’ of biomass producers.

From a biophysical perspective, the species to be planted should be selected based on appropriate site conditions, i.e. water requirements, soil characteristics, temperature, precipitation and slope. Careful selection of the species can reduce the chance of competition for water between these crops and current land uses. This is an important consideration as competing for water could reduce the potential co-benefits of tree planting.

#### **5.6.1 Pathways for building critical mass**

An analogy between the adoption of new technologies and the ‘valley of death’ is applied to the bioenergy industry. The ‘valley of death’ is a common term used for visualising a place where new technologies or ideas are ‘waiting’ to be used or uptaken (Ernst & Young 2010). In the field of innovation technology, the term is used to describe the challenges of turning an invention into an innovation (Auerswald & Branscomb 2003). Technologies in the ‘valley of death’ could perish before they reach the market (Dal Negro 2014). This analogy is relevant to the discussion of pathways to develop critical mass in the bioenergy context.

A commonly mentioned approach ‘build it and they will come’ is also explained below, together with its merits as a way out of the ‘valley of death’. These technologies are out of the market due to their lack of competitiveness, which results in low cumulative production, as well as fewer opportunities for learning and achieving the necessary levels of competitiveness (Schade 2012). The pathways explored in this thesis outline how bioenergy production from biomass

could emerge from the ‘valley of death’ to the market. The popular adage ‘build it and they will come’ has been identified by at least one bioenergy expert (P Hall 2014, pers. comm., 22 October) as a potential approach to overcome the ‘valley of death’.

In the bioenergy industry, the ‘build it and they will come’ approach refers to a push from actors in the bioenergy industry (e.g., project developers, investment programmes, or venture capitalists) to establish bioenergy plants. These actors can apply their know-how about bioenergy production, learning in the process, and break the vicious cycle of low competitiveness. However, as argued by Parsons Brinckerhoff (2009) and Janzé (2010), large-scale infrastructure projects require a comprehensive project development process and due diligence, and therefore cannot be built entirely on a ‘build it and they will come’ approach. This approach has been identified as an innovation myth by an MIT Sloan review of online tools and communities from 13 global companies (Birkinshaw et al. 2011). In line with Birkinshaw et al. (2011), lessons from the health care sector (Bechtel & Ness 2010) indicate that innovations need to be designed based on careful understanding of end-user needs or challenges facing a company instead of a purely ‘build it and they will come’ approach. This approach also failed during the technology bubble that occurred in the period 1999-2000 because of a lack of market demand (Industrial Biotechnology 2006). In conclusion, there is no evidence that this approach has actually worked. So what pathways could contribute to creation of a bioenergy supply chain in regional Australia?

The following three pathways explore possible responses to this question. These pathways are likely to be more effective if they are interlinked, though one may be more dominant. The primacy of any one approach will vary according to the socio-economic context of each bioenergy case. The three proposed pathways are based on evidence from the case studies presented in Chapter 2 and the lessons from this research case study:

- Interlinked pathway 1: Direct and indirect policies
- Interlinked pathway 2: Bottom-up: Locally driven
- Interlinked pathway 3: Top-down: Corporate driven

#### **a) Interlinked Pathway 1: Direct and indirect policies**

This pathway refers to a favourable policy environment that combines direct and indirect policies (outside the energy realm). A favourable policy environment includes: a price signal for carbon; renewable energy mandates or targets; and grants and subsidies for renewable energy. These policies may be applied using different local, regional and national levels. Indirect policies may include policies related to agricultural or forestry land use, such as waste usage. Regional development policies that may indirectly or directly support the development of renewable energy sources fit into this pathway. Local governments may also play a key role in communicating ideas about renewable energy and motivating discussions around this topic.

The successful renewable energy cases presented in Chapter 2 (e.g., Enköping, Sweden; Mureck, Austria; Lahti, Finland; and Juhnde, Germany) (Table 1 and Table 27) suggest that direct investment in renewable energy projects by different levels of state policies is a key factor, in this pathway. However, this factor does not work in isolation from other policy factors. For example, in Sweden, Finland, and Germany, carbon taxes are also in place. These taxes make renewable energy more attractive than fossil fuels. Other factors such as feed-in tariffs for generating clean electricity are present in Austria and Germany. In the case study region, local governments within the Lachlan catchment have actively promoted discussions on renewable energy initiatives (Central NSW Councils 2011), in particular about planting mallees for co-firing at a local electricity plant in 2011 (Larkin & McMullen 2014). This initial support could be considered a precursor to further discussions and future implementation of tree planting schemes for bioenergy. Pilot schemes to plant trees for bioenergy in the case study area are also in place (see Section 3.3.2).

It is likely that favourable energy policies alone would not be enough for uptake of energy crops, as illustrated in the case of the promotion of miscanthus in the United Kingdom, where despite the existence of energy crops establishment grants, there has been low adoption of these crops (Sherrington & Moran 2010). Establishment grants, on the other hand, were supported as one of the main

reasons behind the adoption of bioenergy crops in Condobolin, a dry area of Central West New South Wales (Baumber et al. 2011). These grants are recommended as key catalysts of bioenergy adoption by farmers (Sherrington et al. 2008).

**Table 27 Policies influencing the adoption of bioenergy crops in successful cases in Europe**

Policies	Cases					
	Enköping, Sweden <sup>a</sup>	Mureck, Austria <sup>b</sup>	Lahti, Finland <sup>c</sup>	Vorarlberg, Austria <sup>d</sup>	Vienna, Austria <sup>e</sup>	Juhnde bioenergy village, Germany <sup>f</sup>
<b>Indirect: Non-energy sectors</b>						
New agricultural policy	X					
Other		X	X			
<b>Direct: Energy sector</b>						
Energy policy		X		X	X	X
Bioenergy project investment grants	X	X	X			X
Carbon tax/fossil fuel tax	X		X			X
Feed-in tariffs					X	X

**Note:** Elaborated based on Table 1 (Chapter 2).

**Source:** <sup>a</sup> McCormick (2011), McCormick & Käberger (2007), Mangoyana and Smith (2011), Roos et al. (2000). <sup>b</sup> McCormick (2011), Tomescu (2005, cited in McCormick & Käberger 2007); <sup>c</sup> Palonen and Nieminen (2005, cited in McCormick & Käberger 2007); <sup>d</sup> Madlener (2007); <sup>e</sup> Madlener and Bachhiesl (2007); <sup>f</sup> Brohmann et al. (2006, cited in Mangoyana & Smith 2011) and IEA Bioenergy (no date provided).

**b) Interlinked Pathway 2: Bottom up: Locally-driven, promoters and alliances**

A second interlinked pathway to build critical mass refers to initiatives emerging from community aspirations and from alliances formed between the community and other actors. Within this pathway, the role of a local leader (also known as local promoter, champion or change agent) is important. The leader is the actor who provides direction in a collaboration network (Head 2008). Who this leader is and how he/she is perceived in the community or by the people he/she would need to influence play a critical role in further uptake and building critical mass, as well as he/she having an initiator role in this process. The leader should respond to community aspirations, be able to balance those aspirations with future business opportunities, and be able to demonstrate to the rest of actors that it is worth investing in planting trees despite an uncertain future.

Only a few of the bioenergy production cases reviewed from the literature show clear community-driven approaches, including local cooperatives and local promoters. For example, the cases of the villages of Juhnde in Germany (Mangoyana & Smith 2011) and Mureck, Austria (McCormick & Kåberger 2007; McCormick 2011) highlight the importance of local producer cooperatives to achieve enough biomass supply to biofuel plants. The importance of local promoters is highlighted in the case of Vorarlberg, Austria (Madlener 2007). These local promoters serve as focal points for other actors across the bioenergy supply chain. Similarly, the pivotal role of innovation champions for the successful uptake of a new technology was emphasised in a review of innovation in 14 wood bioenergy cases in Europe (Nybakk et al. 2011), in particular setting up the pilot trials (from growing trials to bioenergy plant trials). Cooperation though does not exist separate from broader policy. Other factors such as investment grants were needed to cover the initial costs in Germany and Austria. Community aspirations are important as well, as seen in the Juhnde case, where a strong desire to replace fossil fuels prevails.

In the case study, a key driver or ‘local champion’ behind the establishment of the mallee trials has been a local business owner of an agricultural marketing company. He has played the role of broker and marketed the idea of planting

mallees to different bioenergy actors in the value chain, liaising with local government, the biomass purchaser and research agencies. The state government has also partnered in a project that involved a trial of tree energy cropping, specifically, oil mallees, linking farmers with the buyer (an electricity company) through contracts. Given the nature of the case study area, which comprises scattered towns and farms across a large extension of dryland, intensive marketing was required to accomplish the trials. Examples include community information booths at local shows and energy forums, field days at mallee trial sites, focus groups, harvesting and logistical trials, farm visits, liaising with the (former) Catchment Management Authorities, radio interviews, and local media coverage (Larkin & McMullen 2014). These trials are still in the early stages, and therefore it is not possible to derive conclusions about whether or not they have worked as a means of promoting adoption of bioenergy tree crops on a meaningful scale. However, without the local champion, the trials for bioenergy in the case study region may not have happened.

An open and balanced critique of bioenergy development by local agencies would increase trust in the ‘promoter’ and between the actors. Trust is a key factor of a collaboration network, and without it, collaboration may not happen regardless of favourable policies or economic and technical assessments. Therefore, it is important to complement the analysis about planting mallee trees for bioenergy presented in a recent report (see Larkin and McMullen 2014) with broader landholder’s views and responses to some concerns found in the landholder survey. For example, concerns about lack of trust in government policy and private companies, perception of trees as low value products or as bushfire hazards, or a bad experience with planting trees.

A challenge exists in the case study region about involving landholders who have had bad experiences involving tree planting on their farms, such as those who expressed strong negative views about the Managed Investment Schemes in the landholder survey (Landholders No. 140, No. 65, No. 105). Some landholders did not express interest in bioenergy cropping regardless of incentives and were suspicious of policy changes that would affect them. Inertia based on past

negative experiences may result in these landholders being averse to adopting new practices. Possibly only generational change or new landholders moving to the region would consider adopting new practices.

This pathway may also include alliances between local actors and energy technology companies. For example, bordering the dryer areas of Central West New South Wales, mainly Cobar (Figure 6), an initiative by local landholders has spurred the use of woody weeds for bioenergy (Skye 2011; Ecowaste 2013, 2016). Moreover, farmers in the locality of Nyngan in Central West New South Wales have piloted the production of biochar<sup>49</sup> in partnership with a biochar production company (Earth Systems 2012).

In conclusion, this pathway has highlighted the important role of a local leader, either from the community of growers (cases from Europe), or at the broker level or the enterprise/business developer level (part of the case study area). Following this pathway alone would not secure critical mass; the role of the leader or champion, although pivotal, may also be undermined if trust across the value chain is not in place or is in the process of being built. Constantly changing policies (as explained in pathway 1) can also directly affect the feasibility of bioenergy projects. Given the small number of successful locally driven bioenergy production cases available, it is unclear whether or not a primarily community-driven pathway has a higher chance of long-term survival than other pathways.

### **c) Interlinked pathway 3: Top-down: Corporate driven, large consumer demand**

This pathway refers to industry demanding biomass and initiating the process of developing the biomass supply chain, taking advantage of their larger purchaser power. One important characteristic of this pathway is the need for contracts that create a legally binding relationship between the biomass grower and the bioenergy producer or a broker. Following Alexander et al. (2012), contracts for perennial bioenergy crops should have an optimal design and not be too complex,

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<sup>49</sup> Biochar is high carbon materials (charcoal) produced from the slow pyrolysis (heating in the absence of oxygen) of biomass (Chan et al. 2007).

should be credible, address potential risks, incentives and conflicts and have strong enough terms so they do not seem re-negotiable. The initial terms of the contract need to be strong enough so they do not seem re-negotiable, otherwise they undermine the credibility of the original contract. The contracts should also have an optimal design but not be too complex to make them undesirable.

This thesis has presented an exploratory case and parsimonious contract design, focused on three characteristics from the landholders' perspective (length, return and flexibility). An analysis of a series of optimal contract options from the bioenergy producer perspective is an area of further research.

A handful of examples illustrate how this pathway can or could work for regional Australia. In Vienna, Austria (Madlener & Bachhiesl 2007), corporate-led initiatives take advantage of favourable energy policies, such as electricity buy-back rates, and can benefit from portraying a positive image about urban biomass cogeneration. In Australia, the aviation industry is interested in sourcing jet fuels from woody bioenergy through the Sustainable Aviation Industry forum (CSIRO 2011)<sup>50</sup>. Following this interest, The Boeing Company sponsored a regional biomass analysis in Queensland for aviation fuels (Murphy et al. 2015). Also, a partnership between industry and research has explored the sustainability of existing oil mallee plantings in Western Australia (Griffiths 2011; Goss et al. 2014). At the national level, a feasibility study of feedstock and production capacity for sustainable aviation (Qantas Airways Ltd 2013) recognises the technical feasibility and notes the challenges for commercial feasibility of producing sustainable aviation fuels.

Industry's interests include access to suitable volumes of feedstock (McCormick 2011; Qantas Airways Ltd 2013) and a suitable policy environment that provides incentives for the production of renewable energy (OECD/IEA 2011; Qantas Airways Ltd 2013). Although these studies provide evidence of a real interest from the aviation industry in sourcing fuels from biomass, these have been mostly

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<sup>50</sup> Note that jet fuels cannot be sourced from bio-ethanol (as explored in the case study) because of its low energy content (IATA 2016), however they can be sourced from woody bioenergy as explored by the Sustainable Aviation Industry forum (CSIRO 2011).

desk-based, with plans to develop their business case between 2014 and 2016 (Goss et al. 2014). Their combined large purchasing power may result in catalysing bioenergy development faster than policies alone. In addition, bioenergy development may be instrumental for their emissions reporting and disclosure (voluntary or required).

The pulp and paper industry has also shown a clear interest in bioenergy development. In New Zealand, a recent project led by Norske Skog Tasman and Z Energy, investigated the feasibility and commercial viability of producing liquid biofuels from Radiata pine plantation residues (Norske Skog Tasman & Z Energy 2014). Although the results of the study indicate that commercial viability is not yet feasible mainly due to the global energy outlook (low oil price), when conditions are favourable and the fuel certification and testing is completed, commercialisation would be feasible.

A key requirement for this pathway to succeed is internal support within the corporation and also a core group of ‘promoters’. In the case study region, the company Delta Electricity with support from the local council expressed an interest in using trees as a potential source of wood for co-firing (Horner 2011). Combining this expressed demand with the actions of a broker (e.g., Aurora Research Ltd.) led to signing of contracts for 11 trial farms of bioenergy tree cropping.

In conclusion, although this pathway has demonstrated to be the most promising for financing feasibility assessments in regional Australia (e.g. Boeing Company, Qantas Airways in Australia and Norske Skog Tasman and Z Energy in New Zealand), and starting up trials (e.g. Delta Energy in the Central West New South Wales), this pathway requires the other two pathways to be sustainable.

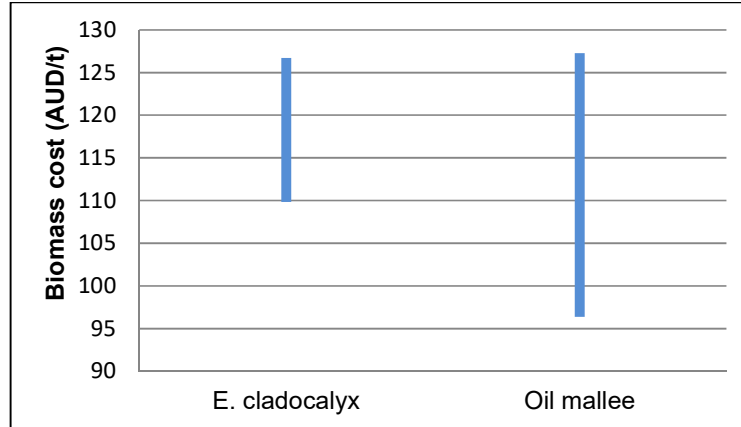
## 5.7 Conclusions

This chapter has analysed the biophysical and economic potential of woody biomass, both from existing softwood plantations and prospective hardwood plantations, for supplying a second-generation bio-ethanol production in the case study region in order to build a critical mass of biomass growers. The findings suggest that a plant with a capacity of 68 ML of ethanol per year, requiring 210 kt of dry biomass per year as feedstock, may be cost-competitive under the conditions of zero fuel excise and oil prices of about USD 153 per barrel when using biomass with a plant gate cost of up to AUD 111 per dry tonne. This oil price falls within a business as usual climate change scenario as described by the International Energy Agency (2016) but is significantly higher than the oil price projection for a two degree Celsius climate change scenario.

Care needs to be taken with these estimates because of the uncertainty in feedstock costs and conversion technologies also recognised in national and regional bioenergy studies (Abadi 2012; Brinsmead et al. 2014; Hayward et al. 2015; Murphy et al. 2015) and globally. Despite these uncertainties, the estimated costs of biomass from new hardwood plantings in the case study area are comparable to the biomass costs for a short rotation tree crop found in Western Australia (Abadi et al. 2012) (Figure 21).

In addition to the uncertainties on feedstock and technology costs, some landholders brought up the issue of trust during the survey. These landholders do not trust government policies due to their constant changing or poor implementation. It is not surprising that new policies are met with such scepticism by landholders. An example of such a policy that generated much debate around Australia was the carbon price changes that occurred while writing this thesis (see Chapter 1 and Chapter 2 for more on carbon policy). Trust is a value that takes time to build (Leach et al. 2002) and is an important issue in long-term initiatives, such as bioenergy cropping. Trust in private organisations is also difficult to build. Short-term projects can fail or are abandoned, and even bottom up organisations could become inactive (e.g. Mallee Condo Pty).

**Figure 21 Comparison of variation in biomass delivered cost at the plant gate**



**Note:** Oil mallee biomass delivered cost is AUD 53 to AUD 70 per tonne at 45 per cent moisture, this is equivalent to AUD 96 to AUD 127 per dry tonne.

**Source:** *E. cladocalyx*: this thesis; Oil mallee: Abadi et al. (2012).

How can the lack of adequate conditions to create critical mass be overcome?

Three potential interlinked pathways have been explored, debunking the old adage of ‘build it and they will come’. These pathways cut across policies, drivers (top-down, bottom-up), promoters (also called leaders or champions) and local alliances (also called collaboration networks). None of these pathways would work on its own but they need all actors to sit at the table, combining their resources (e.g. investment from corporates, lobbying politicians and local governments), capabilities (‘know how’ from growers, technicians and business developers), demonstration or pilot experiences from growers, and trials on bioenergy plants. Given the large level of investment needed, it is argued that corporates may be the main actors with access to resources at all levels (federal and local governments, and local industry) and resources to invest in developing new value chains. For example, The Boeing Company exploring jet biofuels in the Fitzroy Basin (Booth et al. 2014) and in Queensland (Hayward et al. 2015), and Norske Skog and Z Energy in New Zealand (Norske Skog Tasman & Z Energy 2014).

The bioenergy industry requires a balancing act of interests, needs, hopes, and expectations across the supply chain, from biomass growers to end users.

Landholders need to be involved in seminal discussions at the planning stages.

Younger generations could inform new trends in markets, interests and make their

voices heard instead of leaving the planning of the future of the farm to older landholders. Concerns about past bad experiences related to tree planting may be overcome through these dialogues. Given that landholders connected to a higher number of organisations are most likely to be willing to adopt bioenergy tree crops, organisations should be used as entry points to access landholders. One important group in the region could be the young farmers from the New South Wales Farmers Association and younger members of Landcare networks. Limited funding resources of Landcare networks (Landcare Australia Limited 2012; The Guardian 2014) have pushed network members to actively reinvent themselves as an organisation, reinvigorating their agendas, which could be an interesting entry point to deal with, as part of the conversation on critical mass.

Building a critical mass of bioenergy growers is not about picking ‘winner’ strategies, rather, working collaboratively with well connected landholders and their organisations to leverage ways of overcoming issues of trust. The case study identified the conditions that should be in place, starting with a clear market demand or future demand, adequate policies, the role of champions, collaboration networks, local alliances and corporate interests. Scenarios on the impacts of growing trees as biomass can be used as dialogue tools with biomass growers and should be considered in future critical mass research. In the case study region, it was found that the 10-year rotation produces larger amounts of biomass per harvest, however landholders did not favour this longer rotation period. As part of a scenarios exercise, different rotation periods and simulations with different oil prices, exchange rates, conversion technologies, and biomass prices would likely be an important part of the conversation if the biomass based bioenergy sector is to grow.

The next chapter further discusses the issues raised in Chapter 4 and Chapter 5.

## Chapter 6

### Discussion

#### 6.1 Introduction

This chapter discusses the results presented in Chapter 4 and Chapter 5 in the context of the bioenergy literature and conceptual framework introduced in Chapter 2 and the critical mass literature introduced in Chapter 5. The chapter starts by revisiting the conceptual framework used, then discusses the adoption factors (Hypotheses 1 and 2), landholders' preferences regarding contract attributes (Hypotheses 3 and 4) and the overarching research question regarding pathways to build critical mass for a new bioenergy supply chain. The implications of the thesis follow these discussions.

#### 6.2 Discussion about the critical mass framework for understanding landholders' adoption of innovation

This research used a conceptual framework for studying the development of a new bioenergy industry from a landholders' perspective, based primarily on adoption of innovation and diffusion theory (see Chapter 2, Figure 4). Emerging lessons show that policy and market uncertainty are key barriers to building critical mass of biomass growers. While this finding sits well within the initial conceptual framework, further understanding is required about the many roles that actors can play in the development of a new bioenergy supply chain (Table 28). In particular, the initiator and broker are instrumental in bringing together the different actors of a potential bioenergy value chain. The initiator could be any of the stakeholders, though it is usually those who are better connected to social networks.

Further, the inter-relationships among actors and their potentially overlapping roles (from grower to purchaser) will directly impact the type of the interlinked

pathways to achieve a critical mass of biomass growers. Thus, it is not only landholders who need to share common goals to achieve critical mass as identified in the initial conceptual framework, but different actors would also need to converge their goals in a prospective bioenergy value chain.

Once key policy and market barriers have been overcome, further adoption may be promoted by industry through learning about the technology (cf. Hayward et al. 2015), and on the supplier side (the landholder) through gaining experience with the practice of growing trees as energy crops (cf. Ghadim et al. 2005). This learning goes beyond learning about the technology and the crop, but also involves social learning, defined as ‘learning that occurs when people engage one another, sharing diverse perspectives and experiences to develop a common framework of understanding and basis for joint action’ (Schusler et al. 2003, p. 311). Social learning requires bringing together not only facts and figures but also the various goals from growers, project developers, regulators, bioenergy generators and purchasers. In this respect, scenario planning could help with the learning process, by adapting and introducing lessons from pilot experiences, opening up networks to learning from other locations (Kowalski et al. 2009).

**Table 28 Actors and their multiple potential roles in a bioenergy supply chain**

Actors	Roles					
	Grower	Initiator – project developer	Broker	Regulator	Bioenergy generator	Purchaser
Landholder or farmer (individual)	X	X-innovator individuals				X
Landholders or farmer cooperative or group	X	X-depending on skills of the cooperative/group	X	*	X – possibly	X
Private company	X-through landholders or private company operations	X	X-in partnership with growers and generator	*	X	X
Local government	X-possibly initially through pilots	X-directly through partnership	X	X-enforcing regulations	X – possibly	X
Federal government		X-indirectly through policy mandates, incentives, subsidies and programs	X – possibly	X	X – responsive to demands of private sector depending on the scale of projects	

**Note:** \* In Australia private companies and interest groups can lobby to influence governments (regulators) but need to be registered and follow a code of conduct: <http://lobbyists.pmc.gov.au/index.cfm>.

### 6.3 Discussion about adoption factors

A limited set of studies has explored specific factors that influence adoption of bioenergy crops. This body of literature is relatively recent and mostly quantitative (Jensen et al. 2007; Villamil et al. 2008; Bocquého & Jacquet 2010; Paulrud & Laitila 2010; Clancy et al. 2011; Villamil et al. 2012; McKenney et al. 2014) with a few qualitative assessments (Sherrington et al. 2008; Baumber et al. 2011; Convery et al. 2012). Only a couple of studies have explored second-generation bioenergy crop production under contract (Bocquého & Jacquet 2010; Bergtold et al. 2014; Khanna et al. 2014).

Chapter 2 established that the factors influencing adoption of innovation are internal and external. These factors were included as part of the conceptual framework. The landholder survey results (Chapter 4) addressed internal factors of potential adoption, i.e. landholder and farm characteristics. External factors, mainly economics and policy, were explored in Chapter 5. Following is a discussion of the most salient adoption factors that were explored. Overall, the results confirm that both landholder and farm characteristics are important in the adoption process.

#### **Hypothesis 1: Landholder and farm characteristics investigated do not determine the willingness of planting trees as energy crops or the area of planting**

The results of the tobit model show that the area allocated to bioenergy tree crops was significantly influenced by the proportion of unproductive land, the number of organisations of which the landholder is a member, landholder lifestyle, landholder age and farm location. The logit model analysed willingness to plant 50 or more hectares of bioenergy tree crops. In this case, the results of the model show similar influencing factors as the tobit model, except for age, which was not statistically significant in the logit model. In both models, the dummy variable education was not statistically significant. The following six landholder characteristics were explored:

**1. Landholder's age:** In the tobit model, the age-squared variable exerted negative statistically significant influence on the extent of adoption at 10 per cent level. The relationship between age and the dependent variable, logarithm of plant area, is quadratic. This result is consistent with the findings of bioenergy and renewable

energy adoption studies where older landholders would be less willing to plant woody bioenergy than younger landholders (Jensen et al. 2007; Paulrud & Laitila 2010; Joshi & Mehmood 2011; Tate et al. 2012). In a former review of adoption of agricultural innovations, Feder and Umali (1993) claimed that younger farmers were more involved with innovative farming. The results of the tobit model resonate with this claim.

According to the tobit model, it would be better to approach younger landholders in any plantation scheme. Landholder age would be a key constraint to the length of the contract, so that not only would efforts to disseminate information be targeted to landholders with a minimum amount of land, but also a maximum age. I suggest that 55 years old (two years above the average age in the sample) can be considered as maximum age to target because landholders could produce at least one rotation before retirement (officially at 65 years old at the time of conducting the study).

The tobit model shows that the relationship between age and the dependent variable, logarithm of planted area, is quadratic. The negative effect of age-squared means that as people get older the effect of age is lessened. On the other hand, in the logit model, which analysed willingness to plant 50 or more hectares of bioenergy tree crops, the coefficient of age-squared was not statistically significant.

**2. Experience in planting trees:** In a global review of agroforestry studies in the tropics, experience is argued to be an important factor in the ability to make decisions about new technologies (Mercer 2004). Accordingly, it was hypothesised that experience in planting trees would have a positive effect on willingness to adopt. The landholder survey explored: no experience, experience in planting scattered trees, experience in planting strips of trees, experience in planting blocks of trees of less than one hectare, and experience planting blocks of trees of more than one hectare. Each of these levels of experience was tested and the final dummy variable analysed was experience in planting blocks of trees. This variable positively influences willingness to plant 50 or more hectares of bioenergy tree crops in the logit model and is statistically significant at the 5 per cent level. This result is in line with qualitative findings from Baumber et al. (2011) in the case study region but contradicts quantitative findings from Villamil et al. (2008), where farming

experience resulted a negative adoption factor in the adoption of miscanthus (a bioenergy crop) in Illinois, USA.

**3. Education level:** Having tertiary education was included as a dummy variable. The relationship between adoption and education was positive but not statistically significant in any of the models explored. This result was surprising, as other bioenergy and general adoption studies identified education as a key factor to consider in the study of adoption. Specifically, farmer-operators' agricultural education was identified as a positive factor influencing willingness to consider or investigate further growing bioenergy crops (Clancy et al. 2011). On the other hand, there is mixed evidence about the effect of the general education level of the farm operator (Jensen et al. 2007; Clancy et al. 2011).

While the survey asked for the highest level of education attained, this variable was challenging to measure because of the great variety of educational options in the country. Levels of formal education are not easily defined in Australia. A student could be a high school dropout, yet enrol later in a technical degree, or gain adult entry at university, after finishing one year of Year 12 secondary schooling, without having passed through Year 11. Hence, education is not necessarily a linear process, in particular in the farming environment in Australia, which is isolated, far from towns and cities, and where home schooling is common. The education variable was included in the survey to find a discrete tipping point rather than a continuous variable that would influence adoption. Presenting all possible education options could increase the cognitive burden of the respondent. Perhaps a different variable, for example, years in agricultural education, may have provided significant results.

**4. Number of organisations of which the landholder is a member:** In both the tobit and logit models, this variable exerts statistical significance on willingness to adopt. This variable was used as a proxy for trust in organisations (Stolle & Rochon 1998; Lochner et al. 1999; Beugelsdijk & van Schaik 2005). Trust allows to better coordinate among supply chain partners (Kumar et al. 2015). Based on the qualitative observations and discussions with landholders during the study, landholders who are connected to more organisations would be more willing to plant trees as bioenergy crops because they would have access to different types of

support, e.g. technical support, access to current trials, more resources and presumably, an influence on the agendas within the organisations, depending on their involvement. This finding is supported by Baumgart-Getz et al. (2012) in their meta-analysis of adoption literature for best farm management practices in the United States.

**5. Main farming or management goal:** This variable helped in identifying hobby farmers or lifestyle landholders. These landholders would be less willing to plant bioenergy tree crops as demonstrated in both the tobit and logit models, at 5 per cent and 10 per cent level of significance, respectively. Not only is the size of their properties smaller than the rest of the farmers, but also their main goal is not income generation. Therefore, targeting and promotion of bioenergy tree crops should focus on non-hobby farmers.

**6. Landcare membership:** This study initially considered that Landcare members would be interested in planting trees for bioenergy because they are known for their initiatives towards landscape restoration through tree planting, fencing and other activities (Love 2012). The anticipated positive relationship between Landcare membership and willingness to plant was not supported by the model results. Although Landcare members may be more inclined to plant trees, usually their purposes are restoration through bush regeneration, and weed and erosion control (NSW Department of Primary Industries & Landcare New South Wales 2011). They may not see bioenergy tree crops contributing to these goals. When Landcare members plant trees, they do so for the long run; they usually do not remove trees from the landscape, and; they do not treat trees as crops.

**Hypothesis 2: There is no difference in willingness to plant trees as energy crops among those landholders whose properties are located in areas with lower biomass productivity values and those landholders whose properties are located in areas with higher biomass productivity values**

This second hypothesis explores the influence of farm characteristics on adoption. The following five property variables were investigated:

**1. Property size:** There is mixed evidence about the influence of property size on willingness to adopt and extent of adoption of bioenergy tree crops in the sample.

Previous studies have found that landholders with larger properties would be more likely to plant energy crops (Villamil et al. 2008; Clancy et al. 2011). Other studies have found a negative relationship between farm size and willingness to adopt energy crops (Jensen et al. 2007; Paulrud & Laitila 2010). Moreover, farm size was identified as a better indicator of future earnings from a bioenergy crop than current level of farm income (Clancy et al. 2011). The results indicate that property size alone was not statistically significant in either the tobit or logit models. This variable was used to estimate the proportion of unproductive land on each farm.

**2. Proportion of unproductive land by landholder:** The tobit and logit models demonstrated that landholders would be more willing to adopt bioenergy tree crops if their land was mostly unproductive. These results can be explained by the opportunity cost of land. Landholders who perceive that their land is less productive or unproductive would be willing to explore additional income options. However, if land is perceived as mostly productive in relation to property size, then not only is there a risk for the landholder to deviate efforts from their core business, but also to lose income from areas dedicated to bioenergy tree crops.

The definition of unproductive land is important. In the survey, the definition ‘land that you are not obtaining income from’ was used and provides a metric from an economic perspective. Other authors use a loose definition when they refer to lower productivity areas, primarily from the biophysical perspective, simply calling these areas ‘marginal’ (Paul et al. 2013; Schirmer & Bull 2014). Productivity limits, however, were not set in these studies.

**3. Farm location:** Geographical location is a factor influencing adoption. While the tobit model identified location as a positive influencing factor for higher productivity areas (zone 3), the logit model for willingness to adopt 50 or more hectares identified medium productivity areas (zone 2) as a negatively influencing adoption. In a similar way, Paulrud and Laitila (2010) found a negative relationship between geographical area and willingness to adopt. Although the results from the two models may seem to contradict each other, the majority of farms were located in zone 2 but they were also small (smaller than 50 hectares). Because the dependent binary variable in the logit model was willingness to plant 50 or more hectares with bioenergy tree crops, smaller farms would be considered as zero even if they were willing to plant fewer

than 50 hectares. This means that for the majority of landholders, it is physically impossible to participate in a larger scheme in the logit model. In the tobit model, the location variable included a high productive area as a dummy which positively influenced adoption. This result was unexpected as the researcher initially hypothesised that higher productive areas would be unlikely to take part in such a scheme. Willingness to adopt in higher productivity areas (zone 3) can be explained by small landholders in the sample for the tobit analysis. Both the tobit and logit models provide evidence to reject this hypothesis.

**4. Land value:** A land value variable was included as a proxy of landholder income and productivity. Jensen et al. (2007) found a positive relationship between off-farm income and a negative relationship for net farm income on willingness to supply switchgrass. The anticipated relationship between adoption and land value was negative. This variable had the higher number of missing values of the sample (11 per cent) and did not produce significant results and was therefore not used in the modelling stage.

**5. Farming type:** Landholders were asked which type of farming they do, mixed, grazing, cropping, or other. This variable is related to the main farming goal explained earlier. Based on the sample results, there was no significant preference from any specific farming type to target, which resonates with the findings of Palrud and Laitila (2010). In addition, most landholders were graziers and mixed farmers and therefore presented small variability in farming type.

#### **6.4 Discussion about landholders' preferences regarding contract attributes**

Landholders' preferences regarding contract attributes were analysed testing two hypotheses. The first hypothesis relates to preferred contract attributes in general and the second relates to the influence of landholders and farm characteristics on these attributes. Landholders expressed their preferences for three contract attributes in the survey: contract length, annual returns, and flexibility to choose the harvesting company. These three contract attributes were included in a set of choice experiments. The use of choice models for second-generation bioenergy contracts is

limited (Bocquého & Jacquet 2010; Bergtold et al. 2014) and this part of the study contributes to this literature.

### **Hypothesis 3: Landholders' preferences do not influence any of the attributes in the choice experiment**

It is important to understand the tradeoffs between landholders' characteristics and contract attributes explored in the survey. However, this assessment first requires formal testing of the significance and expected signs of the contract attributes (see Section 3.5.2). Based on the results of the MNL and RPL models (Table 16 and Table 17), hypothesis 3 is rejected because all of the contract attributes are statistically significant at 1 per cent level and landholders' preferences correspond to the expected signs, i.e. landholders prefer shorter contracts, higher returns, and flexibility to choose the tree-harvesting company ( $p < 0.001$ ). If this were not the case with the simpler MNL model, then it would not be possible to further explore more complex models such as the RPL and to interact the attributes with farmer characteristics to explore potential tradeoffs.

These results are also consistent with other related studies. For example, Bergtold et al. (2014) found that 'level of net returns above the next best alternative land-use, contract length, having a biorefinery harvest option, availability of insurance, and having monetary incentives/cost share were important contract attributes' (p. 883) for farmers' willingness to produce biofuel feed stocks<sup>51</sup>. These preferences vary according to the crop and location. Furthermore, offering contracts that are sufficiently attractive may be a condition for the development of a secured supply in the long run (Bocquého & Jacquet 2010). In this respect, the levels of return offered in the survey correspond to 5 per cent of land value of low, mid and high market value properties in the study region. Depending on their opportunity costs, landholders would be willing to plant different proportions of the farm with bioenergy crops as follows:

- Average landholder (across the sample): 10% of their farm
- Landholder who would plant 50 or more hectares: 20% of their farms

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<sup>51</sup> These biofuel feedstocks include: two annual agricultural crops (corn stover and sweet sorghum) and one perennial grass (switch grass).

- Outliers (n=3): 100% of their farms.

The outliers are landholders who owned the largest tracts of land in the dryer areas of the region (see Section 4.3.2.d). The returns offered in the survey were likely higher than their current opportunity cost given the low productivity of their farm.

Landholders would probably start experimenting with the crop in smaller areas of their farms, as this would allow for learning and crop diversification. Depending on what specific activity the landholder conducts on their property, contracts will need to be tailored to cover their opportunity costs.

**Hypothesis 4: Landholder and farm characteristics investigated do not influence landholders' preferences for contract attributes in the choice sets.**

The attributes of the contract (length, return, flexibility) were interacted with the landholder and farmer characteristics discussed in Section 6.2. These interactions resulted in different levels of significance in the RPL model (Table 18). Hypothesis 4 is rejected based on the findings of the two factors influencing preferences for contract attributes: 1) Landholders with higher proportion of unproductive areas would prefer higher returns ( $p < 0.011$ ), 2) Landholders with experience in planting blocks of trees would be likely to accept less flexible contracts, i.e. accepting the harvesting company specified by default in the contract ( $p < 0.05$ ).

Since almost all landholders who had experience in planting blocks of trees had planted them as perennials rather than crops, they would be accustomed to longer-term commitments for certain areas of their land. This long-term view could explain why they would be willing to accept the default harvesting company. They may see the harvesting company entering their property only once at the end of the harvesting cycle. Since the contract length options offered in the survey were 5 and 10 years, not annually, they may be less concerned about this. On the other hand, landholders with higher proportions of perceived unproductive land would prefer higher returns. This preference can be explained by the higher relative area at stake, even if this area was identified at the time of the survey as being 'unproductive'; once bioenergy tree crops are in place, these areas could become productive and be comparable to any potential economic activity.

Despite the statistically significant preferences for each of the contract attributes across the sample (Table 18), it seems that landholder and farm characteristics have little effect on specific attribute preferences except for the two characteristics explained above. These findings could indicate that the contracts were attractive to the landholder or that the return options offered may have overestimated the opportunity costs of landholders. An exception however, is presented in the case of landholders who have had bad experiences with tree planting schemes. Regardless of the contract offered, these landholders would not be willing to consider a contract, even if offered higher returns. It is not only profitability that is important to landholders but past experiences also influence landholders' decisions, as explained in Chapter 4.

## **6.5 Discussion about pathways to build critical mass for bioenergy**

This thesis has discussed three synergistic interlinked pathways to build critical mass for bioenergy production. As stated in Chapter 5, these pathways need to work together and preferably be coordinated. These pathways involve policy support, market development built on corporate demand and long-term contracts with local biomass growers. Growers could choose to form cooperatives or groups but also to participate individually.

To date, the issue of bioenergy has been analysed mostly from a technological or bio-economic perspective, with some exceptions treating bioenergy as a complex problem. Examples include the use of policy solutions, analysing *ex post* success factors and conditions, or addressing barriers such as economic conditions, institutional capacity and supply coordination as proposed by McCormick and Kåberger (2007). The proposed pathways aim to integrate the thinking about bioenergy development.

### **a) Interlinked policy driven pathway**

The policy driven pathway could be considered a pre-condition of the successful development of a bioenergy supply chain. Although there is a renewable energy target in Australia, this policy is confined to the electricity sector. Broadening the policy to cover major sources of emissions in the country, e.g. transport and agriculture – or implementing a cross-sectoral policy such as a carbon price – could

expand opportunities to improve the competitiveness of a new bioenergy industry. A carbon price could help reduce the impact of a low oil price. However, the carbon price is uncertain, in particular since legislation changed at the time of the study. Scenario analysis is one way to address uncertainty (Kowalski et al. 2009). Scenarios are narrative descriptions of possible futures that are internally consistent (van der Heijden 2005, p. 14) and could help explore landholders' willingness to grow bioenergy crops under changing policy and market environments, e.g. different levels of carbon price, policies of rewards or compensation for environmental services provided by tree energy crops, and different levels of oil price.

Policy mandates and regulations alone are not enough to adopt bioenergy. In Australia, the Ethanol Production Grants Program has had limited success in achieving its objectives (Australian National Audit Office 2015) and has been discontinued. The successful European bioenergy development cases presented (Table 1 and Table 27) highlight that a combination of policies (e.g., establishment grants, fuel taxes), existing biomass markets and competitive costs of biomass, research and development, a clear vision, community aspirations, and strong cooperation are among the factors that influence bioenergy adoption (Madlener 2007; Madlener & Bachhiesl 2007; McCormick & Kåberger 2007; Mangoyana & Smith 2011; McCormick 2011). A case of on-farm biogas development in Germany shows that investment grants, soft loans and fixed-price premiums were needed to start, while improvements in production efficiency are needed to be sustainable in the long-term (Wilkinson 2011). These examples imply that to be successful, in regional areas like the case study, policies such as investment grants need to be designed in the context of existing biomass markets (e.g. stubble, wood residues) while responding to community aspirations (i.e. regional self-sufficiency), and in the longer term, they need to support improvements in production efficiency.

In the case study region, the Carbon Farming Initiative spurred interest in developing a methodology for carbon sequestered by the roots of the bioenergy tree crop, oil mallee. Carbon credits could have added value to biomass production from oil mallee trees and partially offset establishment costs if a methodology to account for these credits were approved by legislation (Larkin & McMullen 2014). However, the Carbon Farming Initiative legislation was modified in 2013 and 16 of the 26

methodologies approved for carbon accounting on farms, including mallee planting, were revoked from July 2015 (Department of the Environment 2016). Together with the repealed carbon tax (Department of the Environment 2014), these policy setbacks indicate that the development of the bioenergy sector in Australia will need to rely strongly on local actors and corporate initiatives rather than policy. Given the constantly changing energy policy environment present in Australia, stability of these policies is arguably more important than the policies themselves.

#### **b) Interlinked locally driven pathway**

Within this pathway, the role of a local champion or leader to influence the development of bioenergy development has been recognised (Madlener 2007; Mangoyana & Smith 2011; Nybakk et al. 2011). As argued by Clancy et al. (2011), at the local level, early adopters play an important role in influencing other growers to plant and in the facilitation of the adoption process, as is the case of the adoption of bioenergy crops in Ireland. Extension agents may facilitate the adoption process. In Australia, however, there is no agricultural technology extension service. Extension agents come from different local and private organisations and often are not formal extension agents but rather extension is one of their many roles. The recently created Local Land Services agency in New South Wales may play a role in technology transfer as it holds a wealth of experience from the former Catchment Management Authorities and other local agencies.

A common vision and common aspirations (e.g., replacing fossil fuels) are also important to develop local bioenergy initiatives (e.g., the case of Juhnde, Germany) (Mangoyana & Smith 2011). Regional energy security could be a potential common aspiration, which may motivate local interest to drive regional biofuel production. Since most of the regional demand for ethanol in New South Wales is imported from the neighbouring states of Victoria and Queensland (IPART 2012), ethanol supply security becomes an issue for New South Wales. Extreme weather events such as the Queensland floods in 2011 jeopardised the supply from inundated areas and left regional areas of New South Wales cut off from ethanol supplies.

#### **c) Interlinked corporate driven pathway**

Within this pathway, the aviation industry has the potential to play an important role as consumer of biofuels around the world and in Australia. International trends and

global greenhouse gas emissions reduction and voluntary and mandatory commitments are prompting the industry to favour sourcing cleaner fuels. Other industries, such as pulp and paper where demand for their products is declining (except for packaging), are looking into alternatives for the use of their installed capacity and know-how in fibre processing. Liquid biofuels may provide such an opportunity. As a result, investments and partnerships between pulp and paper and fuel distributors are emerging through pre-feasibility studies (Norske Skog Tasman & Z Energy 2014). The main challenges for moving a corporate pathway forward are economic feasibility (negative impacts of low oil prices) and immature technologies for second-generation fuels. On the other hand, low oil prices may provide an opportunity for doing more research and development of cost effective technologies, so that when favourable conditions are in place commercialisation would be feasible.

Contracts are pivotal to setting boundaries and expectations on both sides of the supply and demand for bioenergy tree crops. While reducing the perception of risk, contracts also deal with incentives and strategies to solve potential conflicts. Although this thesis has presented a parsimonious set of contract factors (flexibility, return and length), optimal landholder contracts should be analysed, taking into consideration individual economic, ecologic and social goals. In the case study region, a small group of landholders is trialling oil mallee trees as a bioenergy crop through supply contracts tailored to their specific farm conditions. Although these contracts may result in higher transaction costs than simpler contracts, they provide opportunities for igniting the adoption of an innovation process.

#### **d) Interlinking pathways**

The pathways discussed above are not mutually exclusive. In most of the successful bioenergy adoption cases reviewed (Chapter 2), the pathways are complementary. These cases can also help us understanding the complexities of the bioenergy development conundrum. At times, pathways can run in parallel and converge when the same goal is sought, in this case, building a critical mass of biomass growers.

A combined pathway that includes community ownership and leadership is important, but the processes of participation and collaboration would guarantee the sustainability of new enterprises in the long run. These processes are pivotal where there is a new value chain or immature markets. Although it is recognised that

bioenergy project developers and communities need to respond to market demands, without a joint process of developing an innovation, the product would be weak and the enterprise would be more likely to fail.

To conclude, the suggested pathways need to be interlinked and preferably coordinated. Coordination and dialogue between the actors is needed. A principal issue is building an economic case, based on landholders' goals. A leader or champion may identify a current or future opportunity and play a key role in being a first mover. Targeting the right landholders as innovators is also crucial for adoption. This study has identified key characteristics of landholders and their farms to target, noting that contracts will largely depend on the individual opportunity cost and therefore would likely need to be individualised. The aim of contracts is to share risks among partners/signatories to establish a market and manage the financial risks (CSIRO 2011).

## **6.6 Implications**

### **6.6.1 Implications for practice**

#### **a) First movers, innovation champions and followers**

The actual dynamics of who is going to sign a contract first and under what conditions, is particularly relevant to the first mover dynamic or 'who will go first' (Oliver & Marwell 2001, p. 301). In the case study region, a potential innovation champion has started the process of linking and brokering contracts between biomass buyers and producers. The literature about bioenergy adoption (Chapter 2) does not provide enough detail on the characteristics of these champions. Documenting practical examples could help us understand the process of building critical mass of actors in the supply chain. In the cases of Sweden and Germany (Hoffmann & Weih 2005), the innovation champions responded to a tangible need for heating and power in their regions. Australia, on the other hand, uses coal as the main source of electricity, and it has warmer winters than Europe that do not justify investment in heating and power production facilities.

Therefore, the question about innovation in bioenergy becomes who comes first, the project developer or the supply chain? (Williamson 2010; McCormick 2011). This

still a knowledge gap and formally identifying this gap is one of contributions of this thesis.

**b) Early involvement of landholders**

In practice, my findings suggest that landholders' preferences need to be taken into consideration at the beginning of bioenergy prospecting projects. The risk of a project not starting is increased if landholder views are not considered at the planning stage or if expectations are not managed appropriately. The finding that landholders prefer short-term contracts contrasts with the potential biophysical benefits of higher long-term growth rates (i.e. 10-year rotations produce more biomass than 5-year rotations) would help in negotiating a series of contract conditions (e.g., guaranteed price) that reflect the individual landholders' risk profile. Perhaps a reason why there has been a tender to establish pilot plantings for bioenergy in the case study region is because each contract was negotiated privately based on the specific farm conditions and opportunity costs. Individual negotiations would increase the transactions costs of establishment; however, in the medium to long term this experience could provide valuable lessons for future expansion of plantations in the region.

**c) Scaling up approach**

A community-driven approach does not necessarily mean small scale, nor does industry-driven mean large scale. The issue of scale for bioenergy production in Australia has only been addressed recently in the literature, where a strategy of building smaller modular plants to build up a larger bioenergy plant in the future is sought (Hayward et al. 2015; Murphy et al. 2015). A lower risk strategy for both the bioenergy plant and the supplier landholders would be to start with a modular approach. This entails starting with very small plants that would gradually test and demonstrate to both the bioenergy industry and suppliers the feasibility of such endeavours. In the case study region, when the economic conditions are favourable, modular plants may allow for incremental building of a critical mass of biomass supply.

**d) Brokers or intermediaries**

Brokers can be individuals, specialised enterprises, other businesses, or local government itself: brokers are actors that help match supply and demand. All pathways should consider the use of brokers in their implementation, in particular if

there are multiple actors involved in the development of an industry. Among the pathways explored in this study and conceptualised in Chapter 5, the role of the broker is somewhat implicit. Brokering roles also allow each actor to do their best, i.e. industry actors to process, landholders to produce, marketers to market products, and government to regulate.

### **6.6.2 Implications related to competing industries**

Competition for wood biomass resources can occur between a traditional wood-based products industry and wood for bioenergy (Cowie & Gardner 2007). Given that markets for pulpwood and for a portion of sawmill residues exist, if softwood is used for bioenergy, then the new industry will compete with these established markets (Crawford et al. 2016). Competition within the bioenergy sector can also occur, e.g. biomass for transport and biomass for electricity (Graham et al. 2011b). Carbon tree planting may represent another competing industry for short rotation bioenergy tree crops because both activities target low productive land.

### **6.6.3 Implications about environmental co-benefits and disservices**

Second-generation bioenergy development can produce environmental co-benefits and also disservices across the value chain. Co-benefits may include carbon sequestration and biodiversity enhancement while disservices may include water stress. The Carbon Farming Initiative legislation (Commonwealth of Australia 2011a) may provide a framework for obtaining income from carbon sequestration for landholders. Bioenergy tree crops that use a coppicing system store carbon dioxide in the roots of coppicing trees. Payments for carbon sequestration would reduce the cost of biomass by changing the profitability ratios, potentially in favour of bioenergy tree crops if the transaction costs are justified. However, the Carbon Farming Initiative legislation requires water licensing for commercial plantations in areas greater than 600 mm average annual rainfall (east of the case study region) to cover for the incidental rainfall they use during their growth phase (Baumber et al. 2012). Trees planted for bioenergy may provide the same environmental benefits as trees currently planted in farms (as revealed in the pilot survey), such as: Shade or shelter for stock, improvement in how the property looks, increase in birds and animals on the property, and rehabilitating degraded land.

On the other hand, bioenergy crops may result in strong opposition for disservices to other agricultural crops, e.g. reduction in water yield. Adhering to international sustainability principles about water use and availability is a way of preventing undesired water availability outcomes. International principles and criteria include: water rights, water management plans, no depletion of water resources, and enhancement of water quality (RSB 2011). In the case study region, the potential area for building critical mass is ~22,000 hectares (Table 26). If large scale plantings are needed, these would need to follow these sustainability principles. Past assessments indicate that water impacts vary with species used and with specific sites. For example, in Western Australia, it was found that ‘mallee biomass production would not deplete surface or groundwater resources and will maintain or improve quality of water resources where such off-site impacts may exist’ (Goss et al. 2014, p. 98). In a biomass for bioenergy modelling study, the CSIRO concluded that ‘The use of designated lignocellulosic energy crops either as block or as strip plantings of coppicing eucalypts within agricultural lands, is broadly compatible with the RSB Principles’ (Graham et al. 2011a, p. 45). A detailed assessment of crop competition for water is out of the scope of this research but may play a critical role in the social acceptability of a bioenergy crop, if large scale plantings occur in the future.

## Chapter 7

### Conclusion

#### 7.1 Summary of empirical findings

This research has identified two overlapping gaps in the literature; the first gap is about the lack of studies on adoption of farm forestry for bioenergy in Australia and the second gap is the need for a better understanding of how to implement tree bioenergy cropping. The research has been led by one overarching research question and two supporting research questions:

Overarching question:

What are the potential pathways to build a critical mass of tree growers for bioenergy?

Supporting questions (SQ):

What factors underlie landholders' willingness to plant bioenergy tree crops? (SQ1)

What are the landholders' preferences in the design of contracts for planting these trees? (SQ2)

The case study of Central West, New South Wales, Australia, has illustrated key farm and landholder factors that could determine adoption of tree planting for bioenergy (SQ1). The positive factors are the area of unproductive land and the number of organisations of which the landholder is a member (as a proxy for landholders' trust in organisations). Negative adoption factors include: landholders' age and lifestyle (being a hobby farmer).

A series of contracts was presented to landholders to explore their preferences about contract attributes (length, return, flexibility). When these attributes were interacted with landholder and farm characteristics (SQ2), it was found that landholders who had planted blocks of trees would be less likely to need a flexible contract, while

landholders with larger proportions of perceived unproductive land would prefer higher returns. This means that highly connected landholders with higher levels of unproductive land would be more willing to adopt tree energy crops, whereas planting programmes of 50 hectares or more should target landholders with experience in planting blocks. However, how do we balance these preferences within a highly uncertain policy environment, compounded with a volatile oil price? After assessing the tree biomass available in the case study region, I conceptualised three interlinked pathways to build critical mass that go beyond techno-economic solutions and deal with issues of adoption of innovation.

The assessment in the case study region indicates that at a reference oil price of USD 115.13 per barrel<sup>52</sup>, growing hardwood trees as energy crops does not make economic sense. However, in oil price projections under a business as usual climate scenario for 2050 (OECD/IEA 2016a), growing hardwood trees as energy crops may be economically viable. Regardless of the right oil price and given the complex nature of building a new bioenergy supply chain, the proposed pathways to develop a critical mass of tree growers for bioenergy vary according to the context where second-generation bioenergy development is needed, and whether it is policy driven (direct and indirect policies), locally driven (e.g., promoters, alliances), or corporate driven.

Hence, the main contribution of this thesis to knowledge is the original thinking on the pathways to build critical mass of tree growers for bioenergy. These pathways need to be interlinked for them to work effectively. The policy pathway could be considered a pre-condition for the successful development of a bioenergy supply. Specifically, bioenergy crop establishment grants –despite their mixed successes— can play an important role in their adoption if combined with other policies such as fossil fuel taxes. At the same time, a locally driven pathway needs to be activated. Under this pathway the role of the local champion is key in the initial adoption of innovation and setting up trials. The local champion can also help connect across bioenergy supply actors (see Table 28). In some cases, the local champion can build a relationship with potential investors. In this respect, corporations are already

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<sup>52</sup> TAPIS oil price as of April 2014.

playing a key role as investors and potential main users of biofuels because of their larger purchaser power. In regional Australia, the aviation industry may play such a role as it is pressed to reduce their emissions and is actively looking for sustainable fuel alternatives.

In conclusion, for a second-generation bioenergy industry to emerge, a critical mass of biomass growers needs to be secured. This can be achieved by developing interlinked pathways that include: 1) supportive policies, 2) local support and an innovation champion, and 3) corporate support and/or a potential biomass buyer or investor.

## **7.2 Limitations of the study**

The study has offered an evaluation of second-generation biomass production in the Central West New South Wales region, using a rural environment to sample landholders, through surveys and also face-to-face discussions with landholders, bioenergy and local experts at locally organised events or through semi-structured interviews. Lessons from the literature were also incorporated in the development of the critical mass pathways, with emphasis on their potential application to regional Australia. The study encountered a number of limitations, which need to be considered and these are explained below:

- (i) **Scope.** The study only includes softwood and hardwood biomass supply assessments to evaluate how a critical mass of growers can emerge. However, in the case study area, residues from other crops such as chaff and stubble could also have been considered. Residues have lower density and as a result, are too expensive to transport. The analysis of residues available on nearby farms could enrich further studies that look at the issue of bioenergy as a whole. These residues were not considered in this study in order to focus on the complex challenges of second-generation bioenergy production, in particular, from planted trees. This issue is getting traction in the case study area as well as other regions of Australia (e.g., Queensland), making the case study ‘close to real’. Despite this scope limitation, the case has produced valuable lessons that could be applied to bioenergy development cases across Australia and internationally.

- (ii) Sample size vs. choice of survey method. The number of landholders in the final survey (n=155) and their choices (n=465) is considered acceptable for a choice model experiment and within the planned sample size for regression studies (see Chapter 3). However, this number of responses was limited mainly because of the survey delivery method, which was face-to-face and also the experience of the enumerators (including the main researcher) in doing field surveys. The choice of face-to-face was intentional, in order to gain more insights into the survey and to document comments as they were told. There is a balance between a large number of respondents versus the detail the researcher can obtain using a face-to-face method. Professional enumerators would have been ideal to partially overcome this constraint, but volunteer enumerators were preferred, given the limited resources available.
  
- (iii) Limitations of implementing a mixed-methods approach. Although the research included quantitative and qualitative components, most of the reported results are quantitative. The qualitative data gathered, including observation notes and interview notes, informed the planning and design of the research as well as the development of the bioenergy pathways, discussions, and main conclusions. The discussions held with landholders, local government agencies, bioenergy investors and brokers during forums, conferences, field visits and the preliminary and pilot surveys were instrumental in providing clarity for the quantitative assessment. The reported qualitative data was mainly from landholder survey comments, to illustrate key issues brought up by landholders about adoption of agroforestry and about interest (or not) in planting bioenergy tree crops (see Chapter 4). Follow-up face-to-face discussions with landholders and other actors would have been ideal to discuss the pathways proposed in Chapter 5. However, this activity was not feasible given the time and resource constraints of the study.
  
- (iv) Changing policy environment during the duration of the study. During the duration of the study, there were several major policy changes regarding carbon pricing, as well as the structure of local service agencies in Australia and New South Wales, respectively. The local agency structural changes

announced between the pilot and final surveys and discussions about carbon prices generated heated comments from participants in the preliminary and pilot surveys. The survey adapted to this changing environment by avoiding mention of specific carbon policy or specific local government agencies. Because the landholders were not prompted with the names of specific organisations, it is possible that some data richness was lost in terms of their membership in organisations. In addition, during the analysis of the biomass supply curves (Chapter 5), ethanol subsidy policy changes were treated as policy scenarios, recognising that they can change with any new government.

### **7.3 Recommendations for future research**

Future research priorities areas relate to: (i) refinement and expansion of the methodology, and (ii) ecological variables that directly affect the economics and social acceptability of second-generation bioenergy crops.

In this research, face-to-face landholder surveys were undertaken at landholders' organised events. These surveys did not show the biomass supply curves and scenarios to landholders because at the time that the final survey was undertaken (October 2012) the biomass maps were not readily accessible. We do not know if the landholders surveyed would have made different choices if they were told or shown, for example, that a longer 10-year period would result in more productive bioenergy tree crops. In addition, the contract options provided in the choice cards showed the attributes in text form. Future research should include visuals of different stages of the bioenergy tree crops since trees on farms in the region are used for hedging and not as crops. The methodology could be expanded by discussing the survey results and the proposed critical mass framework with landholders and other key actors. This iterative process would allow for greater depth of interpretation around the critical mass issue and bioenergy development, similar to an action-research type of approach.

A second area of future research is how bioenergy tree crops affect water availability on farms and how these competition areas affect the economics and social acceptability of growing bioenergy tree crops. Although research about competition between trees and crops in Western Australia exists, climatic and soil variability does

not extrapolate these constraints to other regions. Undoubtedly, there will be competition for water among current crops or grazing areas and bioenergy tree crops. However, the level of this competition is unknown for the case study region. The oil mallee pilot trials in the study region are the first step into gathering this type of data and will be particularly useful for dryer areas of Central West New South Wales. Further research on the scale of water competition will help clarify concerns from farmers and researchers in this area. Moreover, the social acceptability of bioenergy tree crops could be affected by changing policies about carbon sequestration on farms. Therefore, different policy scenarios could be tested to estimate the acceptability of bioenergy tree crops, given different carbon sequestration incentives.

#### **7.4 Conclusion**

Bioenergy production is a complex multi-sector and multidisciplinary issue. A key knowledge gap is the understanding of landholders' perspectives on growing trees as energy crops and the key factors influencing the planting of trees as energy crops, as well as potential pathways to build a critical mass of tree growers who could supply a bioenergy industry.

To address this gap, this thesis used a theoretical framework based on adoption of innovation and diffusion theory to explore: 1) underlying factors in landholders' adoption of trees as energy crops, 2) landholders' preferences in the design of contracts for planting these trees in Central West New South Wales, Australia, and 3) potential pathways to build a critical mass of tree growers for bioenergy. The knowledge gained through the case study and the research process allowed us to conceptualise three interlinked pathways to build a critical mass of biomass growers.

The actors involved in forming an innovative value chain need trust to reduce their transaction costs in building a new supply chain. However, given that the processes involved in developing second-generation bioenergy crops are long term, the discussions need to start soon. These discussions should include a variety of scenarios to further quantify the impact of targeted incentives, and the use of different technologies and of policies, either direct or indirect. Despite its limitations, this study has conceptualised and developed three interlinked pathways to better understand how to build a critical mass of tree growers for bioenergy.

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## Appendices

## Appendix 1 Factors that determine bioenergy adoption

Factor type	Dependant variable	Crop(s) studied	Factor	Significant (yes, no)	Sign	Main method(s) used	Issue, Place	Reference
<b>AGE &amp; FARMING EXPERIENCE</b>								
L	Willingness to supply biomass for bioenergy	Woody biomass for bioenergy	Age of landowner	Yes	-	Binomial logistic regression	United States	Joshi and Mehmood (2011)
L	Share of farmland	Switch-grass	Age of farmer	Yes	-	Two limit Tobit model	Willingness to supply switchgrass (USA)	Jensen et al. (2007)
L	Hectares allocated to energy crops	Willow, red canary grass, hemp	Age of farmer	Yes	-	Choice experiment 2	Farmer attitudes to bioenergy (Sweden)	Paulrud & Laitila (2010)
L	Willingness to adopt bioenergy crops	Bioenergy crops (general)	Age of the operator	No	-	Probit model	Willingness to adopt bioenergy crops (Ireland)	Clancy et al. (2011)
L	Potential adoption	Miscanthus	Farming experience	Yes	-	Factor analysis, multivariate ANOVA, categorical data analysis	Potential adoption factors, level of awareness and carbon credits, USA	Villamil et al. (2008)
L	Adoption of short rotation energy crop	Commercial blue mallee	Experience with climate variability, reg.change & gov. support	NA	+, 50% accept less returns	Qualitative: Semi-structured interviews (n=19)	Condobolin, Central West NSW (Australia)	Baumber et al. (2011)

**Appendix 1 Factors that determine bioenergy adoption (continuation 2 of 10)**

Factor type	Dependant variable	Crop(s) studied	Factor	Significant (yes, no)	Sign	Main method(s) used	Place	Reference
<b>EDUCATION</b>								
L	Share of farmland	Switchgrass	Farmer educational attainment	Yes	+	Two limit tobit	Willingness to supply switchgrass (USA)	Jensen et al. (2007)
L	Willingness to adopt bioenergy crop	Bioenergy crops (general)	Agricultural education	Yes	+	Probit model	Willingness to adopt bioenergy crops (Ireland)	Clancy et al. (2011)
			General education level	No	NA			
<b>OTHER FARMER CHARACTERISTICS / VIEWS</b>								
L	Willingness to adopt bioenergy	Bioenergy crops (general)	Contact with extension agents	No	NA	Probit model	Willingness to adopt bioenergy crops (Ireland)	Clancy et al. (2011)
L	Potential adoption	Miscanthus	Awareness regarding carbon credits	Yes	+	Factor analysis, multivariate ANOVA, categorical data analysis	Potential adoption factors, level of awareness and carbon credits, USA	Villamil et al. (2008)
L			Agronomy & Markets, Environmental Services	Yes	+			
L			Concerns, and Inputs Reduction	Yes	-			

**Appendix 1 Factors that determine bioenergy adoption (continuation 3 of 10)**

Factor type	Dependant variable	Crop(s) studied	Factor	Significant (yes, no)	Sign	Main method(s) used	Place	Reference
<b>OTHER FARMER CHARACTERISTICS / VIEWS (continuation)</b>								
L	Dimensions influencing energy wood harvesting	Wood energy crop	Forest management, recreation, forest nature and landscape	Yes	+	Factor analysis (Maximum-Likelihood method, Varimax rotation)	Finland	Rämö et al. (2009)
L	Share of farmland	Switchgrass	Views about on-farm issues <sup>d</sup>	Yes	-	Two limit Tobit model	Willingness to supply switchgrass (USA) <sup>a</sup>	Jensen et al. (2007)
L			Desire to provide wildlife	Yes	-			
L			Views on national policy issues	No	NA			
L	Willingness to engage with bioenergy and woody mass	Bioenergy and woody mass	Economic returns + farming vocation – lifestyle goals	NA	+	Qualitative: 3 group meetings and semi-structure interviews	Willingness to engage with bioenergy and woody mass, Cumbria (UK)	Convery et al. (2012)
L	Willingness to engage with bioenergy and woody mass	Bioenergy and woody mass	Reluctance to change: Lack of confidence in market, farming tradition, iconic area	NA	-	Qualitative: 3 group meetings and semi-structure interviews	Willingness to engage with bioenergy and woody mass, Cumbria (UK)	Convery et al. (2012)

**Appendix 1 Factors that determine bioenergy adoption (continuation 4 of 10)**

Factor type	Dependant variable	Crop(s) studied	Factor	Significant (yes, no)	Sign	Main method(s) used	Place	Reference
<b>OTHER FARMER CHARACTERISTICS / VIEWS (continuation)</b>								
L	Willingness to engage with bioenergy and woody mass	Bioenergy and woody mass	'Follow the leader', info from a respected source, better <u>info</u> , confidence, lack of 'local cases'	NA	- (waiting)	Qualitative: 3 group meetings and semi-structure interviews	Willingness to engage with bioenergy and woody mass, Cumbria (UK)	Convery et al. (2012)
C	Uptake of energy crops at different GM	Miscanthus and willow	Trusted information	NA		Qualitative: Focus group		Sherrington et al. (2008)
<b>ENERGY CROP INCOME &amp; MARKET CONCERNS</b>								
C	Bioenergy crop hectares	Willow, red canary grass,	Net income from crop	Yes	+	Choice experiment 1	Farmer attitudes to bioenergy (Sweden)	Paulrud & Laitila (2010)
C	Dimensions influencing energy wood harvesting	Wood energy crop	Price of energy crop	Yes	*	Factor analysis (Maximum-Likelihood method, Varimax rotation)	Finland	Rämö et al. (2009)
C	Adoption of short rotation energy crop	Commercial blue mallee	Size and consistency of returns from energy cropping	NA	+ 50% < ret, 25% > ret	Qualitative: Semi-structured interviews (n=16)	Condobolin, Central West NSW, Australia	Baumber et al. (2011)

**Appendix 1 Factors that determine bioenergy adoption (continuation 5 of 10)**

Factor type	Dependant variable	Crop(s) studied	Factor	Significant (yes, no)	Sign	Main method(s) used	Place	Reference
<b>ENERGY CROP INCOME &amp; MARKET CONCERNS (continuation)</b>								
C	Uptake of energy crops at different GM	Miscanthus and willow	Perception of the level and the security of financial return – Establishment grant, opportunity cost	NA		Qualitative: Focus group		Sherrington et al. (2008)
C	UK farmers' attitudes and behavioural intentions towards perennial energy crops	Miscanthus and willow	Security and stability of income from contracts, disruption to cashflow, & reduced farm business flexibility; SRC willow, worries about damage to field drains from the roots.	NA	NA	Postal survey	Farmers' attitudes and behavioural intentions towards perennial energy crops (United Kingdom)	Sherrington et al. (2008)
C	Optimal land allocation cropping systems	Switchgrass and miscanthus	Liquidity constraints, price risks	Yes	- loan like contracts + fixed price contracts	Intertemporal choice models (simulations)	Impacts of liquidity constraint and risk preferences, Australia	Bocquého & Jacquet (2010)

**Appendix 1 Factors that determine bioenergy adoption (continuation 6 of 10)**

Factor type	Dependant variable	Crop(s) studied	Factor	Significant (yes, no)	Sign	Main method(s) used	Place	Reference
<b>ENERGY CROP INCOME &amp; MARKET CONCERNS (continuation)</b>								
C	Willingness to engage with bioenergy and woody mass	Bioenergy and woody mass	High establishment cost	NA	-	Qualitative: 3 group meetings and semi-structure interviews	Willingness to engage with bioenergy and woody mass, Cumbria (UK)	Convery et al. (2012)
C	bioenergy and woody mass	mass	Bioenergy markets: how fit with current operations, gross margins, volatility of crops(+), risk	NA	-			
<b>ESTABLISHMENT SUPPORT/INCENTIVES</b>								
C	Uptake of energy crops at different GM	Miscanthus and willow	Perception of the level and the security of financial return – Establishment grant, opportunity cost	NA		Qualitative: Focus group		Sherrington et al. (2008)
C	Adoption of short rotation energy crop	Commercial blue mallee	Establishment support	NA	+ 12/16	Qualitative: Semi-structured interviews (n=16)	Condobolin, Central West NSW, Australia	Baumber et al. (2011)

**Appendix 1 Factors that determine bioenergy adoption (continuation 7 of 10)**

<b>Factor type</b>	<b>Dependant variable</b>	<b>Crop(s) studied</b>	<b>Factor</b>	<b>Significant (yes, no)</b>	<b>Sign</b>	<b>Main method used</b>	<b>Place</b>	<b>Reference</b>
<b>ESTABLISHMENT SUPPORT/INCENTIVES (continuation)</b>								
C	Theoretical uptake of energy crops at different GM	Miscanthus and willow	Establishment grants to address concerns with the security and stability of income from the available contracts.	NA - model	NA	Farm linear programming to maximise the overall farm gross margin in a single year	Simulation of gross margins among different crops, UK	Sherrington and Moran (2010)
<b>OTHER ENERGY CROP CHARACTERISTICS</b>								
C	Bioenergy crop preference (based on crop characteristics)	Generic energy crop	Visual impact on the landscape	Yes	-	Choice experiment 1	Farmer attitudes to bioenergy (Sweden)	Paulrud & Laitila (2010)
C			Rotation period	Yes	-	Choice experiment 1	Farmer attitudes to bioenergy (Sweden)	Paulrud & Laitila (2010)
C	Dimensions influencing energy wood harvesting	Wood energy crop	Impacts of energy wood harvesting on the nutrient balance of the forest soil	Yes	-	Factor analysis (Maximum-Likelihood method, Varimax rotation)	Finland	Rämö et al. (2009)
C	Share of farmland	Switchgrass	Erosion issues <sup>b</sup>	No	NA	Two limit Tobit model	Willingness to supply switchgrass (USA)	Jensen et al. (2007)

### Appendix 1 Factors that determine bioenergy adoption (continuation 8 of 10)

Factor type	Dependant variable	Crop(s) studied	Factor	Significant (yes, no)	Sign	Main method used	Place	Reference
<b>OTHER ENERGY CROP CHARACTERISTICS (continuation)</b>								
C	Adoption of short rotation energy crop	Commercial blue mallee	Impacts on land use flexibility	NA	+ perceived flex > Carbon	Qualitative: Semi-structured interviews (n=19)	Condobolin, Central West NSW (Australia)	Baumber et al. (2011)
<b>FARMING CHARACTERISTICS</b>								
L	Share of farmland	Switchgrass	Off-farm income	Yes	+	Two limit Tobit model	Willingness to supply switchgrass (USA)	Jensen et al. (2007)
L	Share of farmland	Switchgrass	Net farm income per hectare	Yes	-	Two limit Tobit model		
F	Bioenergy crop preference	Generic crop	Farm characteristics <sup>c</sup>	No	NA	Choice experiment 1	Farmer attitudes to bioenergy (Sweden)	Paulrud & Laitila (2010)
F			Type of farming	No	NA	Choice experiment 1		
F	Hectares allocated to energy crops	Willow, red canary grass, hemp	Geographical area	Yes	-	Choice experiment 2		

**Appendix 1 Factors that determine bioenergy adoption (continuation 9 of 10)**

Factor type	Dependant variable	Crop(s) studied	Factor	Significant (yes, no)	Sign	Main method used	Place	Reference
<b>FARM SIZE</b>								
F	Hectares allocated to energy crops	Willow, red canary	Farm size	Yes	-	Choice experiment 2	Farmer attitudes to bioenergy (Sweden)	Paulrud & Laitila (2010)
F	Willingness to adopt bioenergy	grass Bioenergy crops (general)	Farm size	Yes	+	Probit model	Willingness to adopt bioenergy crops (Ireland)	Clancy et al. (2011)
F	Share of farmland	Switchgrass	Farm size	Yes	-	Two limit tobit	Willingness to supply switchgrass to an emerging energy market Tennessee <sup>a</sup>	Jensen et al. (2007)
F	Potential adoption	Miscanthus	Farm size	Yes	+	Factor analysis, multivariate ANOVA, categorical data analysis	Potential adoption factors, level of awareness and carbon credits	Villamil et al. (2008)
F	Decision to plant & areas planted	Willow	Arable land	Yes	+	Tobit model (left censored at zero)	Farm related factors – adoption of SRWC, Sweden	Roos et al. (2000)
F		Willow	Forest land	Yes	+	Tobit model		
F		Willow	Area of other land types.	Yes	+			

### Appendix 1 Factors that determine bioenergy adoption (continuation 10 of 10)

Factor type	Dependant variable	Crop(s) studied	Factor	Significant (yes, no)	Sign	Main method used	Place	Reference
<b>FARM SYSTEM</b>								
F	Willingness to adopt bioenergy	Bioenergy crops (general)	Farm system (specialised crop tillage)	Yes	+	Probit model	Willingness to adopt bioenergy crops (Ireland)	Clancy et al. (2011)
F			Forage area	Yes	-			
F			Farm profit	No	NA			
F			Land tenancy	No	NA			
F	Decision to plant & areas planted	Willow	Institutional ownership	Yes	+	Tobit model	Farm related factors – adoption of SRWC, Sweden	Roos et al. (2000)
F			Leasing out of arable land	Yes	+			
F			Tractor ownership	Yes	+			
F			Irrigation	Yes	+			
F			Pasture area	Yes	-			
F			Tenancy	Yes	-			
F			Animal production (cows, cattle, pig, horses)	Yes	-			
F	Contracts	Sorghum switchgrasses, corn stover	Net returns > best alternative	Yes	+	Choice model	Willingness to produce alternative biofuel feedstock	Bergtold et al. (2014)

**Notes:** Factor type: L (landholder/farmer), farm (F), other (O); U = utility of a crop in function of its characteristics; Relationship between dependant and independent variables (+, -); <sup>d</sup> e.g. market development, use of contracts, or potential harvest limitations under the Conservation Reserve Program.

<sup>a</sup> Majority were not aware and more than half were unsure; <sup>b</sup> Erosion issues did not appear to influence share, desire to provide wildlife habitat did.

<sup>c</sup> leased land, rented land, share of set aside land.

## Appendix 2 Overview of bioenergy technologies for regional Australia

Technology	Advantages	Disadvantages
Co-firing	<p>Low or minimal capital investment if co-fire up to 3% biomass but after that, 17% biomass is needed to make retrofitting worthwhile</p> <p>Could add calorific if added to brown coal</p>	<p>No significant nitrogen oxides or sulphur oxides reductions with 3% biomass co-firing</p> <p>Milling issues arise if co-firing is more than 5%</p> <p>Does not add calorific value if added to black coal</p>
Direct Firing or Combined Heat and Power production (CHP)	<p>Can produce cheap heat</p> <p>It is scalable and the techno-economics are fairly well understood</p>	<p>High cost of electricity produced</p>
Gasification for Electricity	<p>It is scalable and the techno-economics are fairly well understood</p>	<p>Relatively expensive way to produce electricity because of waste heat</p> <p>May not be suitable for the warmer Australian climate (see CHP)</p>
Biomass-to-Liquids (BTL)	<p>The product is a direct drop-in replacement for gasoline</p>	<p>Requires large scale implementation for Fischer-Tropsch reforming after gasification and is therefore probably not suited to regional application</p> <p>Low yields of liquid fuels per dry ton of biomass</p> <p>BTL is an immature technology</p>
Pyrolysis	<p>Promising technology for the production of liquid fuels (drop-in replacement for gasoline)</p> <p>Scalable and the char by-product is potentially of some value</p>	<p>Technology is quite immature</p>
Biochemical conversion (bioconversion)	<p>Produces ethanol and it is a scalable process and reasonable yields of a liquid fuel can be produced</p> <p>The techno-economics of bioconversion are moderately well-understood</p>	<p>Costs highly sensitive to costs of enzymes and feedstocks.</p>

**Source:** Elaborated based on Rodriguez et al. (2011c).

## Appendix 3 Landholder survey instrument



### Survey: Landholders' views about trees as energy crop in New South Wales

#### *About you*

1. For how long you have worked on the land? \_\_\_\_\_ years
  
2. What is your main farming or land management goal?
  - a. Make an income from the land e.g. run farm as a business
  - b. Improve the land condition
  - c. Both
  - d. Other \_\_\_\_\_
  
3. What is your property size?  
\_\_\_\_\_ hectares or \_\_\_\_\_ acres
  
4. Roughly, what area do you consider to be unproductive land in your property? \_\_\_\_\_ hectares or \_\_\_\_\_ acres  
Unproductive land = you are not obtaining any income from the land.
  
5. What type of farming you do?
  - a. Mixed farming
  - b. Grazing only
  - c. Cropping only
  - d. Other \_\_\_\_\_

#### *About trees in your property*

##### **Q1. Have you ever planted trees in your property?**

1. Yes
2. No → Go to Q3.

##### **Q2. How many trees you have planted in your property?**

1. A few scattered trees

2. Strips of trees
3. Blocks of trees less than 1 hectare
4. Blocks of trees more than 1 hectare

**Q3. We would like to have your opinion about how contracts for planting trees as energy crops should be done. Let's assume that there is currently a viable market for biomass from trees and that:**

- The buyer of the biomass will take care of the establishment costs of planting the trees and all harvesting costs.
- You can choose the layout of trees that fits better with your current farming activities.
- One of your neighbours has signed a contract already.
- Now, I am going to show you a series of contract options. (*Show the first choice*): Each contract has three attributes:
  - Length of the contract in years
  - Return in AUD\$ per acre per year
  - If the contract is flexible and you can choose the harvesting company ('Yes') or if you have to accept the default company ('No').
- For each set, you will identify which of the two options you would consider, option A or option B, or if you wouldn't consider either option.

Questionnaire number: 1 2 3 4 5 6 [*circle*]

Choice 1 - Option A, Option B, Option C [*circle*]

Choice 3 - Option A, Option B, Option C [*circle*]

Choice 3 - Option A, Option B, Option C [*circle*]

**Q4. If ALL options chosen were option C, why is this?**

1. I am interested in trees for energy but none of the contracts offered looked interesting to me.
2. I need to see a real life example and market in place before giving my opinion.
3. I need more information e.g. about returns and risks.
4. Other \_\_\_\_\_ → Go to Q4a.

**Q4a. What could make you change your mind?**

1. Nothing will make change my mind
2. 50% higher financial returns than current land use
3. 100% higher financial returns than current land use
4. 200% higher financial returns than current land use
5. I would be interested if I had a financial need
6. Other \_\_\_\_\_ → Go to Q9.

**Q5. Suppose that you go ahead with any of the options you have chosen, then what area would you consider allocating to plant trees as energy crops?**

\_\_\_\_\_ hectares or \_\_\_\_\_ acres

**Q6. Which layout would you prefer for the trees?**

1. Belts
2. Blocks
3. A combination of both

**Q7. Do you have a preference for species to plant? If so, which species**

1. No preference
2. Radiata pine, other pine \_\_\_\_\_
3. Eucalyptus \_\_\_\_\_
4. Don't know

**Q8. Would you prefer to negotiate an agreement to plant trees for energy...**

1. Individually
2. As part of a group with higher negotiation power.

**Q9. Are you a member of any of these organisations?**

1. NSW Farmers' Association
2. Landcare group
3. Other (please specify) \_\_\_\_\_
4. None of the above

**We are about to finish the survey. We realise these questions may be sensitive to you but please be assured that your answers are completely confidential.**

**Q10. What is the name of the nearest town to your property?**

\_\_\_\_\_

**Q11. What is the highest level of education you have?**

1. Primary schooling only
2. Year 10 or equivalent
3. Year 12 or equivalent
4. Diploma or certificate (TAFE)
5. Undergraduate studies or higher

**Q12. What is roughly the estimated value of your property?**

\$ \_\_\_\_\_ per acre or \$ \_\_\_\_\_ per ha

**Q13. Do you have a mortgage on your property? Yes \_\_\_ No \_\_\_**

**Q14. How old are you? \_\_\_\_\_ years**

**Q15. Do you have any final comments or questions?**

*Thank you for your time and helping us with this survey. A report will be available in the coming months, if you would like to receive the report or participate in further discussions, please contact Sandra Velarde (details are in the information sheet). [END OF SURVEY]*

## Appendix 4 Information sheet



### Planting trees for energy in New South Wales – Information sheet

The objective of this study is to obtain your views and preferences about planting trees for energy production in New South Wales. This research is part of the doctoral studies of Mrs. Sandra Velarde, Peruvian forester and economist, student from the Crawford School of Public Policy at the Australian National University, ANU. Her studies are funded by the Energy Transformed Flagship of the Commonwealth Scientific and Industrial Research Organization, CSIRO, and by the ANU. The survey results will be used to better understand landholders' attitudes towards planting trees for energy purposes.

It is expected that this survey will take no longer than 10 minutes. Participation is voluntary. Participants may refuse to answer certain questions, withdraw from the survey at any time without providing any reason, or request that material not be used. Withdrawing from the survey will not have any adverse consequences for the participant.

The information gained from this survey will be used in my thesis, publications, and future research projects. The information you provide will only be used for the purpose for which you have provided it. It will not be disclosed without your consent.

During this research, any collected data will be coded with no personal information attached and securely stored at the Australian National University. Data entered onto a computer will be kept in a computer accessible only by password by the principal researcher.

After the research is completed, the data will be stored in accordance with the ANU Responsible Practice of Research Policies. All information collected during this research will be stored electronically (no personal data attached) for at least 5 years

after publication. The original data will be kept securely in the department, in accordance with the data storage procedures of the Crawford School of Public Policy.

Thank you for your help with this research.

**Contact details**

Mrs. Sandra Velarde, PhD student, Crawford School of Public Policy, The Australian National University, Canberra 0200 ACT, Email: [sandra.velarde@anu.edu.au](mailto:sandra.velarde@anu.edu.au)

Associate Professor Luca Tacconi, Director, Asia Pacific Network for Environmental Governance, Crawford School of Public Policy, The Australian National University, Canberra 0200 ACT, Email: [luca.tacconi@anu.edu.au](mailto:luca.tacconi@anu.edu.au)

This research operates under the research ethics protocols of the Australian National University. If you have any serious complaints or concerns about how the research was conducted should be forwarded to: Human Ethics Manager, Human Research Ethics Committee, The Australian National University, Tel. 02 6125 3427, Email. [Human.Ethics.Officer@anu.edu.au](mailto:Human.Ethics.Officer@anu.edu.au)

## Appendix 5 Experimental Design

### Cyc Design Logfile

Date and time: Wed Oct 10 2012, 11:15:19

#### Design properties

Block design  
Resolvable  
Other design  
Factorial

#### Design parameters

Factors = 2 x 3 x 3  
Number of units/block = 2  
Number of replicates = 2

**Random number seed for design generation = 196**

#### Factorial design average efficiency factors

Effect	Ave Efficiency Factor	(Uper bouds)
E1	1.000000	(1.000000)
E2	0.482143	(0.750000)
E3	0.613636	(0.750000)
E3	0.613636	(0.750000)
E12	0.093750	
E13	0.150000	
E23	0.078035	

#### Randomization 1

**Random number seed for randomization = 681**

**Factorial design randomization**

Fact 1: 1 2  
Factor 2: 1 2 3  
Factor 3: 1 2 3

**Replication randomization**

1 2

**Block randomization**

3 1 7 2 6 9 4 8 5  
3 4 7 9 1 6 2 5 8

**Blocks of the design printed in columns**

Rep 1

Block 1 2 3 4 5 6 7 8 9

Plot

1	(1,2,1)	(2,2,1)	(1,1,1)	(2,1,1)	(1,1,2)	(2,3,1)	(1,3,3)	(1,3,1)	(1,2,3)
2	(2,1,3)	(1,3,2)	(2,3,3)	(1,2,2)	(2,2,3)	(1,1,3)	(2,2,2)	(2,1,2)	(2,3,2)

---

Rep 2

Block 1 2 3 4 5 6 7 8 9

Plot

1	(1,1,1)	(1,3,2)	(2,3,2)	(1,3,3)	(2,2,1)	(2,3,3)	(1,1,2)	(1,3,1)	(1,2,3)
2	(2,2,2)	(2,1,3)	(1,2,1)	(2,1,2)	(1,1,3)	(1,2,2)	(2,3,1)	(2,2,3)	(2,1,1)

---

## **Appendix 6 Choice sets (Questionnaires)**

Six questionnaires were obtained from the design output (Appendix 5) as follows:

Questionnaire 1: replicate 1 blocks 2, 3, 5

Questionnaire 2: replicate 1 blocks 4, 6, 7

Questionnaire 3: replicate 1 blocks 1, 8, 9

Questionnaire 4: replicate 2 blocks 1, 2, 8

Questionnaire 5: replicate 2 blocks 3, 4, 5

Questionnaire 6: replicate 2 blocks 6, 7, 9

Questionnaire 1 (Q1) - Choice 1

Attribute	A	B	C
Length of contract (years)	5	15	Neither A nor B = No additional income (\$0)
Annual return (\$/acre)	53.00	76.00	
Flexibility to choose harvesting company	No	Yes	
I would prefer this option	[ ]	[ ]	[ ]

Q1 - Choice 2

Attribute	A	B	C
Length of contract (years)	5	25	Neither A nor B: No additional income (\$0)
Annual return (\$/acre)	30.00	76.00	
Flexibility to choose harvesting company	Yes	No	
I would prefer this option	[ ]	[ ]	[ ]

Q1 - Choice 3

Attribute	A	B	C
Length of contract (years)	15	25	Neither A nor B: No additional income (\$0)
Annual return (\$/acre)	30.00	53.00	
Flexibility to choose harvesting company	Yes	No	
I would prefer this option	[ ]	[ ]	[ ]

Questionnaire 2 - Choice 1

Attribute	A	B	C
Length of contract (years)	5	15	Neither A nor B = No additional income (\$0)
Annual return (\$/acre)	30.00	53.00	
Flexibility to choose harvesting company	No	Yes	
I would prefer this option	[ ]	[ ]	[ ]

Q2 - Choice 2

Attribute	A	B	C
Length of contract (years)	5	25	Neither A nor B = No additional income (\$0)
Annual return (\$/acre)	76.00	30.00	
Flexibility to choose harvesting company	No	Yes	
I would prefer this option	[ ]	[ ]	[ ]

Q2 - Choice 3

Attribute	A	B	C
Length of contract (years)	25	15	Neither A nor B = No additional income (\$0)
Annual return (\$/acre)	76.00	53.00	
Flexibility to choose harvesting company	Yes	No	
I would prefer this option	[ ]	[ ]	[ ]

Questionnaire 3 (Q3) - Choice 1

Attribute	A	B	C
Length of contract (years)	5	25	Neither A nor B = No additional income (\$0)
Annual return (\$/acre)	53.00	30.00	
Flexibility to choose harvesting company	Yes	No	
I would prefer this option	[ ]	[ ]	[ ]

Q3 - Choice 2

Attribute	A	B	C
Length of contract (years)	5	15	Neither A nor B = No additional income (\$0)
Annual return (\$/acre)	76.00	30.00	
Flexibility to choose harvesting company	Yes	No	
I would prefer this option	[ ]	[ ]	[ ]

Q3 - Choice 3

Attribute	A	B	C
Length of contract (years)	25	15	Neither A nor B = No additional income (\$0)
Annual return (\$/acre)	53.00	76.00	
Flexibility to choose harvesting company	Yes	No	
I would prefer this option	[ ]	[ ]	[ ]

Questionnaire 4 (Q4) - Choice 1

Attribute	A	B	C
Length of contract (years)	5	15	Neither A nor B = No additional income (\$0)
Annual return (\$/acre)	30.00	53.00	
Flexibility to choose harvesting company	Yes	No	
I would prefer this option	[ ]	[ ]	[ ]

Q4 - Choice 2

Attribute	A	B	C
Length of contract (years)	15	25	Neither A nor B = No additional income (\$0)
Annual return (\$/acre)	76.00	30.00	
Flexibility to choose harvesting company	15	25	
I would prefer this option	[ ]	[ ]	[ ]

Q4 - Choice 3

Attribute	A	B	C
Length of contract (years)	5	25	Neither A nor B = No additional income (\$0)
Annual return (\$/acre)	76.00	53.00	
Flexibility to choose harvesting company	Yes	No	
I would prefer this option	[ ]	[ ]	[ ]

Questionnaire 5 (Q5) - Choice 1

Attribute	A	B	C
Length of contract (years)	15	5	Neither A nor B = No additional income (\$0)
Annual return (\$/acre)	76.00	53.00	
Flexibility to choose harvesting company	No	Yes	
I would prefer this option	[ ]	[ ]	[ ]

Q5 - Choice 2

Attribute	A	B	C
Length of contract (years)	25	15	Neither A nor B = No additional income (\$0)
Annual return (\$/acre)	76.00	30.00	
Flexibility to choose harvesting company	Yes	No	
I would prefer this option	[ ]	[ ]	[ ]

Q5 - Choice 3

Attribute	A	B	C
Length of contract (years)	5	25	Neither A nor B = No additional income (\$0)
Annual return (\$/acre)	53.00	30.00	
Flexibility to choose harvesting company	No	Yes	
I would prefer this option	[ ]	[ ]	[ ]

Questionnaire 6 (Q6) - Choice 1

Attribute	A	B	C
Length of contract (years)	25	15	Neither A nor B = No additional income (\$0)
Annual return (\$/acre)	76.00	53.00	
Flexibility to choose harvesting company	No	Yes	
I would prefer this option	[ ]	[ ]	[ ]

Q6 - Choice 2

Attribute	A	B	C
Length of contract (years)	15	5	Neither A nor B = No additional income (\$0)
Annual return (\$/acre)	30.00	76.00	
Flexibility to choose harvesting company	Yes	No	
I would prefer this option	[ ]	[ ]	[ ]

Q6 - Choice 3

Attribute	A	B	C
Length of contract (years)	25	5	Neither A nor B = No additional income (\$0)
Annual return (\$/acre)	53.00	30.00	
Flexibility to choose harvesting company	Yes	No	
I would prefer this option	[ ]	[ ]	[ ]

## Appendix 7 Estimation of fair rent in several localities in the Central West NSW region

Main activity*	Locality	Area		Market property value 2011				Fair rent		
		Has*	Acres	1996 AUD*	2011 AUD	AUD/ha	AUD/acre	5% AUD/ha	5% AUD/acre	
G	Bathurst	683	1,688	2'330,000	5'988,100	8,767	3,548	438	177	
G	Mudgee	943	2,330	927,000	2'382,390	2,526	1,022	126	51	
G	Oberon	191	472	649,000	1'667,930	8,733	3,534	437	177	
G	Orange	238	588	1 290,000	3'315,300	13,930	5,637	696	282	
W	Condobolin	1,392	3,440	593,000	2'033,990	1,461	591	73	30	
W	Cootamundra	289	714	1 310,000	4'493,300	15,548	6,292	777	315	
W	Cowra	266	657	993,000	3'405,990	12,804	5,182	640	259	
W	Grenfell	253	625	269,000	922,670	3,647	1,476	182	74	
W	Parkes	465	1,149	580,000	1'989,400	4,278	1,731	214	87	
W	Narromine	865	2,137	796,000	2'730,280	3,156	1,277	158	64	
W	Gilgandra	762	1,883	715,000	2'452,450	3,218	1,302	161	65	
W	Dubbo	696	1,720	756,000	2'593,080	3,726	1,508	186	75	
W	Carrathool	4,390	10,848	2'100,000	7'203,000	1,641	664	82	33	
								Min	73	30
								Max	777	315
								Median	186	75
								St.Dev.	247.64	100

**Notes:** G = Grazing, W = Wheat, Index (G)\*: 257 (1996=100), Index (W)\*: 343 (1996=100), 1 hectare = 2.47105 acres

**Source:** NSW Land and Property Information (2012a); (NSW Land and Property Information 2012b)

## Appendix 8 R code for tobit and logit models and outputs

### Tobit model (n=155)

```
estResult <- censReg( logpl.1 ~ unpp + aq1 + agesq1 + blocke + edue + hobbe + z31 + z11, data=dat)
summary(estResult)
```

```
Call: censReg(formula = logpl.1 ~ unpp + aq1 + agesq1 + blocke + edue + hobbe + z31 + z11, data = dat)
```

Observations:

Total	Left-censored	Uncensored	Right-censored
155	46	109	0

Coefficients:

	Estimate	Std. error	t value	Pr(> t)
(Intercept)	5.143e-01	3.576e-01	1.438	0.150468
unpp	2.068e+00	5.843e-01	3.539	0.000402 ***
aq1	4.940e-01	1.305e-01	3.784	0.000154 ***
agesq1	-1.345e-04	7.985e-05	-1.685	0.092040 .
blocke	1.907e-01	1.279e-01	1.490	0.136128
edue	5.589e-02	1.189e-01	0.470	0.638190
hobbe	-4.416e-01	2.088e-01	-2.115	0.034466 *
z31	5.620e-01	3.236e-01	1.737	0.082463 .
z11	4.673e-01	4.484e-01	1.042	0.297427
logSigma	2.101e-01	7.352e-02	2.857	0.004270 **

---

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1 -

Newton-Raphson maximisation, 5 iterations; Return code 2: successive function values within tolerance limit

Log-likelihood: -220.3385 on 10 Df

### Logit model (n=127)

```
> mylogit3 <- glm(formula = pl50h ~ unpp + aq1 + agesq1 + blocke + edue + z11 + z31, family = "binomial", data = logitdata)
> summary(mylogit3)
```

Call:

```
glm(formula = pl50h ~ unpp + aq1 + agesq1 + blocke + edue + z11 + z31, family = "binomial", data = logitdata)
```

Deviance Residuals:

Min	1Q	Median	3Q	Max
-1.5940	-0.6800	-0.4207	0.2491	2.3382

Coefficients:

	Estimate	Std. Error	z value	Pr(> z )
(Intercept)	-1.7334451	0.6702398	-2.586	0.009701 **
unpp	5.3738813	1.7479885	3.074	0.002110 **
aq1	1.0698992	0.3022880	3.539	0.000401 ***
agesq1	-0.0003480	0.0002025	-1.718	0.085756 .
blocke	0.5126389	0.2743635	1.868	0.061697 .
edue	0.1349898	0.2691828	0.501	0.616033
z11	1.6863040	0.8067079	2.090	0.036586 *
z31	2.0023416	0.7814501	2.562	0.010397 *

---

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 145.51 on 126 degrees of freedom Residual deviance: 111.52 on 119 degrees of freedom

AIC: 127.52

Number of Fisher Scoring iterations: 5

## Appendix 9 Data codesheet

Variable name	Description	Units	Codes	Notes
choice	choice	yes, no	1,0	Used in MNL and RPL models
len	contract length	years	5,10	Used in MNL and RPL models
ret	contract return	\$/acre	30, 53, 76	Used in MNL and RPL models
flex	flexibility to choose harvesting company	yes, no	1, -1	Effect coded
exp	years of farming experience	years	Continuous variable	--
goal	main farming goal	goal	1,2,3	income, conservation type, both
siz	total farm size	acres	Continuous variable	--
unp	unproductive land	acres	Continuous variable	--
unpp	percentage of unproductive land	%	0 to 1	
act	main farming type	NA	1,2,3,4,	mixed, grazing, cropping, other; tested as dummies
tree	experience in planting trees	yes, no	1,-1	
treeq	amount of trees planted in past		-1,1,2,3,4	no experience, scattered, strips, planted blocks < 1 ha, blocks > 1 ha
block	Experience in planting blocks	Yes, no	1,-1	Effect coded
plantb	Area of plantings if contract signed	acres	Continuous variable	Zero if person chose not to answer
logplantb	log plantb1	NA	Continuous variable	Transformed variable: Log of (plantb+1); used in tobit model
pl	adopt contract	yes, no	1, 0	Dummy coded; explored in early models
pl50h	plant 50 or more hectares	yes, no	1, 0	Dummy coded; used in logit model

## Appendix 9 Data codesheet (continuation)

Variable name	Description	Units	Codes	Notes
spp	preferred species to plant preference to negotiate contract: individually or group	a, b, c, d	1, 2, 3, 4	Qualitative, analysed in text
neg	type of organisation the landholder is a member of	ind, group	1,2	Qualitative, analysed in text
asc	Number of organisations in which the landholder is a member	a, b, c, d	1,2,3,4	Qualitative, analysed in text
aql		#	0 to 3, based on responses obtained	Assumes zero for no response
town	landholders' farm location	Town name	1 to 52	Town location used to generate dummies for productivity zones: zone 1 (low), 2 (med), 3 (high) No education, Primary schooling only, Year 10 or equivalent, Year 12 or equivalent, Diploma or certificate (TAFE), Undergraduate studies or higher
ed	level of education	NA	0,1,2,3,4,5	
edu	Tertiary education	Yes, no	1, -1	Effect coded Not modelled: High variability and 18 missing individual values, transformed to value per acre
valt	total land value	\$	Continuous variable	
valac	value per acre	\$/acre	Continuous variable	Not modelled: 18 missing individual values
mort	if landholder has a mortgage	yes, no	1,-1	Not modelled: not enough variability in sample
age1	landholders' age	#	Continuous variable	Assumes mean for 5 missing values

### Appendix 9 Data codesheet (continuation)

<b>Variable name</b>	<b>Description</b>	<b>Units</b>	<b>Codes</b>	<b>Notes</b>
ages	Age square = age1*age1	#	Continuous variable	Used in tobit model
sex	landholder's gender	male, female	1,-1	Not modelled: not enough variability in sample, mostly male
hobb	hobby farmer	yes, no	1, -1	Effect coded
z11	farm location in low productivity area	yes, no	0,1	Dummy coded
z21	farm location in medium productivity area	yes, no	0,1	Dummy coded, missing values replaced with medium productivity
z31	farm location in high productivity area	yes, no	0,1	Dummy coded

## Appendix 10 Random Parameters Logit model specification in NLOGIT 5

```

|-> sample; all$
|-> NLOGIT
    ; choices = A, B, C
    ; lhs = choice, cset, altij
    ; rpl
    ; fcn = len(n), ret(t,*), flex(u), con(n)
    ; halton
    ; pts = 1000
    ; pds = 3
    ; Model:
    U(A) = len*len + ret*ret + flex*flex /
    U(B) = len*len + ret*ret + flex*flex /
    U(C) = con$
Normal exit:   5 iterations. Status=0, F=   439.8419

```

```

-----
Start values obtained using MNL model
Dependent variable           Choice
Log likelihood function      -439.84190
Estimation based on N =     465, K =   4
Inf.Cr.AIC =      887.7 AIC/N =    1.909
Model estimated: Feb 12, 2014, 09:08:34
R2=1-LogL/LogL* Log-L fncn R-sqrd R2Adj
Constants only must be computed directly
                Use NLOGIT ;...;RHS=ONE$
Response data are given as ind. choices
Number of obs.=   465, skipped    0 obs

```

CHOICE	Coefficient	Standard Error	z	Prob.  z >Z*	95% Confidence Interval	
LEN	-.08432***	.00959	-8.79	.0000	-.10313	-.06552
RET	.02083***	.00402	5.18	.0000	.01295	.02872
FLEX	.42220***	.06957	6.07	.0000	.28585	.55855
CON	.13690	.25256	.54	.5878	-.35811	.63191

Note: \*\*\*, \*\*, \* ==> Significance at 1%, 5%, 10% level.

-----  
 Normal exit: 21 iterations. Status=0, F= 356.6324  
 -----

Random Parameters Logit Model [RPL1]  
 Dependent variable CHOICE  
 Log likelihood function -356.63237  
 Restricted log likelihood -510.85471  
 Chi squared [ 7 d.f.] 308.44468  
 Significance level .00000  
 McFadden Pseudo R-squared .3018908  
 Estimation based on N = 465, K = 7  
 Inf.Cr.AIC = 727.3 AIC/N = 1.564  
 Model estimated: Feb 12, 2014, 09:11:36  
 Constants only must be computed directly  
 Use NLOGIT ;...;RHS=ONE\$  
 At start values -430.7115 .1720\*\*\*\*\*  
 Response data are given as ind. choices  
 Replications for simulated probs. =1000  
 Used Halton sequences in simulations.  
 RPL model with panel has 155 groups  
 Fixed number of obsrvs./group= 3  
 Number of obs.= 465, skipped 0 obs

CHOICE	Coefficient	Standard Error	z	Prob.  z >Z*	95% Confidence Interval	
-----+-----						
Random parameters in utility functions						
LEN	-.19587***	.03651	-5.36	.0000	-.26743	-.12432
RET	.03650***	.00841	4.34	.0000	.02002	.05298
FLEX	.69104***	.15579	4.44	.0000	.38569	.99639
CON	-1.26032**	.63852	-1.97	.0484	-2.51179	-.00884
Distns. of RPs. Std.Devs or limits of triangular						
NsLEN	.16560***	.03575	4.63	.0000	.09553	.23567
TsRET	.03650***	.00841	4.34	.0000	.02002	.05298
UsFLEX	1.08189***	.40202	2.69	.0071	.29395	1.86984
NsCON	4.91153***	.95013	5.17	.0000	3.04932	6.77374
-----+-----						

Note: \*\*\*, \*\*, \* ==> Significance at 1%, 5%, 10% level.

## Appendix 11 Cost data used for biomass feedstocks in the case study region

### 11A. Softwood plantations in case study area (2011)

<b>Feedstock</b>	<b>Distance (km)</b>	<b>Biomass (dry t)</b>	<b>Farm gate cost (\$/t)<sup>a</sup></b>	<b>Transport cost (\$/t)<sup>a</sup></b>	<b>Plant gate cost (\$/t)</b>
Pulp logs	0-50	22,289	113.0	20.59	133.59
	50-100	107,247	113.0	35.90	148.90
Harvest residues	0-50	4,243	49.63	25.34	74.97
	50-100	21,485	49.63	38.02	87.65
Sawmill residues					
Chips	0-50	7,444	63.36	18.48	81.84
Bark	0-50	1,293	20.06	11.61	31.67
Sawdust and shavings	0-50	3,347	26.40	18.48	44.88

**Note:** Costs updated to March 2014 using Consumer Price Index (Australian Bureau of Statistics 2014).

**Source:** <sup>a</sup>Rodriguez et al. (2011c).

### 11B. Softwood plantations in case study area (2020)

<b>Feedstock</b>	<b>Distance (km)</b>	<b>Biomass (dry t)</b>	<b>Farm gate cost (\$ / t)<sup>a</sup></b>	<b>Transport cost (\$/t)<sup>a</sup></b>	<b>Plant gate cost (\$/t)</b>	<b>% of total biomass softwood</b>
Pulp logs	0-50	28,954	113.0	20.59	133.59	9%
	50-100	124,836	113.0	35.90	148.90	38%
Harvest residues	0-50	7,576	49.63	25.34	74.97	2%
	50-100	30,280	49.63	38.02	87.65	9%
Chips	0-50	17,298	63.36	18.48	81.84	5%
	50-100	65,774	63.36	33.79	97.15	20%
Bark	0-50	3,005	20.06	11.61	31.67	1%
	50-100	11,425	20.06	21.12	41.18	3%
Sawdust and shavings	0-50	7,778	26.40	18.48	44.88	2%
	50-100	29,577	26.40	32.73	59.13	9%

**Note:** Costs updated to March 2014 using Consumer Price Index (Australian Bureau of Statistics 2014).

**Source:** <sup>a</sup>Rodriguez et al. (2011c).

### 11C. Hardwood plantations in case study area (2020)

<b>Feedstock</b>	<b>Distance (km)</b>	<b>Biomass (dry t)</b>	<b>Farm gate cost (\$ / t)<sup>a</sup></b>	<b>Transport cost (\$/t)<sup>a</sup></b>	<b>Plant gate cost (\$/t)</b>	<b>% of total hardwood biomass</b>
<i>E. cladocalyx</i>	0-10	5,382.06	93.99	15.84	109.83	2%
	10-20	17,225.22	93.99	16.89	110.88	5%
	20-30	25,778.06	93.99	17.95	111.94	8%
	30-40	31,118.28	93.99	21.11	115.10	10%
	40-50	39,561.69	93.99	23.23	117.22	12%
	50-60	39,577.34	93.99	25.34	119.33	12%
	60-70	36,936.84	93.99	27.45	121.44	12%
	70-80	41,061.00	93.99	28.51	122.50	13%
	80-90	43,542.06	93.99	30.62	124.61	14%
	90-100	37,391.91	93.99	32.73	126.72	12%

**Note:** Eucalyptus cladocalyx high stocking (2,500 stems/ha) at 2.5% adoption level. Costs updated to March 2014 using Consumer Price Index (Australian Bureau of Statistics 2014).

**Source:** <sup>a</sup>Rodriguez et al. (2011c).

## Appendix 12 Description of CSIRO Background IP provided to this thesis

### Appendix 12A. CSIRO databases of modelled biomass production – Part A

Descriptor	Hardwood modelled new plantings		Softwood modelled plantings		
	10 year rotation	5 year rotation	2011	2020	2030
Species	Eucalyptus cladocalyx	Eucalyptus cladocalyx	Pinus radiata	Pinus radiata	Pinus radiata
Units	Dry weight tonnes/ha/10 year rotation	Dry weight tonnes/ha/5 year rotation	Dry weight tonnes/ha/year	Dry weight tonnes/ha/year	Dry weight tonnes/ha/year
Output (rings)	Sum of dry weight tonnes To obtain total tonnes/year per ring: Sum per ring/16 and by 10	Sum of dry weight tonnes To obtain total tonnes/year per ring: Sum per ring/16 and by 5	Sum of dry weight tonnes	Sum of dry weight tonnes	Sum of dry weight tonnes
Data files	cl10_tagb_mk.dbf	ch5_tagb_mk.dbf	ch1611t1_sres.dbf ch1611t1_stwt.dbf ch2411t2_pulp.dbf ch2411t2_sawl.dbf ch2411t2_sres.dbf ch3011cf_pulp.dbf ch3011cf_sawl.dbf ch3011cf_sres.dbf	ch1620t1_sres.dbf ch1620t1_stwt.dbf ch2420t2_pulp.dbf ch2420t2_sawl.dbf ch2420t2_sres.dbf ch3020cf_pulp.dbf ch3020cf_sawl.dbf ch3020cf_sres.dbf	ch1630t1_sres.dbf ch1630t1_stwt.dbf ch2430t2_pulp.dbf ch2430t2_sawl.dbf ch2430t2_sres.dbf ch3030cf_pulp.dbf ch3030cf_sawl.dbf ch3030cf_sres.dbf
Pixel resolution	25 x 25 m	25 x 25 m	NA	NA	NA
Description in Rodriguez et al. 2011b	low stocking average climate 10 years rotation (LSAC10Y)	high stocking average climate 5 years rotation (HSAC5Y)		softwood biomass	
GIS analysis performed by CSIRO	Buffer ring area every 5 km		Buffer ring area every 50 km		

**Appendix 12A. CSIRO databases of modelled biomass production – Part A (continuation)**

Descriptor	Hardwood new plantings	Softwood existing plantings
GIS software	ArcGis Desktop 10	ArcGis Desktop 10
Mask	Central West New South Wales region <sup>a</sup>	Central West New South Wales region <sup>a</sup>
Location	100 km buffer around outskirts of Orange, Central West, New South Wales	100 km buffer around outskirts of Orange, Central West, New South Wales
Spread sheet results	Biomass reported every 10 km and 50 km	Biomass reported every 50 km (2 rings)
Related documentation	Polglase et al. (2008), Almeida et al. (2007) and Rodriguez et al. (2011c), p.68-75	Polglase et al. (2008), Almeida et al. (2007) and Rodriguez et al. (2011c), p.75-81
CSIRO project	‘Assessment of the environmental and economic opportunities and constraints associated with bioenergy production from forest biomass in two prospective regions of Australia’	
Funding agency	Department of Agriculture and Water (formerly DAFF)	
Date when data was obtained	December 2013 and March 2014	
Processing & review/ How used	Processed March 2014. Reviewed May 2014 and January 2015. These datasets were inputted into an excel spreadsheet created by myself. This spreadsheet was then used to create summary tables (see Section 5.3, Table 21 and 22) and to build the build the second biomass supply curve (Figure 19) for the Orange case study region.	Processed from January 2014. Reviewed May 2014 and January 2015. These datasets were inputted into an excel spreadsheet following a format provided by CSIRO. This spreadsheet was then used to create summary tables (see Section 5.3, Table 19) and to build the build the first and second biomass supply curves (Section 5.3, Figures 17 and 19) for the Orange case study region.

**Note:** <sup>a</sup> It only includes data from this division, not of surrounding divisions.

## Appendix 12B. CSIRO databases of modelled biomass production – Part B

Descriptor	Data description/How used	Documentation (if available)
Biomass productivity	<p>A Microsoft Excel spreadsheet with extracted softwood biomass productivity values for the Central West New South Wales region:            CW_50K_100K_SW_clips_for_Totals_final.xlsx            This spreadsheet was used to summarise the softwood data described in Appendix 12A – Part A.</p>	<p>Rodriguez, LC, et al. 2011, Opportunities for Bioenergy. An assessment of the environmental and economic opportunities and constraints associated with Bioenergy production from biomass resources in two prospective regions of Australia, Department of Agriculture, Fisheries and Forestry; CSIRO, specifically, Table 4-10, Table 4-10, p. 77-78</p>
	<p>A Microsoft Excel spreadsheet with extracted biomass productivity values for landholder sites:            landholdermap_proonly.xlsx            These values were used to classify landholder sites into 3 productivity zones: Low (Z1), Medium (Z2) and high (Z3). The values Z1, Z2, Z3 were mutually exclusive categories and were used as dummy variables in the different economic models. Note that for dummy modelling, always one category is left out.</p>	<p>Velarde, SJ 2012, Unpublished dataset of landholder sites from the landholder survey, 1.0 edn.</p> <p>Polglase P, Paul K, Hawkins C et al. (2008) Regional opportunities for agroforestry systems in Australia. Report to the Rural Industries Research and Development Corporation, CSIRO, Canberra, Australia</p>
	<p>Maps showing productivity values and landholder sites in JPG format:            Sandras_orange_points_prod.jpg and            Sandras_orange_points_prod_no_KD.jpg            The second map is presented in Section 4.3, Figure 11.</p>	<p>As above.</p>

### Appendix 12C. CSIRO database of economic profitability & transport model

Descriptor	Data description/How used	Documentation (if available)
Economic profitability	<p>A set of GIS files of the agricultural profit map for Australia for the year 2005-2006 in raster format. Values for profit at full equity (PFE)<sup>a</sup> provided in \$/ha. Spatial resolution ~1 km pixel for a set of commodity classes (e.g. winter cereals, winter oilseeds) and broad land use categories (e.g. grazing, natural pastures)</p> <p>Note: Initially CSIRO extracted data for the landholder sites from this GIS dataset. However, the extracted data showed high variability in neighbouring cells. Since the landholder sites were only approximated locations, it was decided not to use this dataset.</p>	<p>Marinoni, O, Navarro Garcia, J, Marvanek, S, Prestwidge, D, Clifford, D &amp; Laredo, L 2014, Agricultural profit map for Australia for the year 2005-2006. v1. CSIRO. Data Collection (Publicly available), &lt;<a href="http://doi.org/10.4225/08/53017F4EC8C83">http://doi.org/10.4225/08/53017F4EC8C83</a>&gt;.</p> <p>Marinoni, O, Navarro Garcia, J, Marvanek, S, Prestwidge, D, Clifford, D &amp; Laredo, LA 2012, 'Development of a system to produce maps of agricultural profit on a continental scale: An example for Australia', <i>Agricultural Systems</i>, vol. 105, no. 1, pp. 33-45.</p>
Transport model	<p>A Microsoft Excel spreadsheet by Barry May based on Lambert &amp; Quill (2006).</p> <p>This model was used to crosscheck the values for transport costs in the updated tables on biomass cost used in this thesis (see Appendix 11).</p>	<p>May, B 2011, A transport model for biofuel/bioenergy generation in Microsoft Excel CSIRO, Unpublished database.</p> <p>Lambert, J &amp; Quill, D 2006. Growth in blue gum forest harvesting and haulage requirements in the Green Triangle 2007 - 2020, Woollybutt Pty Ltd, Victoria.</p>

**Note:** <sup>a</sup> PFE is the revenue minus all fixed and variable costs, assuming the land is fully owned.

## Appendix 12D. GIS boundary files and landholder sites provided by CSIRO

Descriptor	Data description/How used	Documentation (if available)
Boundary files	<p>A set of GIS files of a 100 km buffer area around the town of Orange, Central West New South Wales:            Orange_100km_buff.dbf, Orange_100km_buff.prj            Orange_100km_buff.sbn, Orange_100km_buff.sbx            Orange_100km_buff.shp, Orange_100km_buff.shp.xml            Orange_100km_buff.shx            These files were used to extract data from the biomass datasets i.e. boundary of the Orange case study area.</p>	NA
	<p>A set of GIS files of the Central West New South Wales Statistical Division boundary:            Central_West_NSW_SD07_alb94.dbf            Central_West_NSW_SD07_alb94.prj            Central_West_NSW_SD07_alb94.sbn            Central_West_NSW_SD07_alb94.sbx            Central_West_NSW_SD07_alb94.shp            Central_West_NSW_SD07_alb94.shp.xml            Central_West_NSW_SD07_alb94.shx            These files show the boundaries of the case study region.</p>	NA
Landholder sites	<p>A set of GIS files of landholder sites. These files were transformed by CSIRO from their original KML format (Velarde 2012) into ArcGIS readable:            survey_points_15102013_alb94_prod_values.dbf, .prj, .sbn, .sbx, .shp, .shx            These files were used to create Figure 10.</p>	<p>Velarde, SJ 2012, Unpublished dataset of landholder sites from the landholder survey.</p> <p>Note: Landholder sites were randomly assigned to the outskirts of the towns the landholders mentioned.</p>
	<p>A series of figures showing landholder sites and Central West New South Wales boundaries:            Map_all_points.jpg, Map_orange_points_labels.jpg            Map_orange_points.jpg, Sandras_orange_points_no_KD.jpg            These files were not used.</p>	<p>Velarde, SJ 2012, Unpublished dataset of landholder sites from the landholder survey</p>

### Appendix 13 Retail petrol pump price (RPP) in Australia for different TAPIS oil prices

													+100	
	Unleaded petrol (ULP)	Unit	Value <sup>a</sup>	-75%	-50%	-25%	-20%	-10%	+10%	+20%	+25%	+50%	+75%	%
1	<b>Oil price per barrel TAPIS</b>	USD/barrel	<b>115.13</b>	<b>28.78</b>	<b>57.56</b>	<b>86.35</b>	<b>92.10</b>	<b>103.62</b>	<b>126.64</b>	<b>138.15</b>	<b>143.91</b>	<b>172.69</b>	<b>201.48</b>	<b>230.26</b>
2	Exchange rate	USD/AUD	0.9648	0.9648	0.9648	0.9648	0.9648	0.9648	0.9648	0.9648	0.9648	0.9648	0.9648	0.9648
3	Volume conversion	L/barrel	159.00	159.00	159.00	159.00	159.00	159.00	159.00	159.00	159.00	159.00	159.00	159.00
4	Oil price per litre TAPIS	AUD/L	0.7505	0.1876	0.3753	0.5629	0.6004	0.6755	0.8256	0.9006	0.9381	1.1258	1.3134	1.5010
5	Refining cost petrol ex Singapore	AUD/L	0.0685	0.0685	0.0685	0.0685	0.0685	0.0685	0.0685	0.0685	0.0685	0.0685	0.0685	0.0685
6	Petrol price per litre MOPS95	AUD/L	0.819	0.256	0.444	0.631	0.669	0.744	0.894	0.969	1.007	1.194	1.382	1.570
7	Australian fuel excise	AUD/L	0.38143	0.38143	0.38143	0.38143	0.38143	0.38143	0.38143	0.38143	0.38143	0.38143	0.38143	0.38143
	Wholesale margins and other													
8	costs	AUD/L	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
9	Importing costs to land fuel	AUD /L	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
10	Australian GST (10% of TGP)	AUD /L	0.13	0.07	0.09	0.11	0.12	0.12	0.14	0.15	0.15	0.17	0.19	0.21
11	Terminal Gate Price (TGP)	AUD /L	1.430	0.811	1.018	1.224	1.265	1.348	1.513	1.596	1.637	1.843	2.050	2.256
	Retailer cost and margin (5% of													
12	RPP)	AUD /L	0.08	0.04	0.05	0.06	0.07	0.07	0.08	0.08	0.09	0.10	0.11	0.12
13	<b>Retail Petrol Pump Price (RPP)</b>	<b>AUD/L</b>	<b>1.506</b>	<b>0.854</b>	<b>1.071</b>	<b>1.289</b>	<b>1.332</b>	<b>1.419</b>	<b>1.593</b>	<b>1.680</b>	<b>1.723</b>	<b>1.940</b>	<b>2.158</b>	<b>2.375</b>
14	Tax (7+10)	AUD/L	0.51	0.46	0.47	0.49	0.50	0.50	0.52	0.53	0.53	0.55	0.57	0.59
15	Wholesale & retailer cost and													
	margins (12+8+9)	AUD/L	0.18	0.14	0.15	0.16	0.17	0.17	0.18	0.18	0.19	0.20	0.21	0.22
16	Refined product cost (13-14-15)	AUD/L	0.82	0.26	0.44	0.63	0.67	0.74	0.89	0.97	1.01	1.19	1.38	1.57
17	Distribution cost (8+9)	AUD/L	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

**Note:** Base value: USD 115.13 per barrel as of April 2014.

#### Appendix 14 Production cost, pump price and price equivalent to petrol pump price of ethanol for different costs of biomass

Feedstock	Distance (km)	B (\$/t)	B (\$/L)	K (\$/L)	O (\$/L)	Ep (\$/L)	D (\$/L)	GST (\$/L)	X (\$/L)	M (\$/L)	Epp (\$/L)	EqRPP (\$/L)	B/Ep %
<b>Softwood biomass</b>													
Bark A	0-50	31.7	0.10	0.34	0.25	0.69	0.125	0.08	0	0.047	0.94	<b>1.37</b>	14%
Bark B	50-100	41.2	0.13	0.34	0.25	0.72	0.125	0.08	0	0.049	0.97	<b>1.42</b>	18%
Sawdust and shavings A	0-50	44.9	0.14	0.34	0.25	0.73	0.125	0.09	0	0.049	0.99	<b>1.44</b>	19%
Sawdust and shavings B	50-100	59.1	0.18	0.34	0.25	0.77	0.125	0.09	0	0.052	1.04	<b>1.52</b>	24%
Harvest residues A	0-50	75.0	0.23	0.34	0.25	0.82	0.125	0.09	0	0.055	1.09	<b>1.60</b>	28%
Chips A	0-50	81.8	0.25	0.34	0.25	0.84	0.125	0.10	0	0.056	1.12	<b>1.63</b>	30%
Harvest residues B	50-100	87.7	0.27	0.34	0.25	0.86	0.125	0.10	0	0.057	1.14	<b>1.66</b>	31%
Chips B	50-100	97.2	0.30	0.34	0.25	0.89	0.125	0.10	0	0.059	1.17	<b>1.71</b>	34%
Pulp logs A	0-50	133.6	0.41	0.34	0.25	1.00	0.125	0.11	0	0.065	1.30	<b>1.90</b>	41%
Pulp logs B	50-100	148.9	0.46	0.34	0.25	1.05	0.125	0.12	0	0.068	1.36	<b>1.98</b>	44%
<b>Hardwood biomass</b>													
<i>E. cladocalyx</i>	0-10	109.83	0.34	0.34	0.25	0.93	0.125	0.11	0	0.061	1.219	<b>1.78</b>	36%
<i>E. cladocalyx</i>	10-20	110.88	0.34	0.34	0.25	0.93	0.125	0.11	0	0.061	1.223	<b>1.79</b>	37%
<i>E. cladocalyx</i>	20-30	111.94	0.34	0.34	0.25	0.93	0.125	0.11	0	0.061	1.227	<b>1.79</b>	37%
<i>E. cladocalyx</i>	30-40	115.10	0.35	0.34	0.25	0.94	0.125	0.11	0	0.062	1.238	<b>1.81</b>	38%
<i>E. cladocalyx</i>	40-50	117.22	0.36	0.34	0.25	0.95	0.125	0.11	0	0.062	1.246	<b>1.82</b>	38%
<i>E. cladocalyx</i>	50-60	119.33	0.37	0.34	0.25	0.96	0.125	0.11	0	0.063	1.253	<b>1.83</b>	38%
<i>E. cladocalyx</i>	60-70	121.44	0.37	0.34	0.25	0.96	0.125	0.11	0	0.063	1.261	<b>1.84</b>	39%
<i>E. cladocalyx</i>	70-80	122.50	0.38	0.34	0.25	0.97	0.125	0.11	0	0.063	1.264	<b>1.85</b>	39%
<i>E. cladocalyx</i>	80-90	124.61	0.38	0.34	0.25	0.97	0.125	0.11	0	0.064	1.272	<b>1.86</b>	39%
<i>E. cladocalyx</i>	90-100	126.72	0.39	0.34	0.25	0.98	0.125	0.11	0	0.064	1.279	<b>1.87</b>	40%

**Notes:** B = Biomass, K = capital cost, O = operational cost, Ep = Ethanol production cost, D = distribution cost, M = retail margin = 5%, Epp = Ethanol price at the pump ( $E_p + D + GST + X + M$ ), EqRPP = Ethanol price equivalent to retail petrol pump price ( $Epp * 1.46$ ), GST = 10 % \* (Ep + D).

**Appendix 15 Hardwood biomass supply in the case study region, 5 year rotation**

Species	Distance (km)	Biomass (dry t)		
		Adoption rate (area based)		
		2.5%	5%	10%
<i>E. cladocalyx</i>	0-10	5,382	10,764	21,528
<i>E. cladocalyx</i>	10-20	17,225	34,450	68,901
<i>E. cladocalyx</i>	20-30	25,778	51,556	103,112
<i>E. cladocalyx</i>	30-40	31,118	62,237	124,473
<i>E. cladocalyx</i>	40-50	39,562	79,123	158,247
<i>E. cladocalyx</i>	50-60	39,577	79,155	158,309
<i>E. cladocalyx</i>	60-70	36,937	73,874	147,747
<i>E. cladocalyx</i>	70-80	41,061	82,122	164,244
<i>E. cladocalyx</i>	80-90	43,542	87,084	174,168
<i>E. cladocalyx</i>	90-100	37,392	74,784	149,568

**Appendix 16 Look up table oil price, retail pump price and biomass cost**

<b>Oil price (USD/bl)</b>	<b>RPP (AUD/L)</b>	<b>Biomass cost (AUD/t)</b>	<b>Oil price (USD/bl)</b>	<b>RPP (AUD/L)</b>	<b>Biomass cost (AUD/t)</b>
75.00	1.20	0.00	116.00	1.51	58.00
76.00	1.21	1.00	117.00	1.52	59.00
77.00	1.22	2.00	118.00	1.53	61.00
78.00	1.23	4.00	119.00	1.53	62.00
79.00	1.23	5.00	120.00	1.54	63.00
80.00	1.24	6.00	121.00	1.55	65.00
81.00	1.25	7.00	122.00	1.56	67.00
82.00	1.26	10.00	123.00	1.57	69.00
83.00	1.26	11.00	124.00	1.57	70.00
84.00	1.27	12.00	125.00	1.58	71.00
85.00	1.28	14.00	126.00	1.59	74.00
86.00	1.29	16.00	127.00	1.60	75.00
87.00	1.29	17.00	128.00	1.60	76.00
88.00	1.30	18.00	129.00	1.61	77.00
89.00	1.31	19.00	130.00	1.62	79.00
90.00	1.32	21.00	131.00	1.63	81.00
91.00	1.32	22.00	132.00	1.63	81.00
92.00	1.33	23.00	133.00	1.64	82.00
93.00	1.34	25.00	134.00	1.65	84.00
94.00	1.35	27.00	135.00	1.66	87.00
95.00	1.35	28.00	136.00	1.66	87.00
96.00	1.36	30.00	137.00	1.67	88.00
97.00	1.37	31.00	138.00	1.68	91.00
98.00	1.38	32.00	139.00	1.69	92.00
99.00	1.38	33.00	140.00	1.69	93.00
100.00	1.39	34.00	141.00	1.70	94.00
101.00	1.40	36.00	142.00	1.71	96.00
102.00	1.41	38.00	143.00	1.72	98.00
103.00	1.41	39.00	144.00	1.72	100.00
104.00	1.42	40.00	145.00	1.73	101.00
105.00	1.43	42.00	146.00	1.74	102.00
106.00	1.44	44.00	147.00	1.75	104.00
107.00	1.44	45.00	148.00	1.75	105.00
108.00	1.45	46.00	149.00	1.76	106.00
109.00	1.46	48.00	149.50	1.77	107.00
110.00	1.47	50.00	150.00	1.77	108.00
111.00	1.47	51.00	151.00	1.78	109.00
112.00	1.48	52.00	152.00	1.78	110.00
113.00	1.49	54.00	153.00	1.79	111.00
114.00	1.50	56.00	154.00	1.80	113.00
115.00	1.505	57.00	155.00	1.81	115.00

**Appendix 16 Look up table oil price, retail pump price and biomass cost  
(continuation)**

<b>Oil price (USD/bl)</b>	<b>RPP (AUD/L)</b>	<b>Biomass cost (AUD/t)</b>	<b>Oil price (USD/bl)</b>	<b>RPP (AUD/L)</b>	<b>Biomass cost (AUD/t)</b>
156.00	1.81	116.00	186.00	2.04	159.00
157.00	1.82	118.00	187.00	2.05	161.00
158.00	1.83	119.00	188.00	2.06	163.00
159.00	1.84	121.00	189.00	2.06	164.00
160.00	1.84	122.00	190.00	2.07	166.00
161.00	1.85	123.00	191.00	2.08	167.00
162.00	1.86	125.00	192.00	2.09	169.00
163.00	1.87	127.00	193.00	2.09	170.00
164.00	1.87	128.00	194.00	2.10	172.00
165.00	1.88	130.00	195.00	2.11	173.00
166.00	1.89	131.00	196.00	2.12	175.00
167.00	1.90	132.00	197.00	2.12	175.00
168.00	1.90	133.00	198.00	2.13	176.00
169.00	1.91	134.00	199.00	2.14	179.00
170.00	1.92	136.00	200.00	2.15	180.00
171.00	1.93	138.00	201.00	2.15	181.00
172.00	1.94	140.00	202.00	2.16	183.00
173.00	1.94	141.00	203.00	2.17	184.00
174.00	1.95	142.00	204.00	2.18	186.00
175.00	1.96	144.00	205.00	2.18	187.00
176.00	1.97	146.00	206.00	2.19	189.00
177.00	1.97	147.00	207.00	2.20	190.00
178.00	1.98	148.00	208.00	2.21	192.00
179.00	1.99	150.00	201.00	2.15	181.00
180.00	2.00	152.00	202.00	2.16	183.00
181.00	2.00	153.00	203.00	2.17	184.00
182.00	2.01	154.00	204.00	2.18	186.00
183.00	2.02	156.00	205.00	2.18	187.00
184.00	2.03	157.00	206.00	2.19	189.00
185.00	2.03	158.00	207.00	2.20	190.00

## Appendix 17 Benchmark energy prices

### 17a. Biomass costs – case study

Feedstock	Distance	\$/t	\$/GJ <sup>b</sup>	USD/GJ
Softwood bark	0-100	31.67 – 41.18	1.95 – 2.54	1.89 – 2.45
Softwood sawdust and shavings	0-100	44.88 – 59.13	2.77 – 3.65	2.67 – 3.52
Softwood dust <sup>a</sup>		57	3.52	3.39
Softwood residues	0-100	74.97 – 87.65	4.63 – 5.41	4.46 – 5.22
Softwood chips	0-100	81.84 – 97.15	5.05 – 6.00	4.87 – 5.79
E. cladocalyx	0-10	109.83	6.78	6.54
E. cladocalyx	90-100	126.72	7.82	7.55
Softwood pulplogs	0-100	133.59-148.9	8.25-9.19	7.96 – 8.87

**Note:** <sup>a</sup>Biomass cost at break even oil price USD 115.13; Conversion factor Wood (dry) = 16.2 GJ/t; Exchange rate: 1 USD = 1.036484245 AUD. **Source:** <sup>b</sup>BREE (2014).

### 17b. Range of costs of typical biomass sources (Australia)

Resource	Indicative cost (AUD/GJ)	Indicative cost (USD/GJ)
Animal wastes, sewage sludge, landfill gas	Zero or may be negative if disposal costs are avoided	0
Wood process residues, bagasse etc. used on site	0 – 0.20	0 – 0.19
Short cycle crops (such as oil mallee)	5.00 – 7.00 (near term)	4.82 – 6.75
	3.00 (mature industry)	2.89
Wood pellets	12 <sup>a</sup>	11.58

**Source:** ITP Power (2015). **Note:** <sup>a</sup>Add AUD 0.3/GJ up to 15km, AUD 0.8/GJ up to 70km

**17c. Biomass feedstock characteristics and feedstock price in the United States of America**

<b>Feedstock</b>		<b>Typical moisture content</b>	<b>Heat value MJ/Kg</b>	<b>Price (2014 USD/GJ)</b>
Forest residues	Pine residues	30-40%	17.5 – 20.8	1.2 – 1.5
	Hardwood residues	30-40%	17.5 – 20.7	0.9 – 1.4
Woodwaste		5-15%	19.9	1.1 – 3.2
Agricultural residues		20-35%	15.1 – 18.1	1.4 – 3.5
Energy crops	Poplar	10-30%	17.7	1.5 – 3.6
	Switchgrass and other	20%	16.8 – 18.6	2.4 – 3.4
	Miscanthus	15%	17.8 – 18.1	2.8 – 8.2
	Bagasse	10-30%	17.7 – 17.9	2.2
	Sorghum	20%	14.3 – 18.3	2.3 – 2.9
	Willow	10-30%	16.7 – 18.4	3.1 – 3.4

**Source:** IRENA (2015).

### 17d. International pellet prices

Pellet type	USD/t	USD/GJ
Industrial (July 2014) <sup>a,c</sup>	185	10.88
Industrial forecast 2018 <sup>a,c,e</sup>	151 – 165 – 179	8.88 – 9.71 – 10.53
Heating – retail prices <sup>b,d,e</sup>	230 – 273 – 304	13.53 – 16.06 – 17.88

**Source:** <sup>a</sup> Strauss (2017); <sup>b</sup> Strauss (2018). **Notes:** <sup>c</sup>Prices for industrial pellets are for CIF-ARA (cost, insurance and freight in the Amsterdam-Rotterdam-Antwerp area); <sup>d</sup>Retail median prices (USA), December 2017 for three states. Conversion rate: Calorific value of wood pellets: 17 MJ/kg = 17 GJ/t (FAO, 2015); <sup>e</sup>Low, medium and high estimates.

### 17e. Australian average coal export prices (2014)\*

Coal type	USD/t	USD/GJ
High quality coking coal (USD/t) <sup>a</sup>	116	4.00
Semi-soft coking coal (USD/t) <sup>b</sup>	105	3.89
Thermal coal (USD/t) <sup>c</sup>	82	3.56

**Source:** BREE (2014). **Note:** <sup>a</sup>Also known as metallurgical coal, calorific value = 29 MJ/kg, <sup>b</sup>calorific value = 27 MJ/kg; <sup>c</sup>Calorific value = 23 MJ/kg.