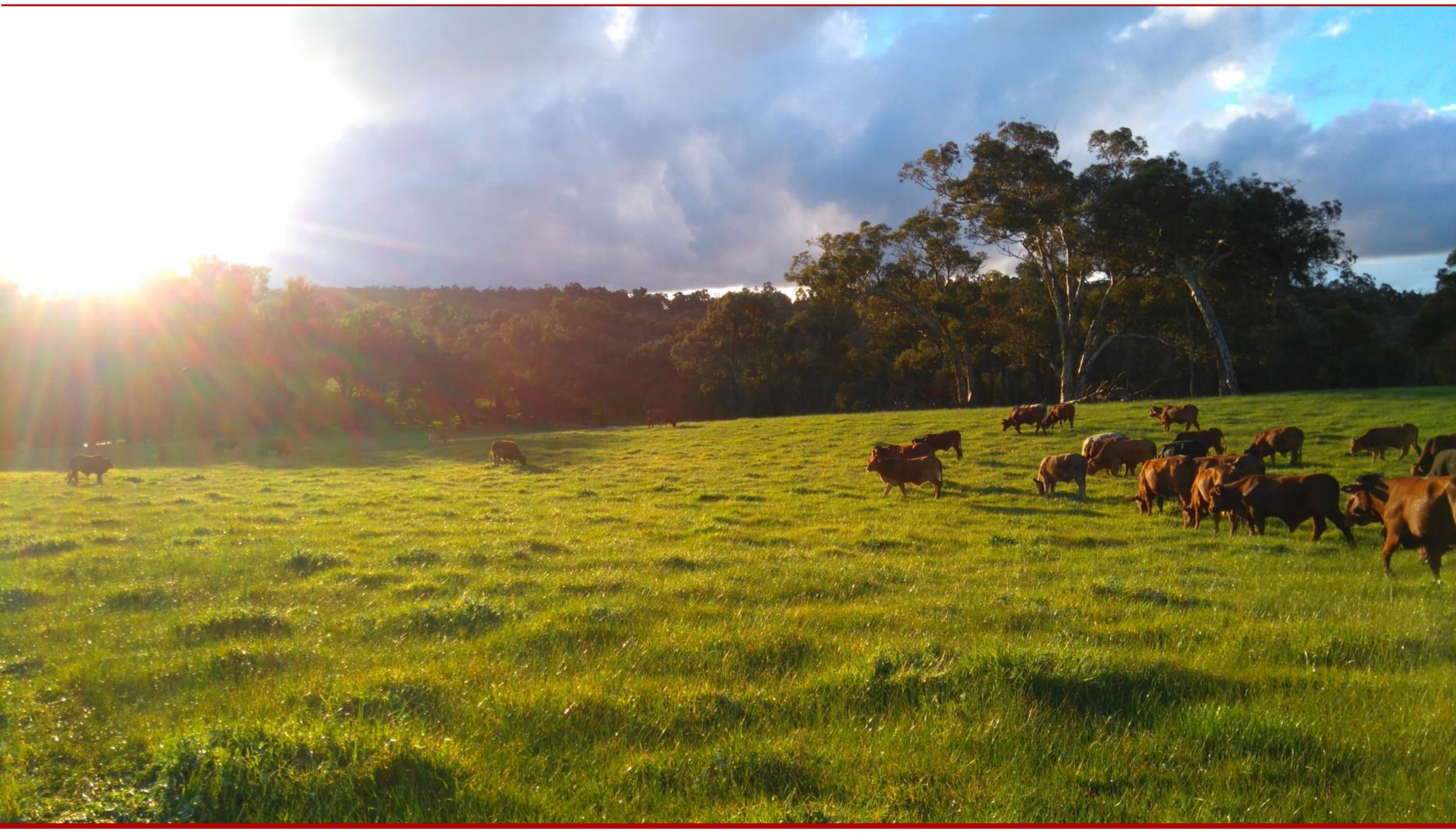
AN EXPLORATION OF SUSTAINABLE AGRICULTURE OPTIONS FOR THE WEST-AUSTRALIAN WHEATBELT

ENVIRONMENTALLY, SOCIALLY AND ECONOMICALLY SUSTAINABLE AGRICULTURE FOR THE FUTURE



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PREFACE

Wide Open Agriculture is a small company founded in March 2015 in the Western Australian Wheatbelt. Both founders of this social impact venture grew up in the Wheatbelt and saw a gradual decline in the health of both the environment and the small rural communities. Wide Open Agriculture's aim is to revitalise and diversify the Wheatbelt, using innovative thinking and delivering four returns: the return of natural capital, social capital, financial capital and returning inspiration to communities in and around the Wheatbelt. Since their foundation they have achieved amazing results with a very small team. For more info visit www.wideopenagriculture.com.au or their Facebook page on facebook.com/wideopenagriculture.

I came into contact with this company in January last year. I was looking for a meaningful project for my MSc thesis, they were looking for someone to explore alternative, sustainable options to broad-acre agriculture in the Wheatbelt. My background in Earth Sciences and Economics matched their search and so we began.

This project has been very educational to me in many ways. Not only have I learnt a lot about a beautiful part of the world, and about how (not) to write a thesis, e.g. I should have made much more use of sparring partners during the process, I also got to meet some magnificent people whom I admire for their hospitality, their courage to try something different when their peers are not, and for their amazing willingness to share. As a nosy student wanting to know everything about their businesses I was expecting at least some reserve among farmers and researchers, but instead I was heartily invited to join them for work during the day and for dinner at night (and the best thing about researching Australian farmers: they all want to impress you with their cooking and fresh farm products!). They also happily shared their knowhow and data for the good cause. I found the same hospitality and willingness to share among the many other people I have met during my time in Australia; they shared their network, research, literature and data with me and gave me helpful advice during the process. Without them this research would not have been possible and for that I owe them many thanks.

I would also like to thank the team at Wide Open Agriculture specifically for the warm welcome, the support and the great fun we had, as well as the people who read through early drafts of this report and provided advice and support during the process of writing it. Also thanks to Commonland for making this project possible.

A list of the people who contributed to this report is given above. I have tried to not forget anyone, but if I did, please write in. This report concludes my studies in Earth Sciences, specialisation Earth Sciences and Economics, at VU University in Amsterdam. I hope it is useful for you in some way, even if it were just inspirational. This project has certainly inspired me. Enjoy!

Bas van Dijk

29-01-2017

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EXECUTIVE SUMMARY

The Western Australian Wheatbelt, a mainly wheat-growing region in the south-west of Australia, is facing problems of environmental degradation and decline of rural communities. The region, one of thirty-three global biodiversity hotspots, has been progressively cleared of up to 95% of its original vegetation over the course of the last century to make way for an industrial-style approach to agriculture, characterised by high input, large machinery, large scale cropping and livestock (sheep and cattle) systems. However, climate change, rising prices of vital farm inputs and soil constraints arising from the land clearing and the subsequent decades of industrial agriculture, have led to slowly but steadily shrinking farm operating margins. This trend may be an important factor explaining the significant decline in the number of farms in the last few decades: between 1970 and 2013 62% of all farms in the region disappeared. The remaining farms have grown substantially in their scale of operations, in an attempt to increase profit margins by capitalising on economies of scale.

Previous research has shown that as the scale of farming increases, the health of rural communities declines. In the Wheatbelt, job provision dropped 12% between 2001 and 2006, and rural towns saw 7-35% of their inhabitants leave permanently between 1981 and 2001. This rural depopulation puts a strain on essential social services, such as medical and educational facilities as well as police services. They shut down as minimum population thresholds are crossed.

This thesis argues that the approach to land management in the Wheatbelt since land clearing began could be the explanation of both the environmental and the social problems which have grown in both extent and severity. This argument would also explain why the measures aimed at reducing these problems up until now have been unsuccessful at solving them permanently, despite the large efforts and good intentions that have been put into them: those measures do not address the root cause.

This study explores whether alternative approaches to agriculture in the context of the Wheatbelt may be a more sustainable option than continuing with industrial agriculture. Four ecological farming systems were designed based on literature and examples observed in the study area and compared to continuing with 'business-as-usual' (industrial cropping) on the three 'pillars of sustainability': environmental, social and financial sustainability. A whole-farm modelling approach, modelling each farming system for two case study locations over a time period of thirty years, was chosen as method for these analyses. The case study locations are Buntine and Arthur River, which have been selected to explore the theoretical effect that different precipitation levels have on the sustainability of the farming systems. The purpose of the study is to do a brushstroke analysis which covers many topics limitary, to guide future, more detailed research on each topic.

The baseline system for comparison is called 'business-as-usual' (**BAU**) and consists of industrial cereal cropping in rotation. The four ecological farming systems are **pasture cropping**, **perennial grazing**, **dehesa** and **wood products**. Pasture cropping consists of cropping annual crops straight into a perennial, native pasture, which is grazed using successional rotational grazing with cattle, chickens and sheep. Perennial grazing is a livestock-only system; a similar grazing system as in pasture cropping is used but the perennial native pastures are interplanted with alleys of native fodder shrubs. The dehesa

system is based on a traditional Spanish agricultural system which has been developed over centuries under similar conditions as those in the Wheatbelt. It is a silvopastoral system with native perennial pastures and a mix of holm oaks, cork oaks and carobs. The wood products scenario is designed to recreate a biodiverse, endemic ecosystem for conservation purposes, but allows the farmer to make a profit on the process by including wood-based products such as timber and sandalwood for essential oils.

The long term environmental sustainability analysis was performed following the principles of environmental impact assessment, and scored each scenario on their perceived effect on a number of environmental indicators. The results show that some ecological farming systems should be able to reverse the environmental degradation that has arisen over the last decades. This was confirmed by several field observations. The most environmentally sustainable scenario is wood products, closely followed by perennial grazing and dehesa. Pasture cropping is fourth, and BAU is the least environmentally sustainable system in this analysis.

The social sustainability of each scenario was assessed through the expected on-farm employment. The whole-farm models allowed calculation of the labour force necessary to run each system. Both the dehesa and the pasture cropping systems were indicated to employ over ten times as many people on-farm as current conventional farms do on the same effective farming area, which make them the socially most sustainable systems. Perennial grazing still shows a significant increase over BAU, but the wood products scenario is the least socially sustainable system because there is little work to be done once the trees are planted. It is suggested that this potential rise in employment could contribute to revitalising rural Wheatbelt communities in the future.

The financial sustainability analysis was performed using detailed financial accounting models based on the whole-farm models. The results first of all show that ecological farming systems may take a number of years to mature. The dehesa system for example makes use of trees which only come into production after 19-25 years. This can be a severe hindrance if a landowner applies for a loan to finance the transition to such a system. However, some scenarios (such as pasture cropping) require little up-front investment, which makes it an attractive alternative for landowners with less financial capital. Another solution to this problem of finance is to transition slowly; only parts of the farm at a time or slowly adding farm enterprises as time progresses.

After correcting the modelling results for drought years, interest on finance and other factors that arose from a robustness analysis the most financially sustainable scenario in the long term is the dehesa system, even though BAU is the most profitable system in the short (5-year) term. The dehesa system requires a significant up-front investment, but the system in this analysis is able to earn that investment back even before the system becomes fully operational. The wood products scenario is the second-most financially attractive scenario at the Buntine case study location, but due to a difference in the type of wood products between the locations the Arthur River wood products scenario is in third place. Pasture cropping is the second-best at Arthur River and third-best at Buntine, and perennial grazing and the BAU scenario are on par in the long run.

Overall, this analysis shows the dehesa system to be the most sustainable system for the Wheatbelt in the long run. However, this was an exploratory study looking at only four ecological farming systems, which were not optimised for this occasion. There are other systems possible in the Wheatbelt which may be even more sustainable, or the systems considered here could be designed differently so there is, for instance, less up-front investment required. A combined system that results from the integration of the four ecological systems considered separately in this study may prove to be more sustainable than each system by itself. The definitive single most sustainable system, if there will ever be one, cannot be determined based on the results of this study. However, some important design imperatives for ecological farming systems can be deduced. A high potential ecological farming system should have:

- High diversity of (complementary) farm enterprises
- Low initial investment and/or short earn-back time
- High employment
- Integration of animals

Judging from the results of this study an alternative approach to land management in the Wheatbelt not only seems possible, but preferable over the current conventional approach. Whether such an approach will truly be able to restore the environment and contribute to revitalising rural communities will have to be proven by on-farm trials, but at first glance it seems possible. Wide-scale diffusion of such an approach throughout the region may take some effort however, as several potentially substantial obstacles to adoption have been identified. These are connected to awareness and a lack of knowledge on ecological practices in the context of the Wheatbelt, difficulty to access finance for and support during the transition period, and social pressure which some communities seem to apply to practitioners trying a different approach.

These obstacles should be researched in more detail. Another recommendation for future research are trialling these and other ecological farming systems in different areas in the Wheatbelt to verify the results of this study. The link between land management and the health of rural communities deserves more attention and the effects that ecological farming systems can have on both rural communities and the environment, especially in the context of the Wheatbelt, should be further investigated. Finally, the effects of future climate change were not taken into account in this study and should be looked into.

Recommendations for practitioners are to increase knowledge sharing and awareness-raising on ecological farming and the transition process, as well as organising field trials to experiment with different ecological systems and ways to transitioning, in order to find those best suited to their situation.

The finance sector may need to reconsider the timeframe in which loans are paid back, as well as reconsider the risk assessment of investments both for industrial and ecological agricultural systems. It may be beneficial if financers would provide assistance to farmers in the transitioning process.

Policymakers should look into obstacles to adoption that arise from their policies, and into how they can create an enabling environment in which practitioners are stimulated to experiment with and transition to ecological farming systems.

This study explored options for a more sustainable future for the WA Wheatbelt. The results from this study are positive: ecological agriculture may contribute to solving many of the environmental and social problems the rural Wheatbelt currently faces. This study's implications may even reach further than the Wheatbelt, as there are many regions throughout the world in similar situations. Ecological agriculture may prove to be a promising solution for these regions. Healthy communities start with healthy soils.

1 INTRODUCTION

This year was promising to be a great season for farmers throughout the Western Australian Wheatbelt. Rain kept falling consistently and fields seemed greener than ever before; farmers were expecting bumper crops and record livestock sales (Jasper & Smith, 2016; Stanley, 2016a). This season was supposed to become a blessing in a tough agricultural climate that is characterised by periods of drought and bushfires.

However, towards the end of the growing season a series of frost events hit large parts of the region. At the time of writing, harvest results are coming in. Some farmers have been not or only slightly affected and are indeed yielding record crops (GIWA crop report December 2016), but others experience significant crop losses; some have lost 70-90% of their crops due to frost damage (Stanley, 2016b). ABC Rural stated communities are 'shell-shocked'. "I think we really just have to physically hold hands and regroup at the end of this harvest and see where we are all at" (Varischetti, 2016) said farmer Lindsay Tuckwell from Kondinin, Western Australia (WA). The total cost of frost damage to farmers was estimated at $140 million at the start of the harvest.

1.1 THE WESTERN AUSTRALIAN WHEATBELT

The Western Australian Wheatbelt is one of several wheat-growing regions in Australia, located in the State of Western Australia (WA). There are different definitions of its exact boundaries; this study follows the one of the State's Department of Food and Agriculture (figure 1). The region is home to about 138,000 people (Australian Bureau of Statistics, 2014), and is roughly eight times the size of the Netherlands, spread over an area 750 kilometres north-south and about 550 kilometres west-east (Department of Food and Agriculture, WA, 2012).

Not having been subject to any major geological event for tens of millions of years, the surface is very old and weathered (Commander, Schoknecht, Verboom & Caccetta, 2014, Wheatbelt NRM, 2013).The region consists of an ancient peneplain, incised by later drainage systems (Commander et al., 2014). There is a variety of soil types that can be found throughout the region, with sandy soils, sandy duplexes and loamy sands or gravels, sometimes underlain with shallow granite or protruded by granite outcrops (Stoneman, 1990, Stoneman, 1991, Commander et al., 2014). Soils are classified as Chromosols, Kandosols and Sodosols (McKenzie, Jacquier, Isbell & Brown, 2004). Most soils are regarded as nutrient poor (Hatton, Ruprecht & George, 2003).

The region is characterised by a Mediterranean climate, with warm, wet winters and hot, dry summers (Ludwig & Asseng, 2006). Annual precipitation averages between 250 and 450 mm, becoming gradually drier moving from the southwest to the northeast (figure 1).

Figure 1 - Map of the Western Australian Wheatbelt. Source: Department of Agriculture and Food, WA (2012)

These conditions have given rise to a large number of endemic and globally unique species. This, combined with the fact that the habitat for these species has dropped well below 30% of its original area, has given the region the dubious honour to be declared a global biodiversity hotspot (figure 2): a place which is unique in its high number of endemic species and in the high risk of those species becoming permanently extinct (Myers, Mittermeier, Mittermeier, Da Fonseca & Kent, 2000). In 2000 over 90% of the original vegetation in this hotspot had been removed for agriculture (Bradshaw, 2012; Hobbs, 1993).

The primary land use is broad-acre industrial cropping and sheep and cattle farming (Planfarm & Bankwest, 2014), before then it was called 'virgin bush' managed by the Aboriginal population (Pascoe, 2014). The Wheatbelt region produces nearly half the State's total agricultural produce (CEDA, 2014). There are no large cities within the Wheatbelt, but the Perth region and Bunbury to the west, Albany and Esperance to the south and Geraldton to the northwest have seaports and are relatively nearby. Within the Wheatbelt there are small towns often spread 35 or more kilometres apart.

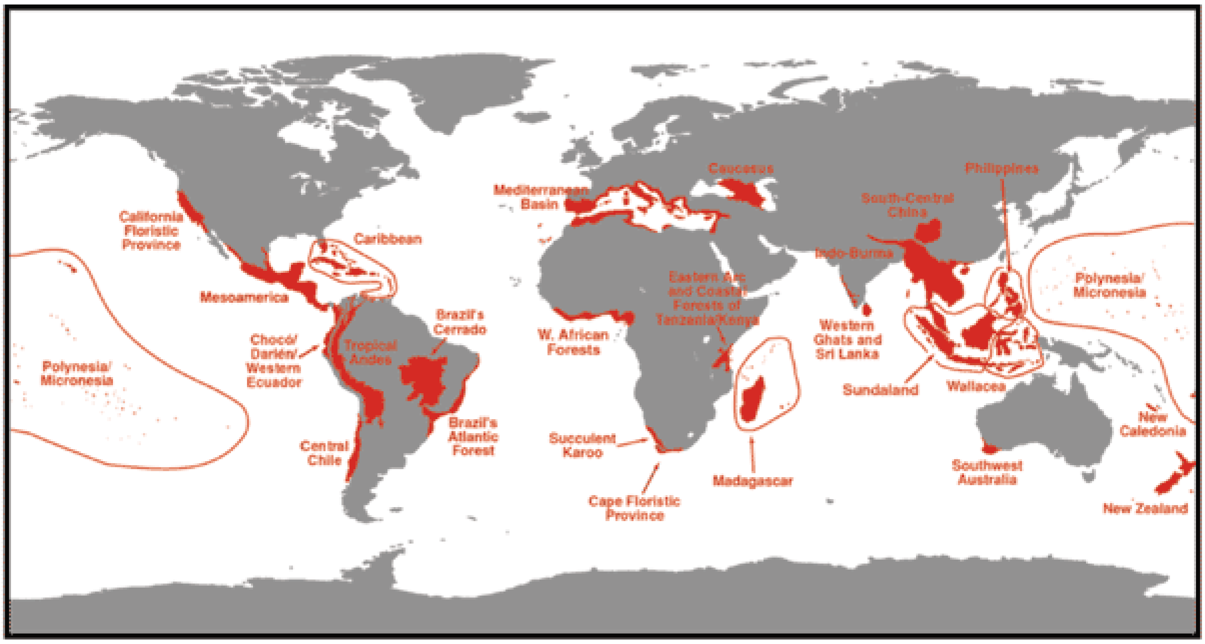


Figure 2 - Global biodiversity hotspots, from Myers, Mittermeier, Mittermeier, Da Fonseca & Kent (2000)

1.2 HISTORICAL TRENDS

Approximately 120 years ago most of the Wheatbelt was forested and only very sparsely populated. At the turn of the twentieth century the goldfields in the east of Western Australia had brought prosperity to the state, but food production was still too little to meet own demand and most food was imported (State Library of Western Australia, 2001). The government devised many incentives to (have civilians) clear as much land as possible as quickly as possible in order to create farmland to feed the state and also export. Conditional immigration, conditional land purchases or land claims, veteran soldier reward programs and elaborate road- and railway-construction projects are just some examples of these incentives (Moncrief & Mauldon, 1963; Gaynor, 2015). The following statement in the *West Australian Settler's Guide and Farmer's Handbook* is indicative of the attitude towards the bush: "*Western Australia may be likened to a huge pie, the crust of which has only, as yet, been nibbled around the edges... We want Jack Horners here to pull out the plums, and plums there are undoubtedly for men of all avocations*" (Gaynor, 2015). The wilderness had to be cleared as fast as possible for agriculture to bring new prosperity to the State.

Figure 3 - The northern Wheatbelt before clearing

This strategy of land clearing was very successful in expanding farmland. Large tracts of land were cleared, towns were settled and subsequently prospered. Today, in some parts of the Wheatbelt 80-95% of the original vegetation has disappeared, with most of the remaining patches fragmented and in bad condition (Hobbs, 1992). The invention of diesel-powered farm machinery meant and unprecedented area of land could be worked by a single worker, artificial fertilizer enabled farmers to achieve relatively high yields in these nutrient-poor conditions. The invention of agro-chemicals allowed farmers to stay on top of weeds and pests that became a problem.

1.3 CURRENT TRENDS

However, over recent decades signals have arisen that suggest the State's strategy of land clearing has not brought the kind of prosperity the government was hoping for; at least not in the long run. Despite prospering originally, farmers have had to face tough years due to weather and climate extremes. At the same time they have had to accept losing valuable farmland to processes such as salinization. Also over recent decades, rural communities have been in decline as families left the countryside and essential social services in the smaller rural towns have had to shut down.

1.3.1 Threats to Agriculture

The weather and climate extremes can make for very challenging conditions for farmers in the Wheatbelt. Industrial agriculture is susceptible to these conditions. The frost event mentioned in the introduction is one example of these conditions, but events like this, with "the potential to wipe out tens of millions of dollars of Western Australian crops", occur on average every two years according to the state's Department of Food and Agriculture (Department of Agriculture and Food, WA, 2016b). Another example are droughts and bushfires. The climate in WA is one with recurring periods of drought that can last several years, and climate data show that over recent decades the region has become still warmer and drier (Department of Agriculture and Food, WA, 2016b). Seasons with droughts, frosts or fires cause significant crop and livestock losses, which can take farmers several years to recover from.

Susceptibility to climate and weather extremes is one threat to agriculture in the region. A second kind are soil constraints. The major ones currently affecting farmers are salinity, sodicity, alkalinity, acidity, compaction, hardsetting, crusting, non-wetting, water repellence and nutrient deficiencies. These constraints are increasing in extent and severity (Rengasamy, Chittleborough & Helyar, 2003).

Figure 4 - Fertile farmland is being lost to salinity at the rate of 19 football ovals per day

Salinity is considered as being the greatest environmental threat facing Western Australia (Gaynor, 2002). In south west WA alone, 1.1 million hectares was salt-affected by 2007 and this is rising at a rate of 19 football ovals per day (WA State of the Environment Report, 2007). A total of 5.4 million hectares is thought to be at risk of salinization in the region. In 2001, the costs to society of dryland salinity were roughly estimated at $664 million for Australia as a total, with about 75% of affected areas located in Western Australia (Commonwealth of Australia, 2001). Salinity has been demonstrated to be a direct result from the clearing of the land and the subsequent installation of industrial agriculture through a major shift in the water balance in Wheatbelt valleys (Hatton, Ruprecht & George, 2003, Kington & Pannell, 2003; Peck & Williamson, 1987; Rengasamy, Chittleborough & Helyar, 2003; Bettenay, Blackmore & Hingston, 1964).

Soil sodicity and alkalinity are affecting soils in an area a quarter the size of the state and concentrated in the south-western agricultural region (Cochrane, Scholz & Vanvreswyk, 1994) and are linked to the salinity problem and to low soil organic matter levelswhich in turn can be linked to conventional agricultural approaches to grazing or continuous cropping (So & Aylmore, 1993; Reeves, 1997; Parton, Schimel, Cole & Ojima, 1987). Acidification is a result of, inter alia, the use of inorganic fertilizers and other chemicals, and is estimated to affect two-thirds of the Wheatbelt to some extent (Western Australia Environmental Protection Authority, 2007).

1.3.2 Solutions and their shortfalls

Attempts at solutions for these issues have generally been of a technical nature. Some examples are the construction of fire breaks, genetic modification of crops for increased drought tolerance or decreased frost susceptibility, installing dams to catch and store surface runoff or optimising the time of sowing, liming, employing no-till, and building drains. Despite these on-going efforts, farmers and researchers have not succeeded yet in solving these soil constraints permanently.

A possible explanation for this is that these (mostly) technical measures do not address the root cause of the problems, but instead focus on the mechanisms through which they affect farmland. As stated above, many of the soil constraints can be linked to practices that are inherently part of industrial agriculture. An increasing body of evidence from around the world confirms that undesired and unintended side-effects like these can arise from industrial agricultural practices (Matson, Parton, Power & Swift, 1997; Horrigan, Lawrence & Walker, 2002). This would mean that, in order to solve the problems facing the Wheatbelt sustainably, a more profound change in the way agriculture is practised may be required.

If no such sustainable solution is found, current trends are expected to continue (Kingwell and Pannell, 2005; Kingwell & Pannell, 2008). The recent frost and the 2010 drought proved that weather and climate extremes can still be substantial problems for Wheatbelt farmers. The area affected by soil constraints is still rising and activities like liming have to be repeated once every couple of years to keep acidity levels at bay. As an example, the application of lime and dolomite as a measure against acidification in the Wheatbelt region increased by 900% between 1990 and 2004 (Western Australia Environmental Protection Authority, 2007), with more than 1.6 million tonnes of lime being spread annually on WA farms to keep acidity levels constant (Western Australia Department of Agriculture and Food, 2009). Weeds and pests are, through the course of natural selection, becoming increasingly resistant to chemicals (Heap, 2014; Oerke, 2005; Powles & Howat, 1990). Farmers are required to use other agrochemicals and other farm inputs, or use them in larger quantities. At the same time, prices for critical farm inputs such as fuel and fertilisers have been rising consistently (see figures 5 and 6).

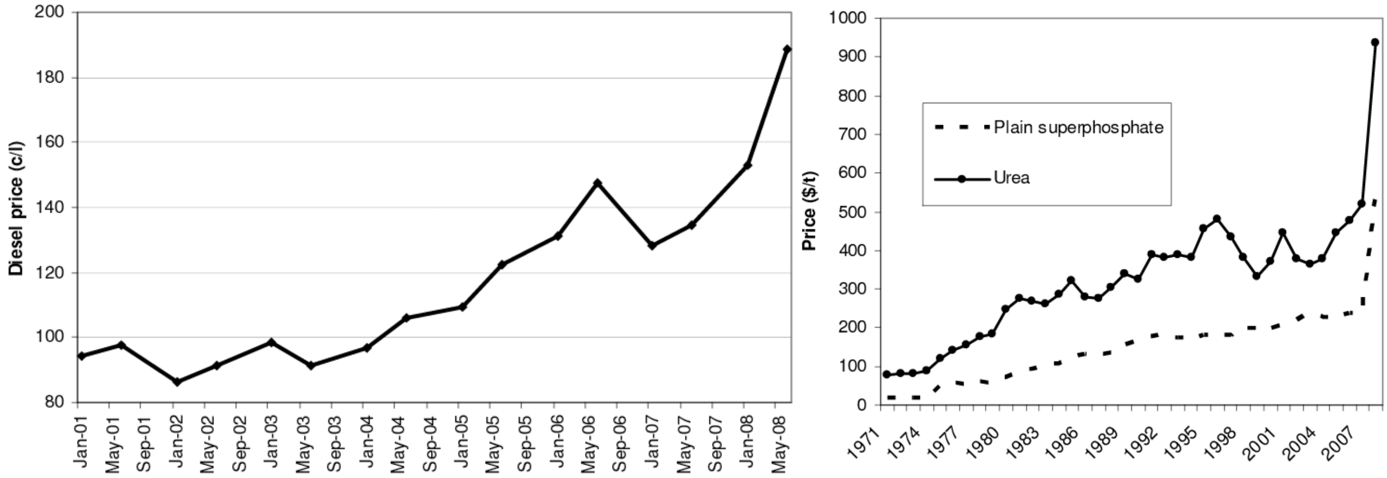


Figure 5 - The price of diesel in the WA Wheatbelt, 2001 to 2008 and prices of plain superphosphate and urea, 1971 to 2008. Based on FuelWatch historical prices & data from ABARE & CSBP. Source: Kingwell and Pannell, 2008.

Farmers are spending more money each year, and this trend is expected to continue in the years to come (Kingwell & Pannell 2008; Kingwell & Pannell, 2005; Wheatbelt NRM, 2013b). Until recently this increase in costs was balanced by an increase in income through increased crop yield, but this is no longer the case (see figures 7 and 8) (Ellis, 2016; Kingwell & Pannel, 2008; Planfarm & Bankwest, 2014). Yields have stabilised and become significantly more variable, and wheat prices are more volatile and not increasing either. These trends appear to have resulted in a steady decrease in farm profitability. This phenomenon is referred to as the cost-price squeeze (McKenzie, 2000; Gruen, 1962).

Figure 6 - Global wheat price in USD per bushel, source: macrotrends.net

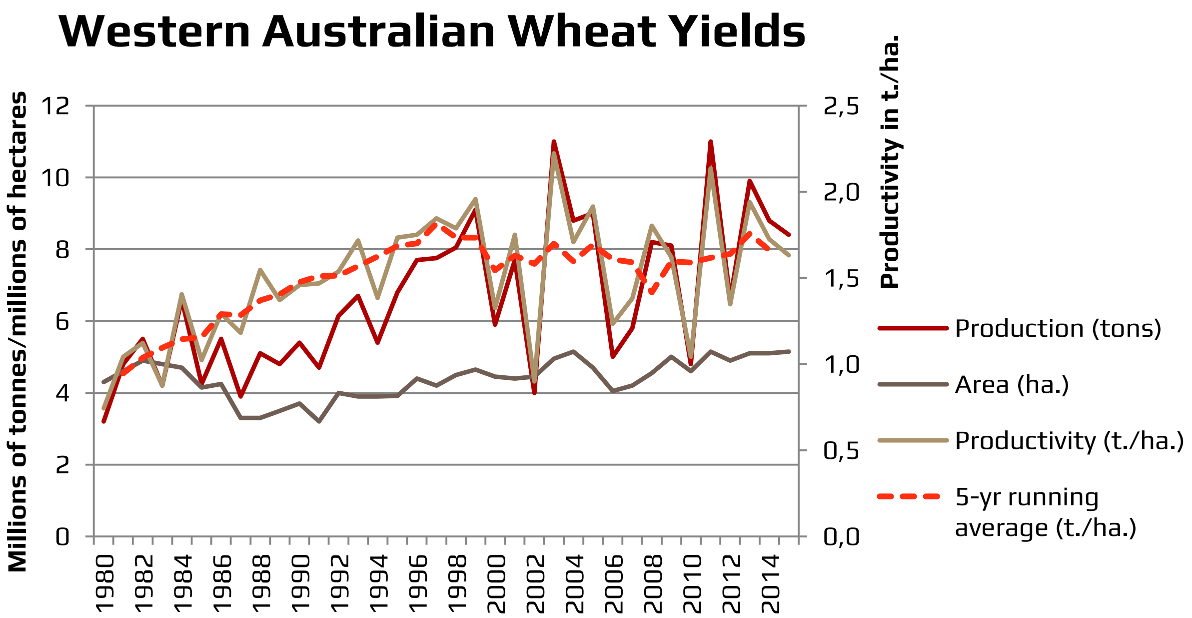


Figure 7 - Wheat yields and productivity in Western Australia, based on data from DAFWA. Wheat productivity has risen steadily during the 1980s and early 1990s, but has since stabilised and become more volatile

1.3.3 Socio-economic trends

Under these conditions of increasing cost and stagnated and highly variable yield, the weakest farmers are not able to make a profit anymore (Planfarm & Bankwest, 2014; Farmanco, 2014) and are forced off the land (McKenzie, 2000). Other businesses may try to increase profitability through capitalising on economies of scale (Kingwell & Pannell, 2008). They increase their scale of operations and take over (parts of) the farms that have foreclosed. There has been a steady increase in farm size over the last few decades. Out of 13,106 farms in the Wheatbelt in 1970, only 38% remained in 2013, while the area under farming has remained more or less the same (Ellis, 2016).

This scale increase has had a stark effect on rural job availability. Being the largest direct employer at 48% (Wheatbelt NRM, 2013b), job provision in agriculture dropped with 12% in the Avon River Basin (which covers approximately half of the Wheatbelt) in the period between 2001 and 2006 (Wheatbelt NRM, 2013b). Most rural towns saw 7-35% of their residents leave permanently between 1981 and 2001 (Tonts, 2004). This development has the potential to become a downward spiral because certain population thresholds have been identified below which essential social services, such as medical and education facilities and police stations, tend to shut down, making the town less attractive to live and potentially causing more people to leave (Wheatbelt NRM, 2013b). This has also resulted in the fact that inspiring younger generations to become farmers and finding qualified personnel are two major challenges for farmers in the Wheatbelt (Kingwell & Pannell, 2008).

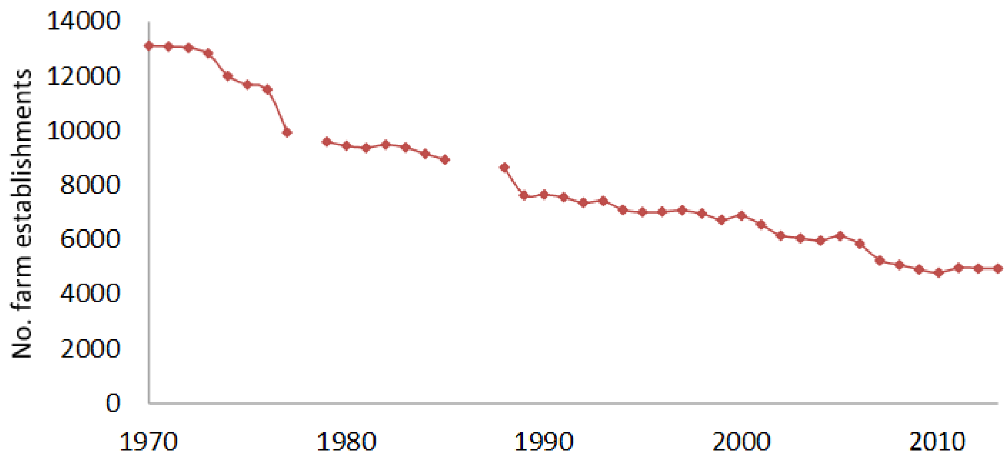


Figure 8 - Number of farms in the WA Wheatbelt. Based on data from the Australian Department of Agriculture and Water Resources. Source: Ellis, 2016

1.3.4 Sustainable agriculture

The solution for many of the problems facing farmers in the WA Wheatbelt does not lie in problem-specific, technical measures, because they do not address the root cause of the problems. A more profound change in the way WA farmers perform agriculture may be necessary. One source goes as far as stating the Wheatbelt may have reached a tipping point, which necessitates transformational adaptation for the region to continue as a functioning social, ecological and economic unit (Ellis, 2016). If such a transformation does not take place, both an increase in the extent and severity of soil constraints and a steady fall in the number of farms will continue (Kingwell and Pannell, 2005). It is unlikely that mere technical developments will provide more than temporary fixes, so a sustainable approach to agriculture suitable to Wheatbelt conditions needs to be designed.

The term ‘sustainable agriculture’ generally refers to agricultural practices (cropping and husbandry) that can be sustained indefinitely. The FAO states that sustainable agriculture requires the protection of rural livelihoods (UN FAO, 2014). The United States Congress defined sustainable agriculture as follows:

"*the term sustainable agriculture means an integrated system of plant and animal production practices having a site-specific application that will, over the long term:*

- *satisfy human food and fiber needs;*
- *enhance environmental quality and the natural resource base upon which the agricultural economy depends;*
- *make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls;*
- *sustain the economic viability of farm operations; and*
- *enhance the quality of life for farmers and society as a whole*."

(United Stated Department of Agriculture, 2007)

The current common approach to agriculture in the Wheatbelt can be described as industrial agriculture. As with sustainable agriculture, there is no single definition for industrial agriculture. Some examples are that industrial agriculture:

- "*is a form of intensive agriculture that relies heavily on industrial methods, characterised by innovations to increase yield*" (Wikipedia)
- "*is a form of modern farming that refers to the industrialized production of livestock, poultry, fish and crops. The methods of industrial agriculture are technoscientific, economic and political*" (New World Encyclopedia)
- "*is a modern form of capital-intensive agriculture in which machinery and purchased [goods] are substituted for the labour of human beings and animals*" (Economy Watch)
- "*is based on agro-industrial inputs. [...] Its major features are improved genetic varieties, chemical fertilisers, herbicides, pesticides, pharmaceutical chemicals, feed concentrates, pelleted feed and mechanisation.*" (FAO)

Industrial agriculture can often be characterised by specialisation in monocultures (in rotations), a high machinery intensity/low labour intensity, commodity farming, susceptibility to pests, weeds and diseases, and a dependency on technological developments and inorganic inputs to increase yield and profits.

From the previous sections it follows that industrial agriculture in the WA Wheatbelt is not sustainable, as it is putting rural livelihoods at risk through loss of employment and the cost-price squeeze, it reduces the quality of life of farmers and society as a whole through the rural flight and related closing of essential social services, and it generally degrades the environment and the natural resource base it depends upon through unintended side effects, causing soil constraints to extend and become worse. It cannot be sustained indefinitely.

There is a range of different approaches to agriculture, of which organic, biodynamic and industrial may be the best known ones. All these approaches are difficult to order into some kind of hierarchy, because they vary significantly in their characteristics. Some of these approaches are used to describe a set of tools or practices, others are or have become a list of criteria for certification, others again are holistic views to agriculture that can go as far as being a lifestyle. There can be many overlaps; for instance, biodynamic agriculture and organic agriculture have many principles in common.

Out of all these terms, ecological agriculture was chosen to explore as a potential solution in this study. Defined as a system that involves "*building the strengths of natural ecosystems into agroecosystems, purposely disturbed to produce food and fiber*" (Magdoff, 2007), ecological farming regards the farm as an ecosystem, and tries to maximise ecosystem functions through employing practices that grow healthy plants with good natural defences, stress pests and enhance and stimulate populations of beneficial organisms. Ecological farming systems have been proven in the past to be capable of removing soil constraints, improving yield, eliminating the need for inorganic farm inputs and pesticides, herbicides and fungicides all the while increasing yields (McMahon, 2016). Ecological systems can qualify as organic systems, they can employ methods from biodynamic farming, they can fall into the category of conservation agriculture and may employ regenerative practices and/or techniques borrowed from permaculture (which itself can qualify as an ecological system). It was found a very comprehensive system in terms of principles and guidelines without being too stringent on what practices and products can and cannot be used, while showing potential to be at least as profitable as industrial agriculture due to decreased costs and increased yields under certain conditions.

Ecological systems with their imperative perennial plants can help solve many environmental problems and soil constraints, storing carbon, holding and using water and preventing nutrient leaching (Doane et al., 2016, Farrington & Salama, 1996, Doit, 1999, Pannell & Ewing, 2006), they are much more resilient to weather extremes, and arguably through diversity of products much more resilient to economic extremes as well (Altieri, Nicholls-Estrada, Henao-alazar, Galvis-Martínez & Rogé, 2015; McMahon, 2016; Mirova, 2016). Finally, ecological systems can be sustained indefinitely.

Ecological systems are potentially scoring well on all three 'pillars' of sustainability: environmental sustainability, social sustainability and financial sustainability. Despite it seeming a win-win-win scenario however, only a few farmers in the Wheatbelt farm ecologically at present.

1.4 RESEARCH SCOPE

The purpose of this study is to gain insight in the functioning of and the potential opportunities that are provided by ecological farming systems, as a first step towards finding a sustainable agricultural system that could turn around the current trends of degradation and loss of family farms and communities in the WA Wheatbelt. As explained previously, ecological agriculture was chosen as a promising option to explore in this context. The study employs a scenario-based approach to test whether ecological agriculture may indeed offer an alternative that is preferable over current practices. This is done by comparing four alternative, ecological farming systems and a baseline scenario on the three pillars of sustainability: environmental, social and financial sustainability (Lozano, 2008). The baseline scenario consists of conventional, industrial cropping as it is currently performed by many farmers in the region. When the most sustainable alternative has been selected, a brief additional analysis is performed to explore barriers that potentially stand in the way of wide-scale adoption of this alternative in the Wheatbelt region and explore ways to remove them.

1.4.1 Research Questions

Given that ecological agriculture may be a solution that solves the social decline in the Wheatbelt at the source, this research focuses on the question how this approach to farming could best be implemented on a large scale in the Wheatbelt, with the following research questions (*main* and subquestions):

How can agriculture in the Western Australian Wheatbelt be practised in an environmentally, socially and financially sustainable manner? Are ecological farming systems more sustainable than industrial agriculture?

1. Which alternative system is most profitable in the long run? Since farmers are dependent on the system for their livelihood, it must be profitable. If some farmers are already facing financial struggles with industrial cropping through the cost-price squeeze, an alternative system needs to be more financially attractive or he/she will not switch.
2. Which alternative system provides most jobs? Since the lack of jobs may be an important link between land management and the health of the community (as explained in section 1.3.3), an alternative should be able to provide significantly more jobs than industrial agriculture in order to revitalise communities and stop the downward spiral.
3. Which alternative system provides most environmental benefits? Currently environmental problems are having detrimental effects on farms, an attractive scenario is able to reverse these environmental problems.

1.4.2 Research Goals

The research goal for this study is to do a preliminary study into the possibilities for the establishment and wide-spread adoption of sustainable agricultural systems in the Western Australian Wheatbelt. It is a broad, brushstroke type of analysis, meant to give direction to follow-up research which will be able to focus on more specific subjects. As a consequence, certain generalising assumptions had to be made for this study to be performed. The study is by no means exhaustive, but does provide useful insights into the characteristics of ecological farming systems in the context of the Wheatbelt, and presents a novel holistic way of viewing the region’s challenges which may form the basis for lasting, truly sustainable solutions.

Chapter 2 explains what research methods were used for this study. Chapter 3 presents the results of the whole-farm modelling exercise and the connected robustness analysis. Chapter 4 discusses these results and uses those to select the most sustainable alternative. Chapter 5 concludes the report and provides some recommendations for further action. The Appendices contain additional material on the interpretation and establishment of each farming scenario and an overview of some of the interview protocols that were used in this study.

2 METHODOLOGY

This chapter provides an overview of the research methods used. The first paragraph describes how a scenario-based approach was developed to compare different possible future pathways for farming in the Western Australian Wheatbelt. This comparison was made using whole-farm simulation modelling as a tool. The second paragraph describes the study setting, explaining why case study locations were selected and setting forth several important assumptions that were made. The third paragraph describes how the scenarios were analysed on their sustainability.

2.1 APPROACH

This study takes on a farm-scale scenario-based approach in order to compare different future pathways on their sustainability. The baseline is a modern conventional farm, and the farmer faces a choice between either continuing with industrial cropping (current conventional land use) or transitioning to one of several alternative ecological farming systems. Each resulting choice is a scenario that is studied for two case study locations, which were selected to get some perspective on how representative the conclusions from this study are for the entire Wheatbelt region. Each of the scenarios at each case study location is assessed on three main sustainability criteria, at a point in time thirty years after the farmer's decision was made. The sustainability criteria are indicators of the three pillars of sustainable agriculture: environmental sustainability, social sustainability and economic sustainability (USDA, 1996; Hutchins & Sutherland, 2008; Moldan, Janoušková & Hák, 2012). The indicators will be specified later in this chapter. The assessment period of thirty years was chosen to be able to assess the long-term effects of each scenario; there are indications that some ecological farming systems may take many years to mature. Whole-farm modelling was chosen as a core tool for this study. It should be noted that it is impossible to predict thirty years into the future; the results of the analysis should not be interpreted as a prediction but as a an illustration of how each of the farming systems functions.

2.1.1 WHOLE-FARM MODELLING

Whole-farm modelling is a method where all components of a farm system and their interrelatedness are modelled mathematically, and can be used to compare different technologies in farming under uncertain conditions (Torkamani, 2005). There are two kinds of whole-farm modelling, both aiming to understand or assist in farmer decision-making: simulation modelling and optimisation modelling (Pannell, 1996). Because the scope for this study is explorative the choice was made to not go into optimisation research of each scenario. Future research may do that, this study only observes systems that have already been proven to work.

Several modelling frameworks already exist that are or can be used for whole-farm modelling, with varying degrees of complexity. One example is the Model for Integrated Dryland ASsesment (MIDAS) developed in Western Australia, which is used for, amongst other things, optimising farm decision making (Kingwell, 2010?). It contains many modules, modelling crop growth and yield, pasture productivity, livestock reproduction and machinery and management costs. In the context of this study however it was thought to be too complicated to adapt this model to the perennial and woody nature of some of the scnearios, such as the dehesa or the wood products scenario (see 2.2.2). WOFOST is another model, which was developed by Wageningen UR in the Netherlands. It was designed for explaining crop growth and yield in annual crops (Wageningen UR, 2017). Although it has a wide range of users and it has been adapted to many different regions around the world, adapting it to perennial crops and adding in livestock and farm management was thought too complex for this study. A simpler, spread sheet-based modelling approach was chosen in the end.

2.1.2 Other approaches

Several other methods were also considered for this study, methods which are designed to determine what farming systems or what farming practices are most efficient, profitable or sustainable. One example is regression analysis. Such research usually consists of surveying a large amount of farmers with a standardised questionnaire, which not only contains questions about the practices of interest but also questions on all kinds of other factors that may have an influence on farm profitability. Through fixed effects regression the researchers are able to control for these variables and confidently determine the consequences of certain practices on profitability. Because of the control for other variables this approach has large explanatory power. For this study, fixed effects regression analysis would be the preferred method because of this. However, this method only works if there is a large group of farmers to get data from. It would have required a large survey to be sent out to ecological farmers throughout the region containing questions on many of their practices, as well as on their specific conditions. The analysis would have been performed based on these data, and would have shown which practices are most sustainable. These practices can then be combined into a single best-practice farming system. Unfortunately, preliminary research indicated that there are too few farmers in the region practising ecological agriculture for this method to work.

Another group of researchers has developed a slightly different approach, and tries to explain the change in land use over time through changes in environmental conditions as well as changes in policy and farm economics (Diogo, Koomen & Kuhlman, 2015). The researcher tries to understand the decisions land managers make. There are two reasons this approach did not suit this study however; the scope of the analysis and, again, data availability. This study does not attempt to explain current or future land use changes on the scale of the whole Wheatbelt, rather it is trying to compare different systems on a farm scale. Secondly, there currently are not enough ecological farmers in the region for such an analysis.

2.1.3 Scenario definition

For the scenario-based approach used in this study first several alternative systems were selected that seem to do well in WA Wheatbelt conditions. A farming system in this context means an interconnected set of conditions and related farm practices and enterprises for which a certain development strategy is appropriate (UN FAO, 2016; Liang, 1998). The term ‘system’ stresses the interrelatedness of its components (National Research Council (U.S.A.), 2010). The final selection of ecological farming systems represents a complete range of configurations with uprising vegetation; varying from pasture/cropping with no woody vegetation through a shrubby pasture and a silvopastoral system to a dense (agro)forestry system. Such a range of systems was selected because there is no one ‘optimal’ system for the Wheatbelt yet; so to avoid coincidentally picking a very unfavourable ecological system to represent the entirety of ecological agriculture in this analysis, multiple systems were chosen. Also, this way the analysis may provide insights into what type of system is most suited to the conditions in the Wheatbelt, and is therefore worthy of follow-up (optimisation) research. It is assumed that the current common form of industrial system is an optimised example of industrial agriculture.

The farming systems to be assessed were compiled and conceptualised after a round of farm visits and interviews in the study area. For the baseline scenario extensive field visits and farm tours were undertaken to understand the basic functioning of an average conventional Wheatbelt cropping business. These insights were used to set up the structure of the whole-farm model. Industry average reports, such as the Planfarm Bankwest Benchmarks, were used for input data and for verifying the outputs. The cropping season of 2013 was taken as a benchmark because that was the most recent season complete data was available for at the time of the analysis.

For the building of the ecological scenarios a different approach had to be used; as mentioned before there are very few ecological farmers in the Wheatbelt so there is no ‘average’ ecological farm. This led to the choice to use a slightly more hypothetical approach and, rather than use the exact layout of the visited farms, build conceptual farming systems based on components that have been tried, tested and proven in the WA Wheatbelt and on these farms, and on data and insights gathered from scientific literature and other sources. In order to build the structure of these farming scenarios more farm visits were undertaken to understand the underlying principles of ecological farming in the setting of the WA Wheatbelt, which were documented in small reports. Using existing networks as a starting point and getting referred to other key experts in the field the author was able to visit 18 frontrunner ecological farmers, and talk with 8 policymakers, researchers and government officials. Interviews were held with researchers and government officials who have experience with conventional and sustainable farming practices in the Wheatbelt region with the same objective. Based on these insights, best practices from different farms were combined to build the scenarios defined in this study.

2.1.4 Data collection

After building the scenarios a second round of interviews followed, this time more detailed. They were specifically designed to 1) capture more details to fine-tune the models and 2) to collect data for inputs, such as productivity and costing figures, and 3) to gather figures which could be used to broadly calibrate the models. These data were then compared to the data from the other interviewees, as well as compared to data from scientific literature, field trial results and other literature to assess their validity. For most inputs value ranges were constructed using this range of data; then a conservative approach was used; consistently selecting the more unfavourable values.

Measures were taken to tackle large uncertainties arising from combining farming system components that have not been used in exactly the same configuration under the same conditions before, such as combing a successional, rotational grazing strategy with an oak savannah above native Western Australian perennial pastures. One way in which this was achieved was through thoroughly checking the data gathered from the field to build the models with data from many other sources. Data ranges were constructed based on all this information, and for all ecological scenarios a conservative approach of taking the most unfavourable data points in those data ranges as inputs for the whole-farm models was chosen. A third measure was to perform a robustness analysis, which should point out any sensitivities or areas of large uncertainty which may follow from the chosen approach.

2.2 STUDY SETTING

This section discusses the basic setting of the study. The scenarios that have been selected for the analysis based on the methodology described above are described in broad terms, the case study locations are described and key assumptions that were made in this study are named and explained.

2.2.1 Scenarios

Four ecological farming scenarios (**pasture cropping**, **perennial grazing**, **dehesa** and **wood products**) and a baseline business-as-usual (**BAU**) scenario of industrial cropping were constructed. This section describes several key characteristics of each scenario. A more detailed description of each farming system and its establishment strategy is attached in the appendix.

Conventional cropping (BAU) is used as a baseline in this analysis, and is designed to represent an average Wheatbelt industrial cropping business. It is a 100% cropping enterprise, with cropping during winter and fallow paddocks with crop stubble during summer. The main focus is cereal production (wheat, oats and barley) but a rotation is necessary to keep weed, pest and disease pressure at bay and give the land a rest (Paterson, 2015). A common rotation on soils such as in the case study locations is canola – wheat – lupins – barley – pasture (Stuart McAlpine, personal communication). Both farms have small sections of 'heavy' (clayey) country which supports a more intensive rotation of canola - wheat - barley - pasture. These rotations form the core of the BAU scenario.

Pasture cropping is a system where crops are sown directly into permanent, perennial, native pastures. The pastures are managed using livestock. A leader-follower rotational grazing system seems to work well in combination with perennial pastures (Shepard, 2013), so for this study a relatively simple system consisting of beef cattle, chickens for eggs and sheep for lamb and wool was selected. Cropping straight into pasture (using a disc seeder) has several benefits, if managed properly. The pasture provides 100% year-round groundcover, which prevents erosion and stops weeds. At the same time the pasture is building organic matter and structuring the soil, which has been shown to improve water infiltration, water holding capacity and soil fertility (Warren Pensini, personal communication). Field observations have pointed out that it will not be necessary in most cases to sow these pastures, because native pasture seeds are still present in the seed bank waiting for the right conditions to germinate (Ian & Diane Haggerty, personal communication). This way, the scenario yields significantly more usable biomass than is possible under conventional practices for less costs (Bruce Maynard, personal communication).

The perennial grazing system also relies on perennial, native pastures and employs a similar way of successional, rotational grazing, but does not involve crops. Rather, it is complemented with several endemic shrubs which can serve as fodder and can be planted in several configurations (Emms & Revell, 2015). These shrubs provide the benefits of more nutritious food, cycling of water and nutrients from deeper underground, extended green feed into the summer dry period and a beneficial microclimate that protects both livestock and pasture in extreme weather conditions (Monjardino, Bathgate & Llewellyn, 2014; Monjardino, Revell & Pannell, 2010; Dean Revell, personal communication). It is a livestock-only business.

The third ecological scenario is inspired by a traditional land management system that was developed in Spain for over 2,000 years under conditions similar to those in the Wheatbelt (Alagona, Linares, Campos & Huntsinger, 2013). One trial has been started in the Wheatbelt several years ago (Rampling, 2012). The dehesa is an oak savannah with cork oaks, holm oaks and carobs in a perennial, native pasture that is grazed using the same livestock and principles as the previous two scenarios. What sets this scenario apart is that it has a significant microclimate effect, on top of acorns, carob pods and cork as products. The carob pods can be sold or used as fodder, and acorns can be used as a special feed to finish pigs on (not included in this scenario).

The fourth ecological scenario, wood products, does not involve livestock. It is based on an existing business model/initiative that has an aim that contrasts with the other scenarios. Its main purpose is to restore areas to natural forest for permanent conservation; wood products are included mainly to recover costs of restoration and enable quick scaling up rather than for making a profit. The philosophy comes from the notion that large-scale reforestation projects are rare in the Wheatbelt area, while the need for it is high. The reason for this is that it is difficult to make money from reforestation/conservation practices. This significantly limits its scale potential. With this model money can be made from restoring natural habitat, which potentially opens up a large market of investors, significantly increasing its scale potential. With the main aim being conservation it may not be completely comparable with the other scenarios, but with the inclusion of the sales of carbon emission rights as an extra revenue stream (added to the model in section 3.3.3) it may be able to compete with them nonetheless.

Because of distance to sawmills and climate conditions the wood species used differ between the case study locations; in the Arthur River scenario it is timber from Red Ironbark (Eucalyptus Tricarpa), Sugar Gum (Eucalyptus Cladocalyx) and Swamp and Rock Sheoak (Casuarina Obesa and Allocasuarina Huegliana), in Buntine it consists of the wood (for essential oils) and nuts of Sandalwood (Santalum Spicatum). In both scenarios the principle is that of a biodiverse plantation and low-impact harvesting, which means that when the products are harvested, what is left is a native, natural area that remains under permanent conservation. An important point to note is that in the model on which these scenarios are based carbon right sales form an important revenue stream. Because (some of) the other scenarios considered here also have the potential for the storage of significant volumes of carbon and the subsequent sale of emission rights, the decision was made to not include that revenue stream in the first analyses. It will be added to the models in the robustness analysis to examine to what extent the inclusion would influence the results.

2.2.2 Case study locations

Two case study locations were chosen to explore the extent to which differences in precipitation change which scenario performs best. Precipitation was selected as the main spatial variable because it seems the most critical variable in the current conventional agricultural system (Planfarm & Bankwest, 2014). Other factors such as soil type and quality, distance to Perth, effective farm size and on-farm landscape features, were kept constant. Each farming system is modelled for both case study locations based on information on the case study location’s conditions on the one hand, and information on how those conditions change e.g. productivity of certain crops or pasture species. This results in 10 unique scenarios/models in total.

The two case study locations that were selected are located in the western half of the Wheatbelt. One of these locations is located west of Buntine, in the north of the region; the other is near Arthur River in the south. Table 1 summarises some key characteristics for both locations. The precipitation differs both in the total annual amount and the way in which it is spread throughout the year, as can be seen in figure 11. Both locations are characterised by mainly sandy soils with areas of gravel (figure 12; Stoneman, 1990; Stoneman, 1991); Arthur River with sandy duplexes over clay, Buntine with deep sands. Average farm size is larger near Buntine, but because of larger soil constraints (salinity) in that area the average effective farm area that remains is comparable with that in Arthur River, and has been set to be exactly equal in the whole-farm models for ease of comparison.

	Buntine	Arthur River
Average winter low temperature	5.8 °C	5.5 °C
Average summer high temperature	35.3 °C	31.1 °C
Precipitation	318.7 mm	429.2 mm
Farm area	3700 ha.	3400 ha.
Effective farm area	2920 ha.	2920 ha.
Distance to Perth	289 km	233 km

Table 1 - General statistics for the case study locations. Based on data from Australian Bureau of Meteorology

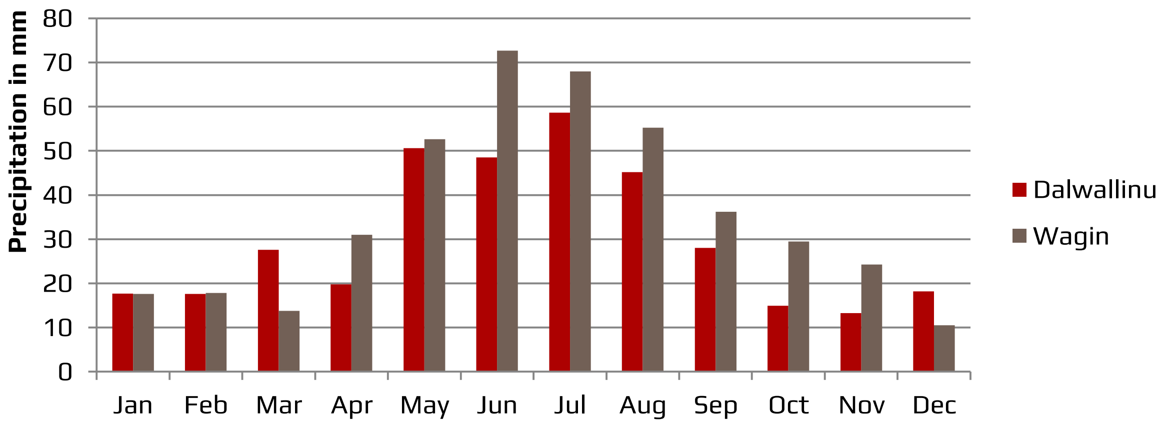


Figure 9 - Average precipitation (1980-2010) for Dalwallinu (near Buntine) and Wagin (near Arthur River). Based on data from the Australian Bureau of Meteorology

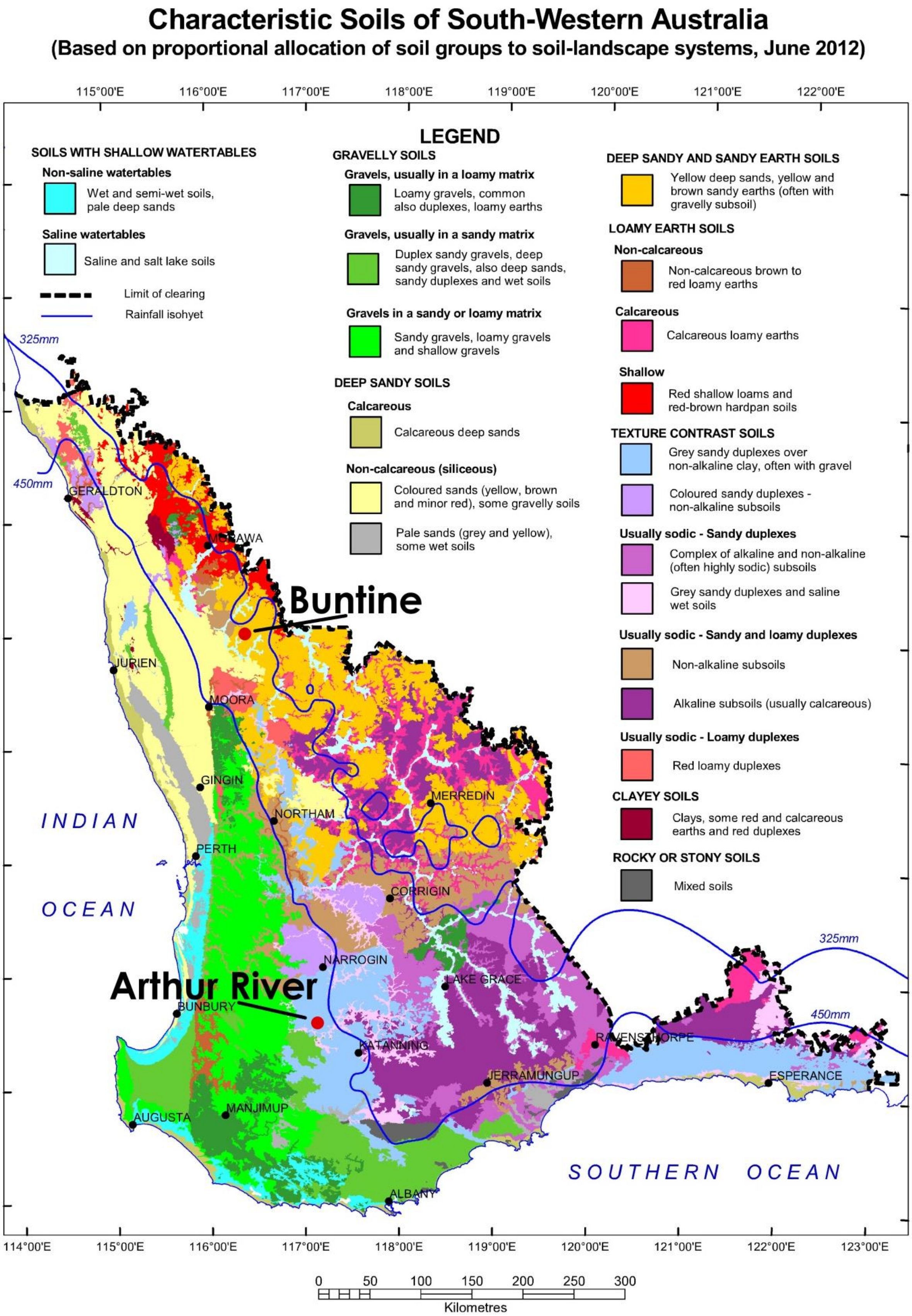


Figure 10 - Characteristic soils and average precipitation of south-west WA, with both case study locations. Adapted from Department of Agriculture and Food, WA (2012).

2.2.3 ASSUMPTIONS

For this study certain assumptions had to be made. The most important ones are shown in table 2.

Assumption/characteristic	**Rationale/explanation**
No inflation	All factor prices are expected to be influenced by inflation in a similar way
No interest/discount rate	Keep analysis comparable across scenarios; discount rate differs depending on risk and not all scenarios face equal risk
No future price fluctuations	Today's prices were assumed to hold for all scenarios; it is impossible to predict future price fluctuations accurately
No financing costs	Depend on many other factors than the scenario; discarded for simplification of analysis
No taxes or subsidies	These might fluctuate over time, discarded for simplification of analysis
No feed or water importing from off-farm	This is a constraint; otherwise large off-farm (environmental) costs may not be accounted in the analysis
No climate change	Not in the scope of this research project
No weather extremes, droughts	Despite having major effects on farms in the study area, these events and their effects are unpredictable. They were assumed to be no factor
No legal constraints	Some regulations may prohibit ecological farming practices or the sales of ecological products. It is assumed that this is no factor

Table 2 - Summary of assumptions in this study

For the modelling, some technical assumptions were necessary, like assuming that inflation, interest/discount rates or taxes and subsidies have no effect on the results. This was necessary to make sure that differences in e.g. financial performance were solely due to the different management systems rather than differences in e.g. subsidy levels. In other words, only the scenarios and location were kept as a dependent variable, other variables were held fixed. The effect some of these assumptions have on the outcome is explored in a robustness analysis.

Another important assumption is that today's (2016) figures (prices, productivity levels and required input quantities) were assumed to remain constant for the runtime of the models. This inherently assumes no technological advances, no efficiency increase through increased knowledge and experience, but also no increased (inorganic) input costs. However, since the latter has been identified as a major threat in the years to come (Kingwell & Pannell, 2008) this assumption was explored in a robustness analysis.

2.3 ANALYSES

The most sustainable scenario for each case study location performs best overall on three different sustainability criteria: environmental sustainability, social sustainability and economic sustainability. Each of these three criteria will be analysed separately using their own indicators; the results of which will form the basis for a discussion where the most sustainable scenario is determined. This section expands on which indicators were chosen for each analysis and what tools are used to perform the analysis.

2.3.1 ENVIRONMENTAL SUSTAINABILITY ANALYSIS

The environmental sustainability was performed based on principles from the field of environmental impact assessment. Environmental impact assessments are often used as a planning tool, "*to analyse the expected environmental effects of a proposed project and its alternatives*" (Ortolando & Shepherd, 1995), for example in civil engineering. It fits the hypothetical nature of the different scenarios considered in this study well. There are different approaches within the area of environmental assessment, of which environmental impact assessment is one (Payraudeau & Van der Werf, 2005). The core of the environmental impact assessment approach is that one or more environmental objectives which are to be achieved are defined, from which suitable indicators are derived (Van der Werf & Petit, 2002). These indicators are preferably based on measurable effects of, in this case, agricultural practices.

Indicators for environmental impact assessments can relate to local, regional or global effects. This study examines one farmer making a choice between different future pathways. This one farmer will not have any noticeable global effect, and low regional effect. Indicators will therefore be related to local effects only. Objectives are generally designed using the following nine environmental impact dimensions (Ran, Lannerstad, Barron, Fraval, Paul, Notenbaert, Mugatha & Herrero, 2015).

- Water (quality & quantity)
- Land use
- Nutrient cycling
- Energy use
- Eco-toxicity
- Greenhouse gas emissions
- Waste products and emissions
- Soil health
- Biodiversity stock
- *Use of non-renewable resources*

The dimension 'use of non-renewable resources' was added to the list, because it was deemed as important as the other dimensions for the assessment of the environmental effects of certain practices, but not reflected enough in the dimensions that are named by Ran et al. (2015). Greenhouse gas emissions were removed because the effect of a single farmer is not noticeable. From these environmental impact dimensions indicators and objectives should be formulated that fit the purposes and conditions of the study. A difficulty here is that the systems considered have not been employed as such in the Wheatbelt, let alone tracked and monitored through the transition. This means that it is impossible to be quantitative in predicting the effects of each system on the environment; rather these predictions will have to be based on observations of current systems in the field and on the increasing amount of (peer-reviewed) literature that is appearing on the effects of industrial and ecological agriculture on the environment. Only relative (qualitative) statements can be made, reasoning from the way each system component has been proven to work, but that is not a problem since the scope of this study is only to perform a brushstroke analysis.

The inability to measure effects quantitatively also has consequences for the specific targets that are set for each indicator; instead of achieving concrete targets each scenario should achieve the highest or lowest effect, depending on the dimension. These objectives have been denoted by arrows in the summation of indicators below; an upwards arrow means that high values for the indicator are better, a downwards arrow means that low values are desired.

The indicators were selected to represent the entire field of environmental impact dimensions, while being suitable for description in broad qualitative terms. Because of the impossibility of taking measurements the analysis will be of a descriptive nature, describing for each scenario what the expected outcome for each indicator would be on a local, regional or global scale should the farming system in the scenario be adopted on a large scale. Relative scores will be given to each scenario on the basis of this analysis, and the results will be tabulated so the scenario can be chosen which is most environmentally sustainable. The following indicators were used to describe the environmental effects of each farming system.

- Water quality ▲
- Water quantity ▲
- Soil erosion ▼
- Soil constraints ▼
- Natural fertility ▲
- Agricultural biodiversity ▲
- Natural biodiversity ▲
- Habitat provision ▲
- Disturbance ▼
- Emissions ▼
- Use of non-renewable resources ▼

2.3.2 SOCIAL SUSTAINABILITY ANALYSIS

Many attempts have been made to develop a methodology for assessing the social aspect of sustainability, but no consensus has been reached on a methodology or set of indicators yet (Hutchins & Sutherland, 2008). Some examples of dimensions or indicators of social sustainability that are used in literature are equity, employment, health, security, education levels, research and development, community attitudes, cultural integration, political participation, community responsibility and community action (Hutchins & Sutherland, 2008; Roth, 2010; McKenzie, 2004). Which set of indicators is used varies between studies, and there is no best practice method (Colantonio, 2007). Many of these indicators, such as community attitudes or political participation, can only be measured in a real-world situation, which makes them unsuitable for the scenario-based approach in this study.

Another field of research which is connected to social sustainability of agricultural practices comes from (rural) sociology. This field concerns the study of the so-called Goldschmidt hypothesis or theorem, which was named after its conceiver who first published about it in 1946 (Goldschmidt, 1946). The Goldschmidt hypothesis states that there is a direct negative correlation between the well-being of rural communities and the scale of farming that surrounds them (Lobao, Schulman & Swanson, 1993). Although having been tested numerous times over the years, the theorem has never been refuted (Green, 1985; Lobao et al., 1993), but no clear consensus exists on the mechanisms through which this effect works. Some researchers explain it through stratification effects (Lobao et al., 1993), some through the fact that people working in larger industrialised farms have less attachment with the communities, which in itself may be explained by having less time for community activities or political engagement. Another important mechanism is the concentrated control over critical production assets and the concentrated political power that comes with it (Lyson & Welsh, 2005).

However, as explained in section 1.3.3 and as suggested in Harris & Gilbert (1982) another pathway may exist which connects farm scale and social sustainability. Increasing farm scale with the intent to capitalise on economies of scale has a direct effect on job availability in agriculture. In rural areas such as the Wheatbelt, agriculture is a major contributor to the local economy and employment, both directly and indirectly through related services. Increasing farm scale thus decreases employment, which means it is not very socially sustainable.

In the case of this study the social sustainability of each scenario can be tested through calculating the labour force required to run each scenario farm. Employment can be predicted reasonably accurately using the scenario-based whole-farm modelling approach since labour costs are part of the financial models. That way, an indication of farm scale and social sustainability can be found. In this case, the higher the employment is, the more socially sustainable the scenario is expected to be.

2.3.3 FINANCIAL SUSTAINABILITY ANALYSIS

Besides environmental and social sustainability, the financial sustainability is examined. After all, farmers are dependent on their farms for their livelihoods. An ecological farming system may prove very environmentally and socially sustainable, but if it does not break even or produce a profit it will not be able to sustain the farmer and any employees and their families. Farm gross profit, also called farm operating surplus, was chosen as an indicator of financial profit. This figure is commonly used in reporting e.g. industry average reports in the Wheatbelt region to compare farm profitability. Farm operating surplus is usually calculated by deducting farm variable and fixed costs from total farm income. This is profit before interest and tax. Net Present Value (NPV) calculations are often used to compare different investments and their returns on longer time horizons, but this requires using an interest/discount rate for its calculation. Section 2.2.3 explains that this study does not involve these interest rates in its calculations, which is why total cumulative cash flow or farm operating surplus was preferred as an indicator over NPV.

To produce farm operating surplus figures the whole-farm models were developed further into spread-sheet-based financial accounting models. This approach also allows viewing the transition from the farmer’s perspective, which helps to understand why he or she makes certain choices (Oviedo, Ovando, Forero, Huntsinger, Álvarez, Mesa & Campos, 2013). The financial accounting models were used to produce a detailed and specified monthly cash flow overview for each hypothetical farm. The financial accounting model is specified mathematically as follows:

$$TI_{s,l} = \sum_{t=1}^{360}\left(\sum FR_{t,s,l} - \sum FC_{t,s,l} + \sum VR_{n_1,t,s,l} - \sum VC_{n_2,t,s,l} + \sum VR_{n_2,t,s,l} + \cdots\right) \qquad (1)$$

With *TI* denoting Total Income, s the scenario, l the location and t time in months. The fixed costs (*FC*) consist of all costs which are considered fixed by farm size and are based on industry averages. They contain overheads, lease costs, machinery and infrastructure replacement and maintenance and a management allowance or imputed salary. Fixed returns (*FR*) are also considered fixed for farm size, to allow for services a farmer might provide irrespective of what is happening on his/her own property. Each farm consists of different farm enterprises (n_1, n_2, etc.) with their own variable costs and returns (VC and VR, respectively). The term between brackets determines the monthly farm cash flow for each scenario and case study location. These are summed over 30 years (360 months) to give the cumulative cash flow which is the sum of farm operating surplus over the years.

The way each whole-farm model is set up is visualised in figure 13. The inputs are controlled from a dashboard, which allows the researcher to easily tweak input data and examine the results on both farm enterprise and whole-farm profitability. The source material also makes clear what the soil and climate conditions are which constrain the possible land uses. From the dashboard the actual land use for each scenario is set, which in turn feeds different modules in the plant and livestock module groups which calculate stock development, productivity and yield, as well as feed and water consumption. The final modules are in the overheads module group, and contain relevant industry average figures on fixed costs adjusted to fit the case study farms.

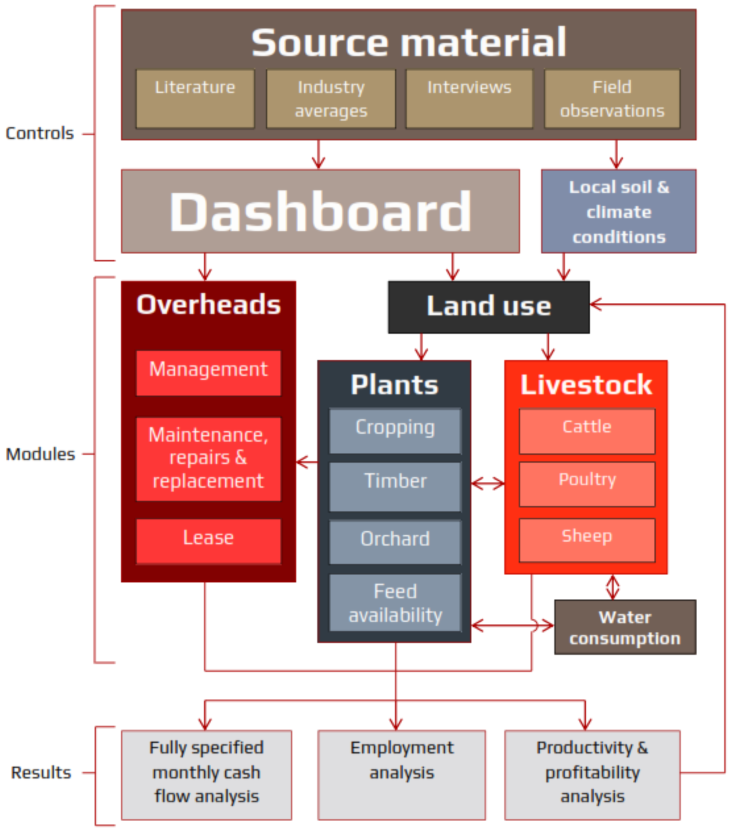


Figure 11 - Visual representation of financial accounting models

All calculations are done on a monthly basis, and allow for tracking the financial performance of each farm enterprise, or of the farm as a whole. For this study certain interactions, such as the surface area allocated to each farm enterprise, had to be set manually, but the models could be developed further to automate these. That would also allow for some optimisation capabilities. The economic sustainability is determined based on the cumulative cash flow/farm operating surplus calculated by the models.

3 RESULTS

This chapter presents the results of the scenario-based analysis. Each sustainability criterion is analysed separately. First, the results from the environmental impact assessment are explained and the environmentally most sustainable scenario is presented. Then, the most socially sustainable scenario is selected on the basis of on-farm employment. Finally, the financial sustainability of each scenario is explored through whole-farm financial modelling, and a robustness analysis is performed to explore uncertainties in the modelling results.

3.1 ENVIRONMENTAL SUSTAINABILITY

Table 3 summarises the relative effects each of the scenarios is expected to have on each of the indicators. The scores denote to what extent the state of each indicator in a future scenario is expected to differ from the current state. For example: water quality in a dehesa scenario is expected to increase significantly (++), while under the baseline scenarios it is expected to decline (-). In the next sections, some important indicators are observed in more detail.

	BAU	Pasture cropping	Perennial grazing	Dehesa	Wood products
Water quality	-	++	++	++	++
Water quantity	+/-	++	++	++	++
Soil erosion	+/-	+	++	++	++
Soil constraints	--	++	++	++	+
Natural fertility	-	++	++	++	+
Agricultural biodiversity	+/-	+	+	+	+/-
Natural biodiversity	+/-	+	++	+	+++
Habitat provision	+/-	+	++	++	+++
Disturbance (sound, vibration)	-	+/-	+	+	++
Emissions	-	+	++	++	+
Use of non-renewable resources	-	++	++	++	+

Table 3 - Overview of environmental impact assessment

3.1.1 Water quality & quantity

Land management can have a significant effect on an area’s hydrology. In a healthy ecosystem, with well-structured soils and ground cover, high rainfall infiltration rates can be achieved and no surface runoff takes place. Underground, the water is protected from evaporation and available for plant use, and only slowly released into surface waters, effectively acting as a big sponge. This way, perennial streams can exist even in climates with prolonged periods of drought. However, as soil structure, soil organic matter and ground cover disappear as a consequence of altered land management, as has been the case in the WA Wheatbelt, the water balance can change dramatically and water will no longer be stored in the subsurface but rather run off superficially. This can in turn lead to erosion, contamination of surface waters and the change from perennial to ephemeral streams. In climates with dry periods, water is no longer naturally available throughout the year and water stress can occur, necessitating technical measures such as building dams to store water and creating swales to capture it when it falls.

From the above it follows that scenarios which build soil structure, build soil organic matter and provide year-round groundcover will score high. Soil structure is built with roots, and can be destroyed through tilling, compaction due to heavy machinery, erosion. Crusting through rainfall impact on bare soil are other ways to reduce a soil's infiltration capacity. As mentioned in chapter 1, industrial agriculture does not provide year-round groundcover, heavy machinery is used, and annual crops do not build large root systems; it is therefore not expected to increase soil structure and thus water quantity. Perennial grasses which are rotationally grazed have proven to be quick at structuring soils (David McFall, Warren Pensini, personal communication), through the extensive root system that is built which partly dies off and is converted into organic matter when the grass is grazed. The systems involving pasture are therefore thought to provide a significant improvement in soil water availability. The wood products scenario is expected to be slightly slower at building soil structure, as the system is not grazed often and the cycle that builds soil may be slower as a result as well. In the long run however, a healthy forest should perform equally well as pasture-based systems. Water quality is expected to decrease under BAU as a consequence of the expected continuation or increase in chemical use described in the Introduction, under ecological scenarios it is expected to improve significantly through the ceasing of chemicals use and the change in water flow from superficial to subsurface.

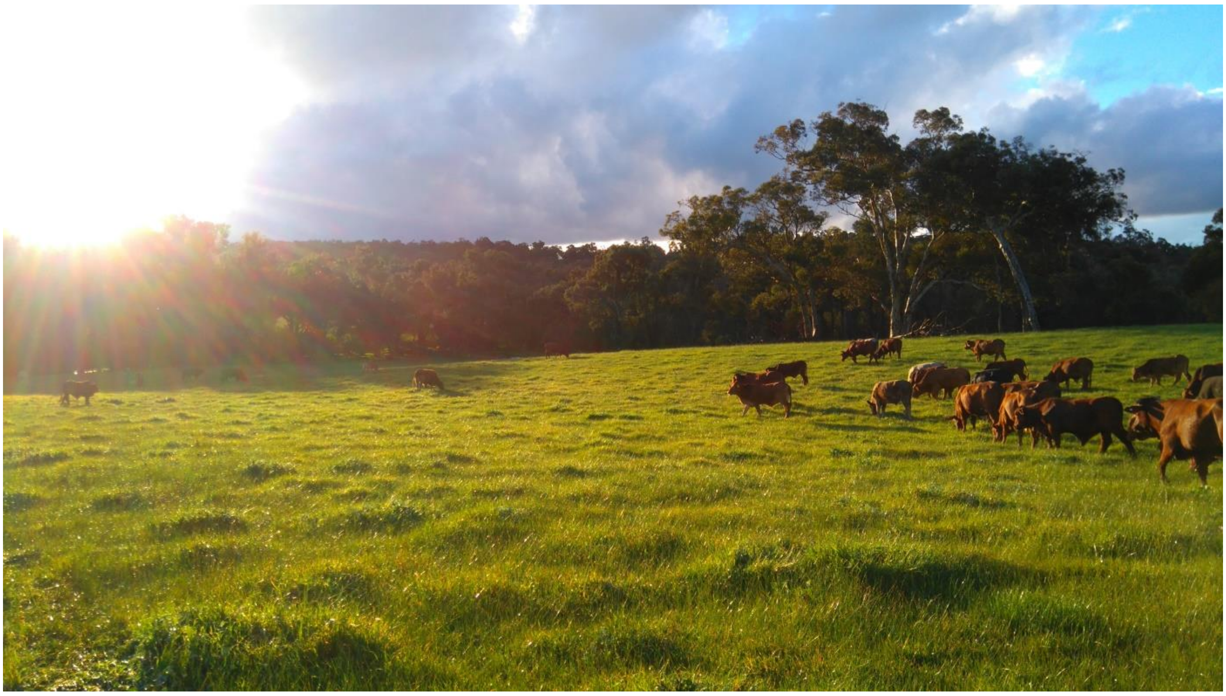


Figure 12 - Beef cattle in a rotational grazing system near Boyup Brook, WA

3.1.2 Soil & Fertility

Soil erosion is expected to stay at similar rates under BAU. Although no-till practices have been adopted by over 90% of farmers in the region (Llewellyn & D'Emden, 2014), there still is only little groundcover during a large part of the year, allowing rainfall events and wind to continue eroding topsoil. Erosion rates are expected to decrease with permanent groundcover (all ecological scenarios), and decrease to a minimum when uprising vegetation is concerned. This as a result of their deeper roots, which can prevent erosion through water even on steep slopes, and of their higher wind speed buffering capacity.

As mentioned in the introduction, soil constraints are expected to continue to increase in extent and severity under the baseline scenario. For many of these constraints, both the soil structure and the soil organic matter content have been demonstrated to be key controlling factors (Reeves, 1997). Pasture-based scenarios have shown to be capable of building soils and reducing these constraints significantly within a few years (Ian & Diane Haggerty, David McFall, personal communication). The wood products scenario is expected to be slower at building organic matter in the soil, and therefore scores slightly less well.

Natural fertility of the soils is dependent on the health of soil microbiology and the presence of soil organic matter (Reeves, 1997; Tiessen, Cuevas & Chacon, 1994). Natural fertility of soils is therefore expected to decrease further under the baseline scenario, while the ecological scenarios can improve the natural fertility. Pasture-based scenarios are expected to perform better than the wood products in this because of their higher organic matter building capacity and their involvement of livestock, the manure of which can stimulate soil microbiology as well.

Figure 13 - Waterlogging and erosion in an industrial cropping paddock

3.1.3 Biodiversity & Habitat

Biodiversity in these systems can be divided into two types: agricultural biodiversity (diversity of crops/livestock) and natural biodiversity (diversity of native/non-productive species). In terms of agricultural biodiversity, both the baseline scenario and the wood products scenario have a variance of about 4-5 productive crops, while the other systems boast more diversity in crops and in livestock. The natural biodiversity of the wood products scenario is expected to be very high, with the native understory and non-productive trees and the conservation aims of the scenario. Natural biodiversity in the baseline scenario will not change much from the current state, which is very low. The perennial pastures, shrubs and oaks in the pasture-based scenarios are expected to facilitate more species, but not nearly as much as the wood products scenario.

The habitat provision is along similar lines. The BAU scenario only provides some habitat while the crop is growing. Pasture cropping provides habitat year-round, but only in tall grass and when the crop is growing, the perennial grazing scenario provides habitat in the shrubs, and the dehesa scenario provides habitat in the treetops. Only the wood products scenario provides habitat at all (ground, shrub and treetop) levels.

3.1.4 Most environmentally sustainable

In this case it is difficult to state which scenario is the overall best performer on environmental sustainability. The end results would be calculated from the individual indicator, but some indicators may be more important to the reader than others. This would normally be solved by giving each indicator a certain weight. The choice was made to not give weights in this study to allow decision makers to assess for themselves which indicators they value most. However, with all weights equal to 1 some conclusions can be made. It is clear that industrial agriculture is the least environmentally sustainable option. The wood products scenario scores best, closely followed by perennial grazing and the dehesa, the latter of which includes exotic plant species which explains the small difference in scores. Pasture cropping's lack of habitat provision puts it in the fourth position. However, all ecological farming systems appear to be capable of improving their environment, while BAU is expected to further degrade it.

3.2 SOCIAL SUSTAINABILITY

On-farm employment was chosen as an indicator for social sustainability. Through employing more people farmers may be able to help revitalise rural communities throughout the region. Job availability on-farm was calculated in the financial models which were used for the financial analysis, as labour costs are important costs for a farm business. The results are presented in figure 16.

The business-as-usual scenario provides more or less constant jobs for 2-3 people or full-time equivalents (FTE). This does not include contracted work, for example carting the harvest to depots. This trend is not consistent with the observed trend of decreasing job availability through scale increase. This is a result of assuming today's numbers for the entire model run.

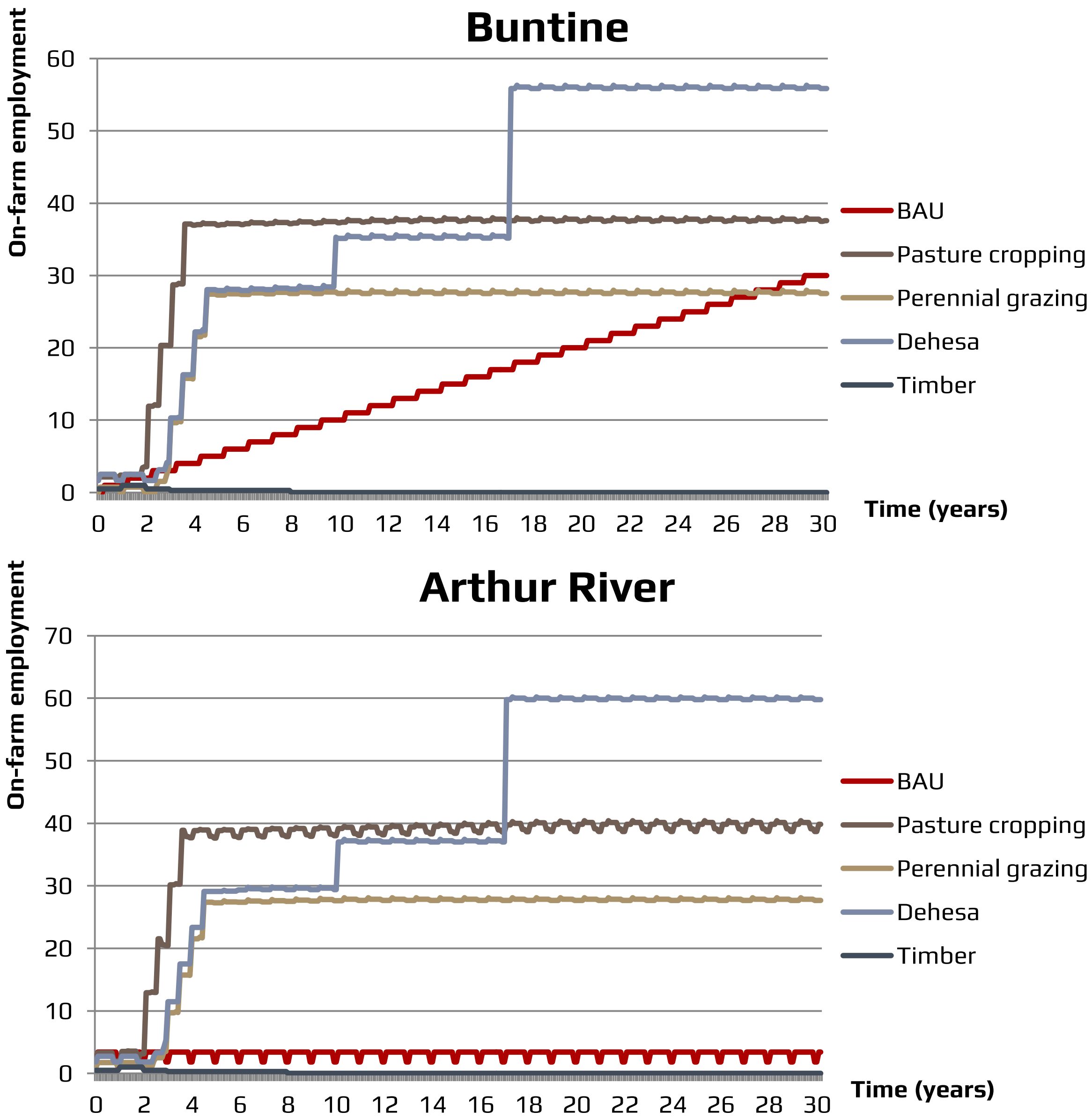


Figure 14 - On-farm employment as indicator of social sustainability

Most of the ecological scenarios manage to employ significantly more people. The wood products scenario provides least jobs; being able to employ 1 FTE only during the establishment phase. The reason for this is that, once the trees are planted, not much labour is required. The actual planting and harvesting in this model are contracting work and therefore not included. One way of internalising this labour would be planting and subsequent harvesting to be spread over multiple years, which would create some jobs. After the final harvest there will be no jobs in this scenario however, since the forest enters conservation.

Perennial grazing provides 28 jobs and comes third. Although pasture cropping initially provides most jobs (approximately 40), after 16 years the oaks in the dehesa start requiring additional maintenance and the dehesa farm surpasses the perennial grazing scenario with 10 jobs. It seems ecological scenarios have the potential to replace costs of machinery and agrochemical inputs with labour costs; employing significantly more people. Over ten times as many people can be employed on the same farm area. This translates to an effective 70-80 hectares per farm worker in a dehesa or pasture cropping scenario (see table 4), respectively, versus 930-960 hectares per worker in a BAU scenario.

Another way of summarising this is by looking at the amount of wages one farm can pay to farm workers. A considerable part of these wages may be spent in the local economy. Table 5 shows the average yearly expenditures on wages. Pasture cropping and dehesa both spend over ten times as much on wages as industrial cropping does. The effect of even one single farm transitioning from industrial cropping to, for instance, a dehesa system on the economy of a rural Wheatbelt town would be significant.

Eff. ha. per FTE @Arthur River	5 yrs	10 yrs	20 yrs	30 yrs
BAU	934	931	929	928
Pasture cropping	155	102	86	81
Perennial grazing	332	161	127	119
Dehesa	283	148	92	71
Wood products	6037	6670	6670	6670
Eff. ha. per FTE @Buntine	**5 yrs**	**10 yrs**	**20 yrs**	**30 yrs**
BAU	967	964	962	961
Pasture cropping	149	99	84	80
Perennial grazing	326	155	123	115
Dehesa	318	155	97	75
Wood products	6021	9146	17460	25774

Table 5 - Effective hectares per labour unit as a measure of on-farm employment

As explained in section 2.3.2, the Goldschmidt theorem states that increasing farm scale has detrimental effects on rural communities. These results show that ecological agricultural systems potentially allow the scale of farming to decrease, and rural communities to be revitalised. Out of the systems explored here, pasture cropping and dehesa seem the most promising examples. In the end, dehesa seems to provide most jobs, and is therefore determined the most socially sustainable scenario in this study.

Avg. wages paid per year @Arthur River	5 yrs	10 yrs	20 yrs	30 yrs
BAU	$ 164.969	$ 165.540	$ 165.829	$ 166.005
Pasture cropping	$ 996.303	$ 1.515.490	$ 1.793.801	$ 1.893.343
Perennial grazing	$ 464.762	$ 956.503	$ 1.211.191	$ 1.297.481
Dehesa	$ 544.954	$ 1.037.899	$ 1.677.480	$ 2.177.365
Wood products	$ 25.520	$ 23.100	$ 23.100	$ 23.100
Avg. wages paid per year @Buntine	**5 yrs**	**10 yrs**	**20 yrs**	**30 yrs**
BAU	$ 158.859	$ 159.443	$ 159.739	$ 159.918
Pasture cropping	$ 1.000.951	$ 1.506.818	$ 1.772.823	$ 1.863.657
Perennial grazing	$ 470.753	$ 989.619	$ 1.251.559	$ 1.340.253
Dehesa	$ 482.765	$ 991.238	$ 1.587.382	$ 2.051.289
Wood products	$ 25.520	$ 16.800	$ 8.800	$ 5.961

Table 4 - Average wages paid over the first 5, 10, 20 and 30 years of the model run. Part of these wages will be spent in the local economy which may in some scenarios receive a significant boost

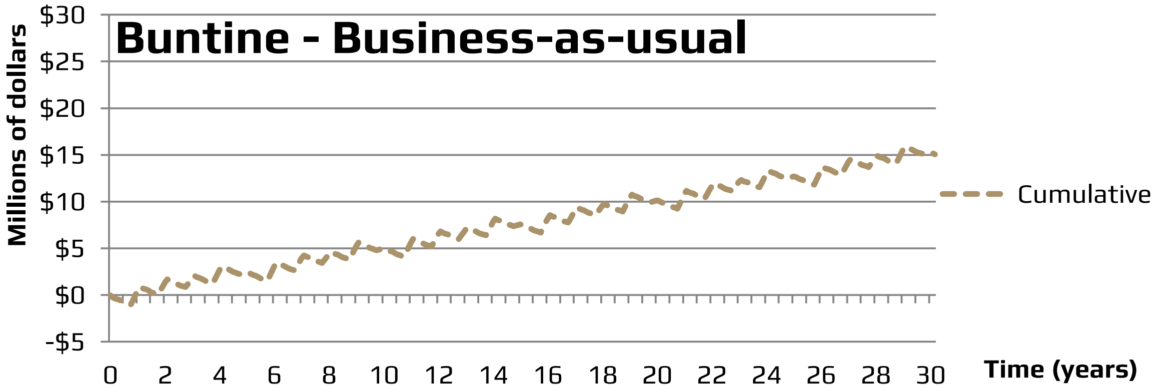
3.3 FINANCIAL SUSTAINABILITY

Each scenario will first be discussed separately in detail, to get acquainted with how each farm system operates over time. Then all scenarios will be compared on different timescales to find which scenario is most financially sustainable in the long run, as well as gain insight in costs and benefits to farmers of transitioning or not transitioning on different timescales. A robustness analysis will test the sensitivity of the results to changes in key variables, after which the basic model specification is adapted. This section ends with finding the most financially sustainable scenario.

3.3.1 Each scenario over time

The baseline scenario is examined first. Figure 17 shows the cumulative cash flow or farm operating surplus for the Buntine and Arthur River case study locations. The scenario is characterised by more or less constant costs throughout the cropping season, followed by a peak cost at and peak revenues after harvest. The five-year crop rotation patterns are clearly visible. In reality, farmers generally have different paddocks in different stages of the rotation, for ease of modelling in this scenario all paddocks are in the same stage. Assuming today's numbers, both farms show a steady increase in cumulative cash flow.

There is a large difference between both case study locations in terms of total farm operating surplus, which amounts to nearly $10 million. This may be explained by the fact that farm input costs in Buntine are almost on par with those in Arthur River, but yields are significantly less. The lower yield can be explained primarily by Buntine receiving less precipitation than Arthur River.



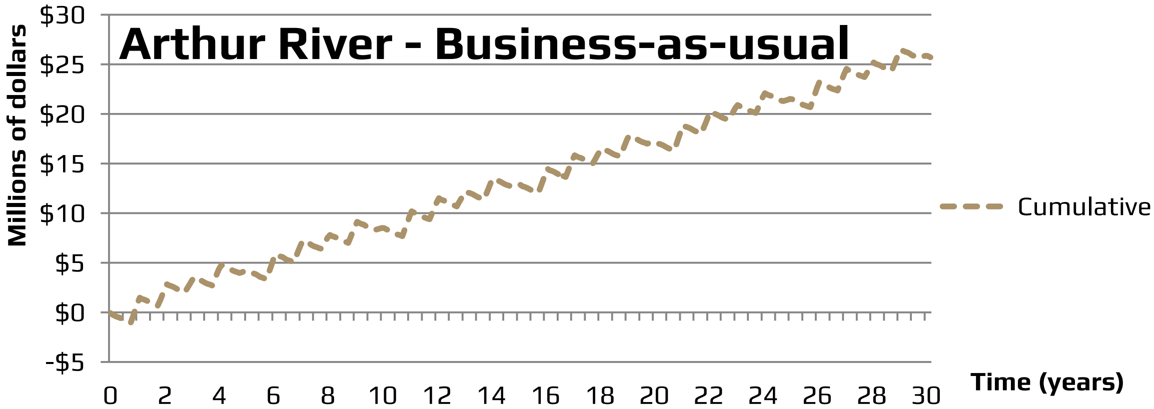
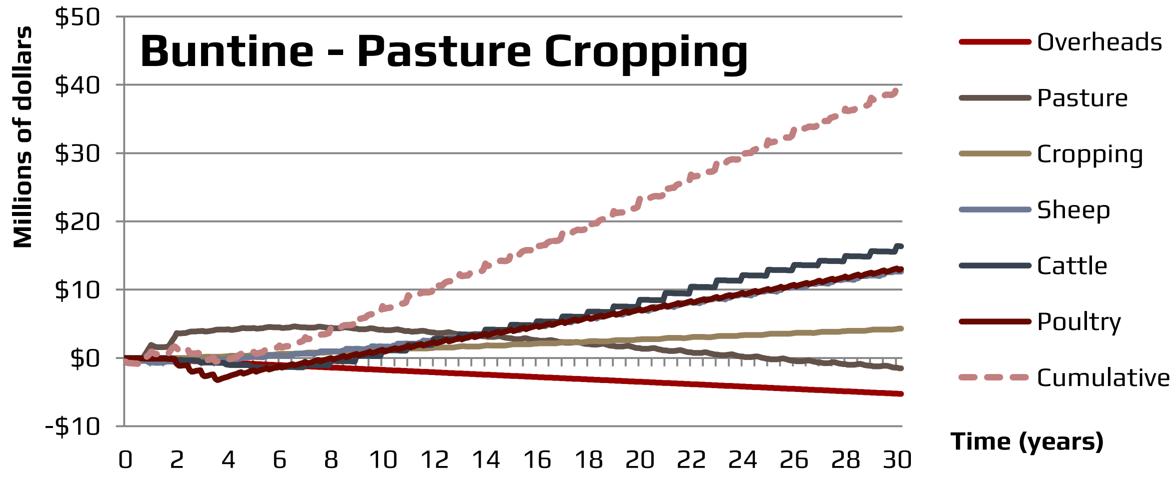


Figure 15 - Comparison of modelling results for industrial cropping (BAU) at Buntine and Arthur River, 30 year model run

These results are not showing the decline in profitability as a result of increasing input costs that was mentioned in the introduction. This is a result of the assumption that today's numbers hold through the length of the model run.

Pasture cropping (figure 18) shows a slightly different cash flow development. Since this scenario consists of multiple farm enterprises, the graph displays the cumulative cash flow of each of the farm components as well as the total cumulative cash flow. The first three years of this scenario are characterised by the transition to the new system. The transition plan used in this study (explained in the appendix) the first two years crops are grown to prepare the soil for pasture. During those years cropping returns comparable to those of the baseline scenario are achieved. After that however, livestock and infrastructure have to be acquired, visible as a dip in the graph. As the pastures become more productive, the carrying capacity grows and the herds' size increases. A steady positive cash flow follows as the system matures.

Contrary to the baseline scenario, both case study locations do not show much of a difference in total operating surplus at the end of the model run. This may be explained by the fact that in this scenario there is a mix of pasture and crops. This mixture is able to make better use of the year-round rainfall in Buntine than the seasonal industrial cropping in the baseline scenario.



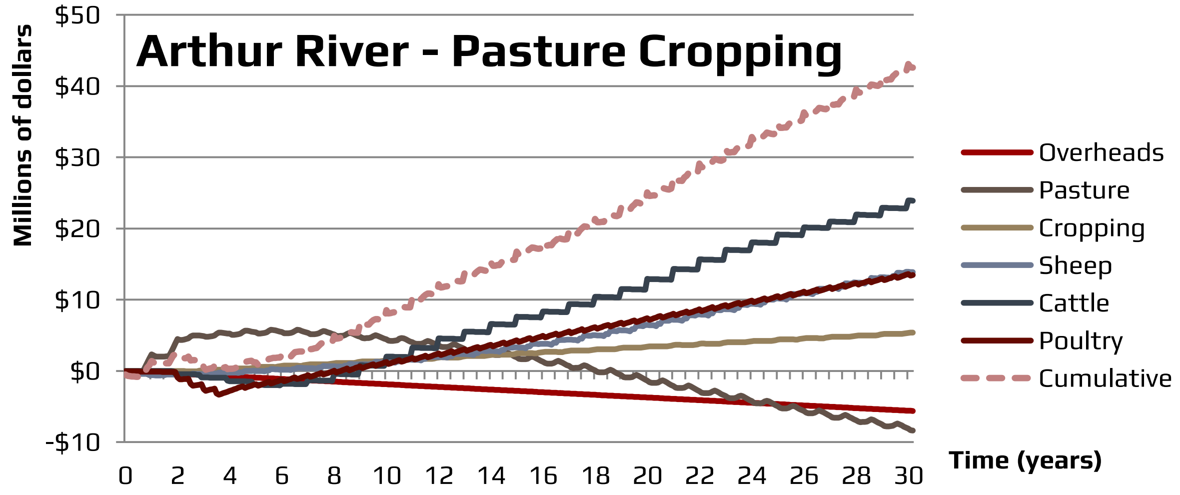


Figure 16 - Comparison of modelling results for pasture cropping in Buntine and Arthur River, 30 year model run

The perennial grazing scenario shows a similar pattern (figure 19). Differences with pasture cropping are that no cropping takes place except during transition, and that shrubs are planted in year two. Differences between both case study locations are again quite small. It is noteworthy that Buntine actually shows a slightly larger cumulative cash flow in year 30, which may be explained by the fact that perennial pastures thrive most when precipitation is spread evenly throughout the year, rather than being seasonal, the former of which is the case at Buntine.

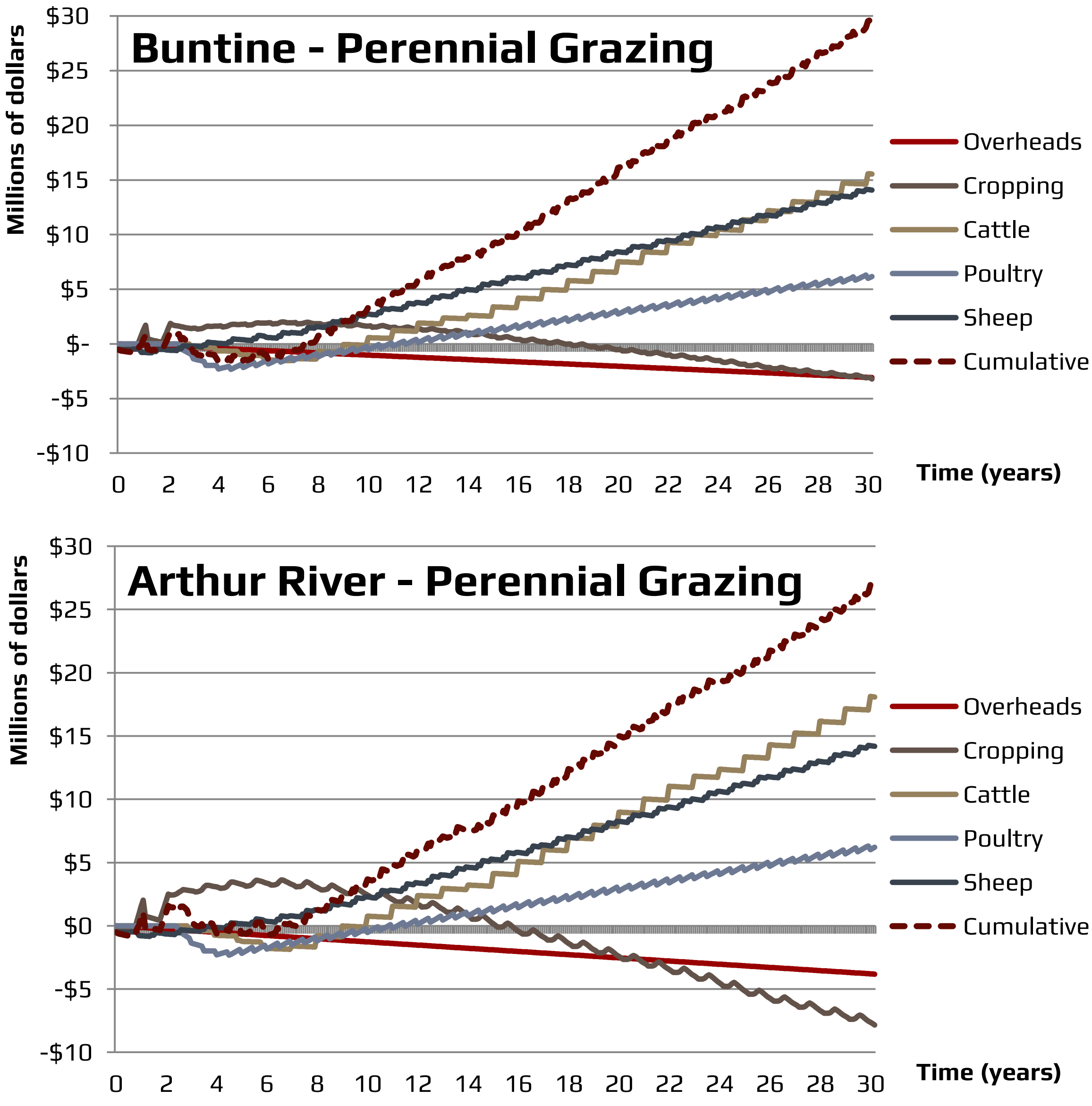
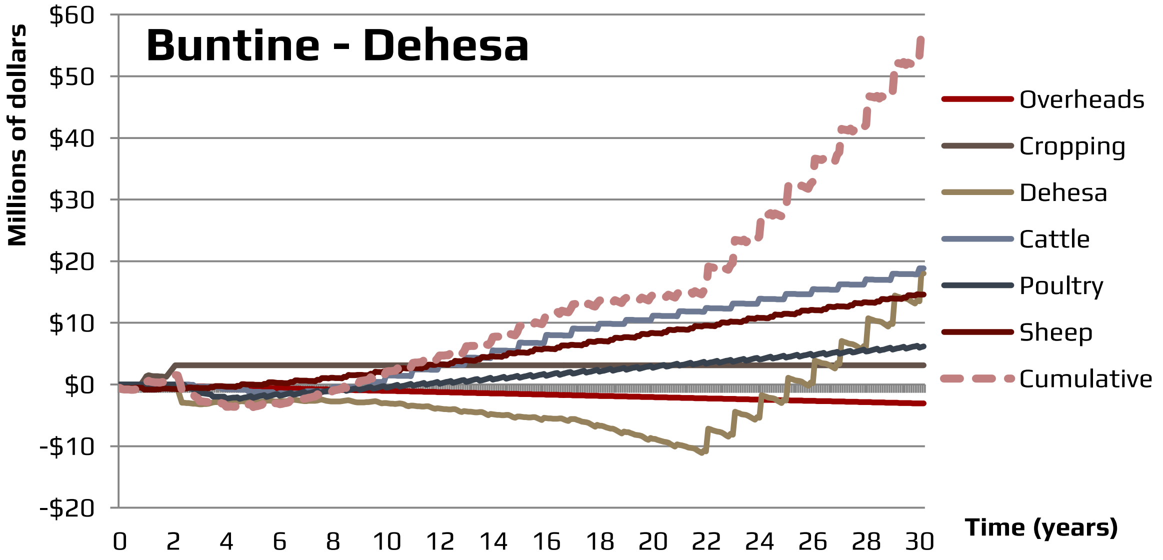


Figure 17 - Comparison of modelling results for perennial grazing in Buntine and Arthur River, 30 year model run

The dehesa system is different from the previous scenarios (figure 20). The oak savannah is established during the first three years, but takes a long time before fully maturing. The pasture underneath the oaks is as productive as it is in previous scenarios, but the oaks need maintenance to assure dependable cork and acorn production at a later age, even when they have yet to start producing those products (Koenig, Díaz, Pulido, Alejano, Beamonte & Knops, 2013). The livestock components are able to cover these costs, but it explains why total cumulative cash flow is significantly lower than in pasture cropping or perennial grazing until age 25, when acorns start dropping. Carobs are productive in this scenario from age 8 onwards. Due to the high value of acorns the system enters a steep rise in operating surplus when the oaks start producing.



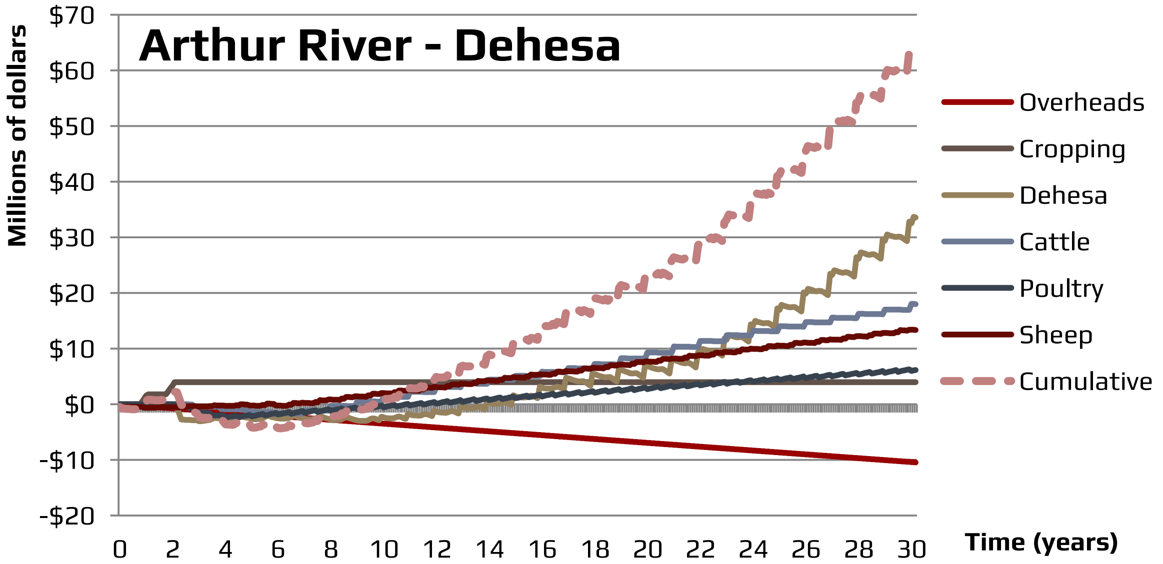
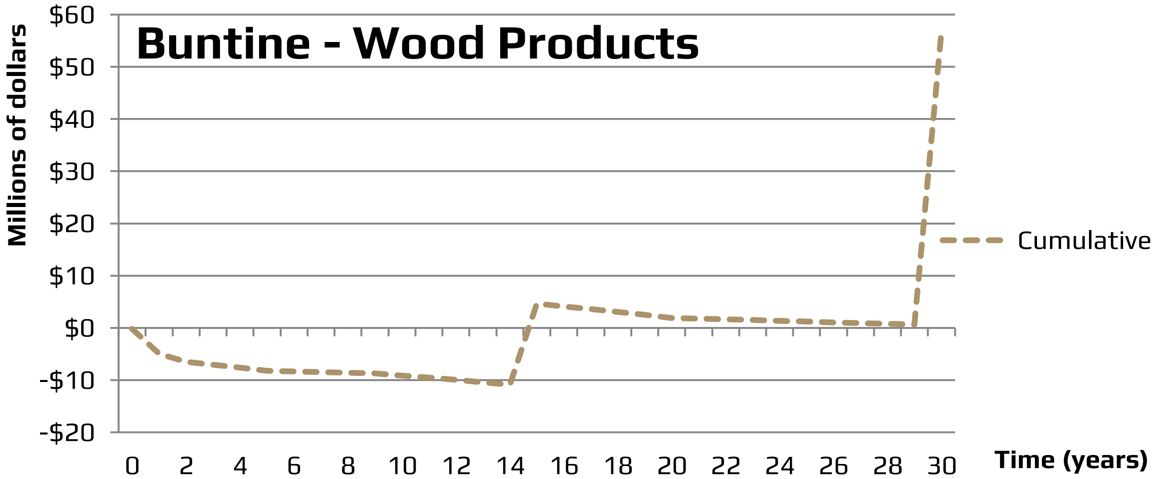


Figure 18 - Comparison of modelling results for dehesa in Buntine and Arthur River, 30 year model run

The wood products scenario (figure 21) differs from all other scenarios in that it does not have annual income; the trees in the plantations take time to reach harvest size. As mentioned before, another difference is that its purpose is conservation instead of annual food production. There are significant differences between both case study locations which are caused by the differences in type of wood product. Harvest times differ slightly between scenarios, but the main difference is total income. The Sandalwood scenario manages to earn back the investment at age 15, in Arthur River it takes the full 30 years before that happens, and even then there is a difference of $40 million in total. This difference can be explained by the large difference in value between both wood products. The Sandalwood can be marketed for essential oils, and is currently of much higher value than the timber coming from the Arthur River case study location. However, the global market for Sandalwood is very small; 5,000 tons per year (Australian Agribusiness Group, 2006), while this farm will produce about 7,250 tons in total. That is expected to have a negative effect on market value, which would make the Buntine scenario less attractive. Also, in the original design that was adapted for this study the Arthur River scenario did include revenues from the sales of carbon rights. This would make the Arthur River scenario significantly more attractive. Both effects will be discussed further in the robustness analysis.



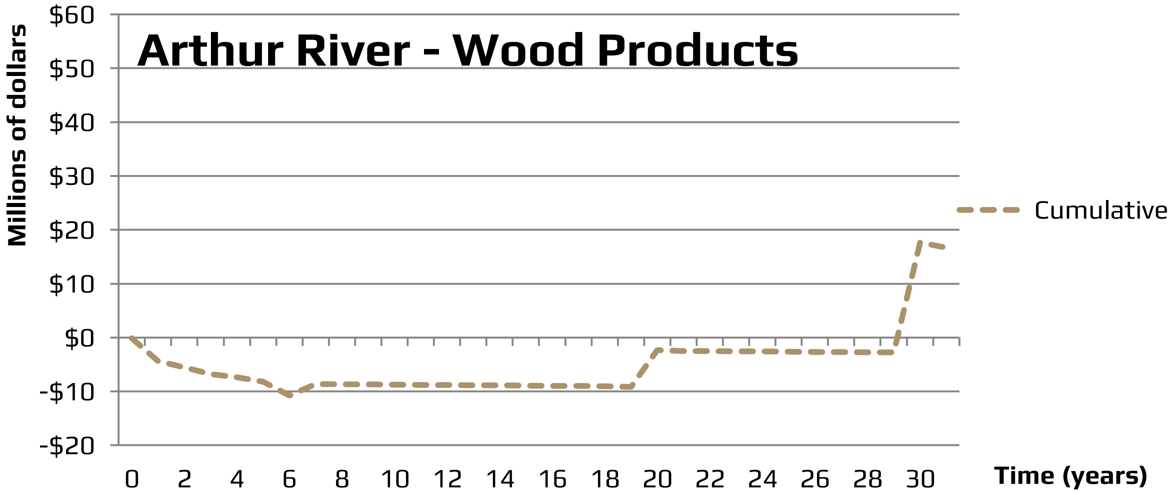
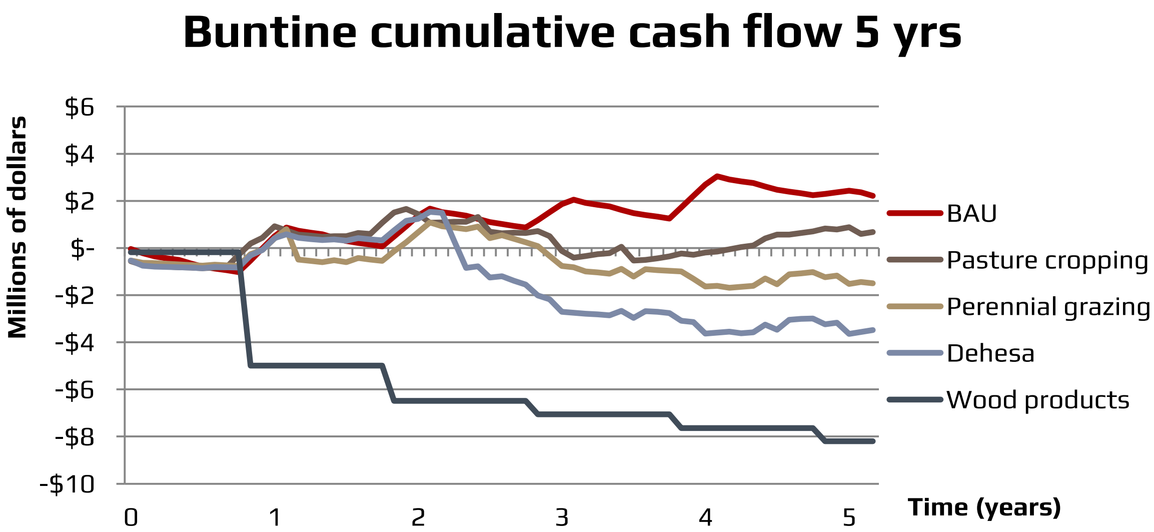


Figure 19 - Comparison of modelling results for wood products in Buntine and Arthur River, 30 year model run

3.3.2 Scenario comparison

The first model run was made five years into the future. The results (figure 22) show that the BAU scenario is a clear winner in both locations. It boasts a short earn-back time (less than a year) and a relatively high cumulative cash flow of about $4 million in Arthur River and over $2 million in Buntine after five years. Pasture cropping produces less cash flow, with $1,3M and $0,9M, respectively, and significant losses are made on the grazing (-$0,6M and -$1,5M), dehesa (-$4,1M and -$3,6M) and wood products scenarios (both -$8M). In short, on this timescale regenerative practices simply seem nowhere near as profitable as conventional industrial agriculture. Most scenarios even show big losses, and cannot be considered profitable at all. After five years, ecological systems are still maturing and recovering from the investments that are not necessary with continuing with industrial cropping.



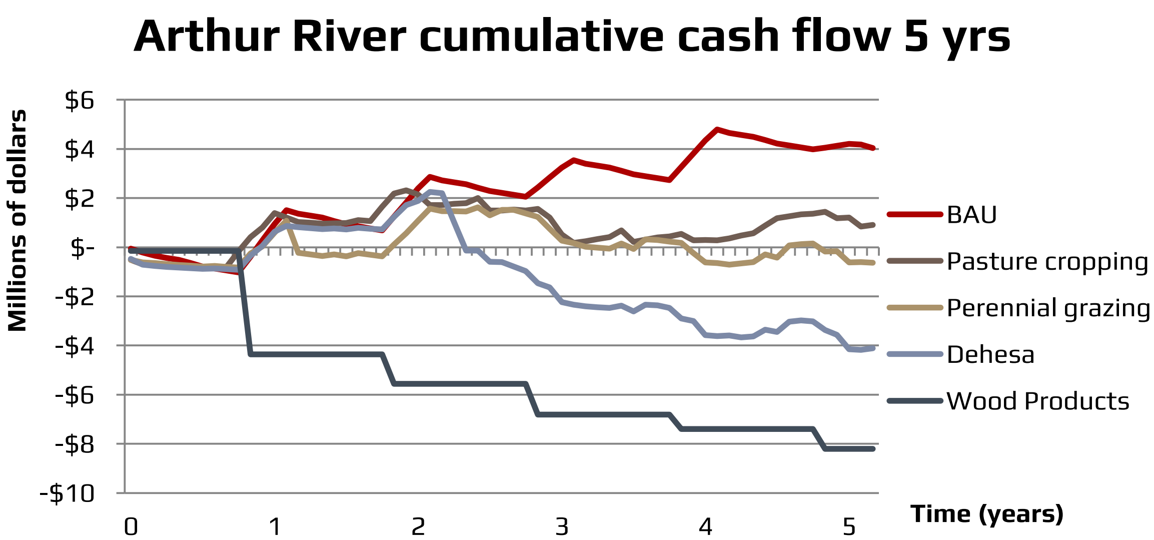
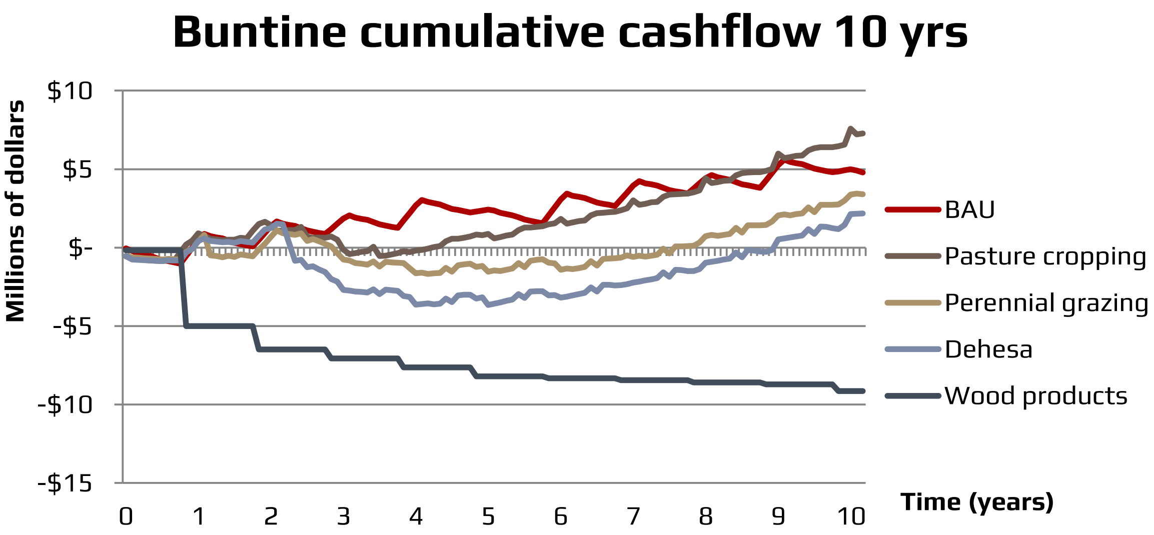


Figure 20 - Comparison of cash flow projections, 5-year model run

The notion that ecological systems take some time to reach full potential becomes more evident when examining the scenarios on a ten-year period (figure 23). The pasture cropping becomes the most profitable alternative for Buntine, and almost the most profitable at Arthur River. On top of that, perennial grazing and dehesa have earned back their investment by year 10. It appears that the timescale at which the investment in ecological agriculture is assessed plays a vital role in which approach to farming is more profitable.



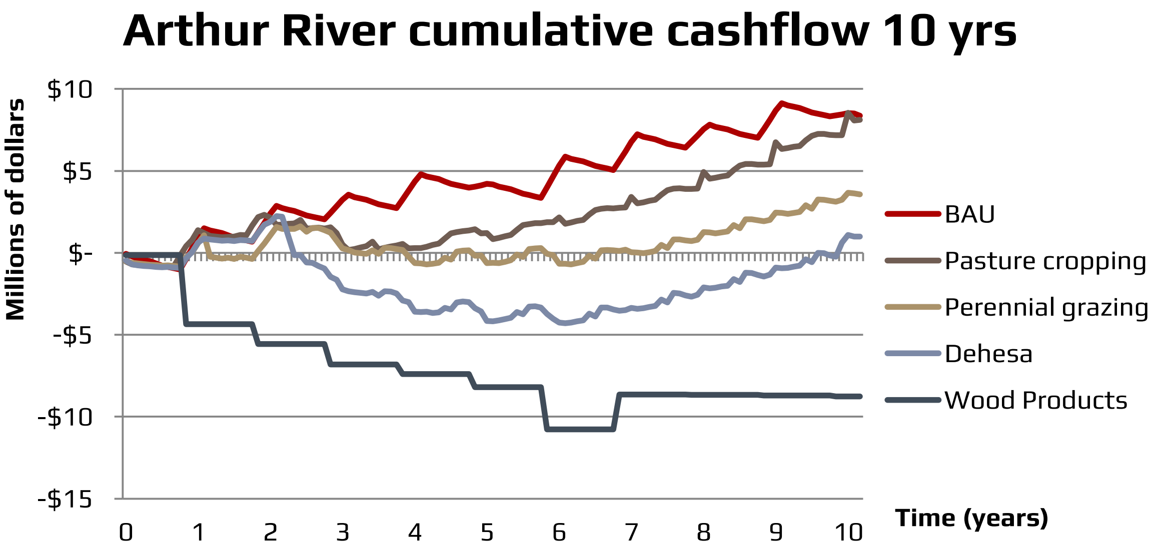
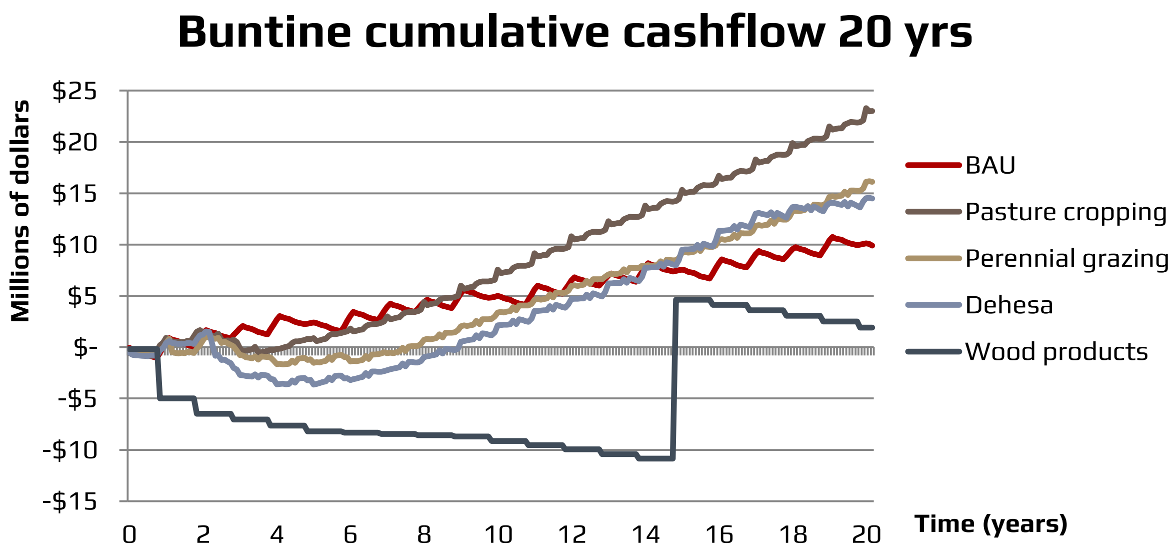


Figure 21 - Comparison of cash flow projections, 10-year model run

After twenty years (figure 24) the picture is different again. Although at Arthur River pasture cropping remains the only scenario more profitable than BAU, in Buntine industrial agriculture is already outcompeted by three ecological farming systems. The only scenario that remains completely unprofitable on a timescale of twenty years is the wood products scenario at Arthur River.



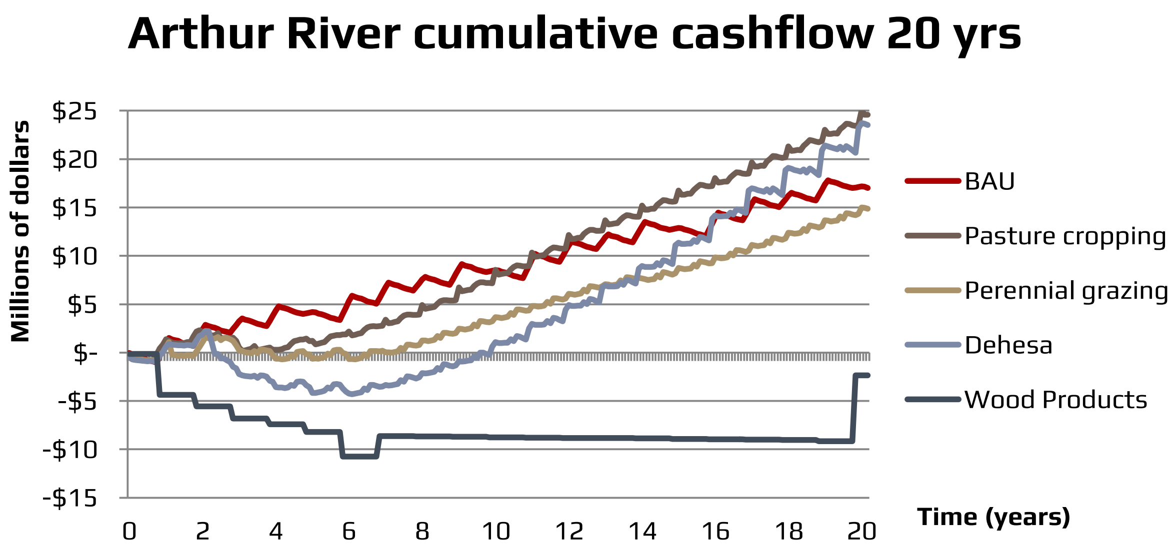
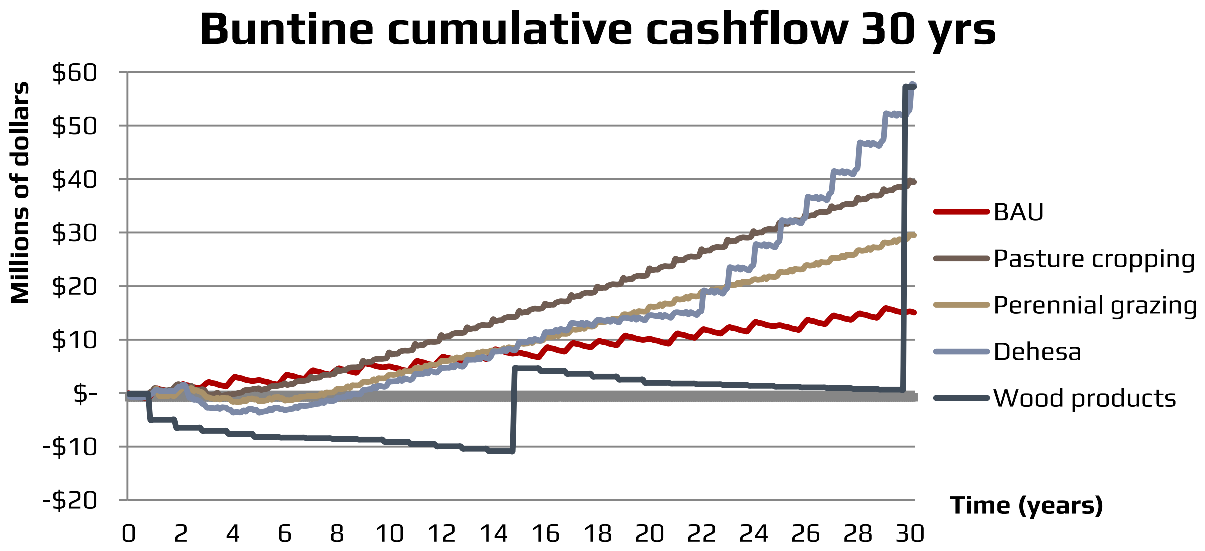


Figure 22 - Comparison of cash flow projections, 20-year model run

Extending the model run time to thirty years delivers results which are almost the complete opposite of those after five years (figure 25). At Buntine, all ecological farming systems are significantly more profitable than industrial agriculture, which generates a total farm operating surplus of $15,1M. The absolute winner is the dehesa system at $57,7M, closely followed by the wood products with $57,3M. Pasture cropping comes third with $48M and perennial grazing a respectable fourth on $29,6M.

At Arthur River the wood products scenario is significantly less profitable than all other scenarios, at $15M. Perennial grazing, at $26,9M, is only slightly more profitable than BAU which grosses at $25,9M. Pasture cropping is the most profitable with $55,5M, closely followed by dehesa at $54,2M.

This demonstrates that the timeframe considered when deciding on future land management can have a large influence on what scenario is or seems most profitable. In the short run, industrial cropping seems the most profitable outcome, but in the long run ecological farming is a much more profitable alternative, even without assuming a decline in profit margins such as was mentioned in the introduction. This observation may be part of the explanation why industrial agriculture still is so popular in the region; if practitioners or policymakers do not plan further ahead than 6-10 years they will come to the conclusion that industrial agriculture is financially the most attractive option.



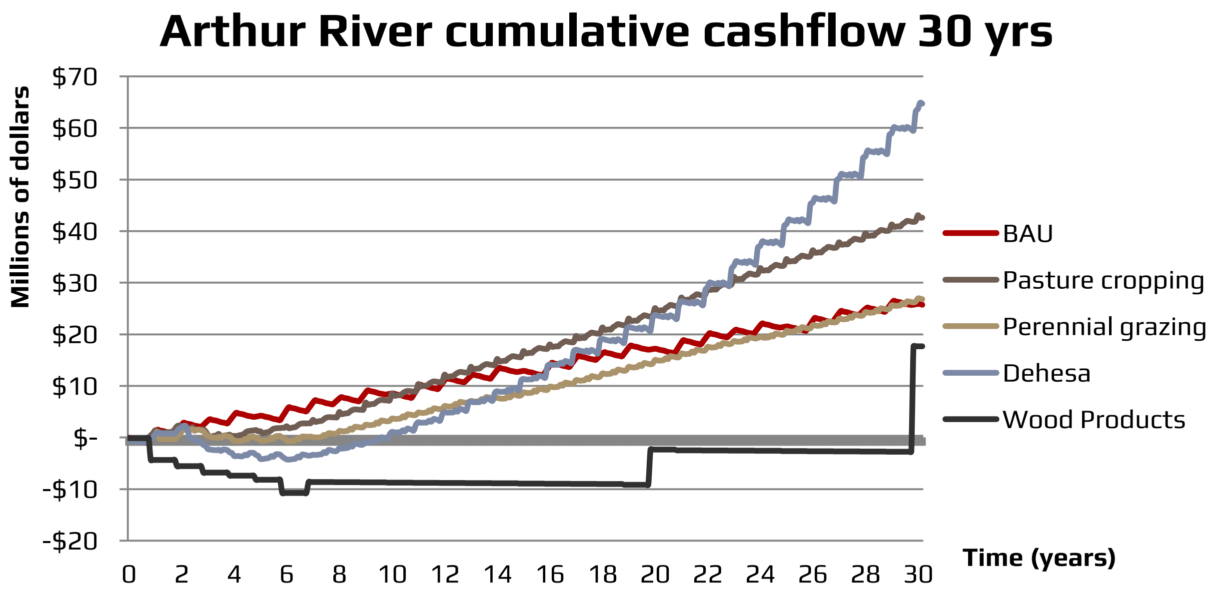


Figure 23 - Comparison of cash flow projections, 30-year model run

3.3.3 Robustness analysis

Based on these results it can be concluded that for both case study locations the dehesa scenario is financially the most sustainable scenario, although in Buntine the wood products scenario only comes second with a very small margin. Before the definitive most financially sustainable alternative could be selected, however, a robustness analysis was performed to fine-tune the models and to verify which variables or assumptions have a strong effect on the modelling results. Small errors in such variables may have a large influence on the end result of the study and is therefore a potential source of uncertainty. As a result, the basic model specification was altered slightly to decrease uncertainty and increase realism. For this section only the case of Arthur River is used as an illustration; results in Buntine were comparable. The large difference between both wood products scenarios will be explored as well.

As mentioned in the introduction, the choice was made to make optimistic estimations for the baseline scenario, and be conservative for the ecological scenarios. Therefore, the results in the previous paragraph are based on 2013 industry averages, without including the trend of increased input costs. 2013 was a very good year for cropping throughout the region. 2010 on the other hand was a year with severe drought constraints, which are reasonably common in the region. To investigate to what extent this choice influences the model results, the same models were run, only with input data for BAU based on 2010 averages. The results are presented in figure 26.

The difference between the two crop seasons is quite dramatic. Cash flow from industrial cropping in 2010 is only 22% of that in 2013. It should be noted that these 2010 numbers are from the better performing farms in the case study area; the worst performing farms made a loss during 2010 (Planfarm & Bankwest, 2014; Farmanco, 2014). Since droughts such as the one in 2010 seem to occur quite frequently, a realistic long-term trajectory for BAU will most likely be somewhere in between the two graphs displayed in figure 26.

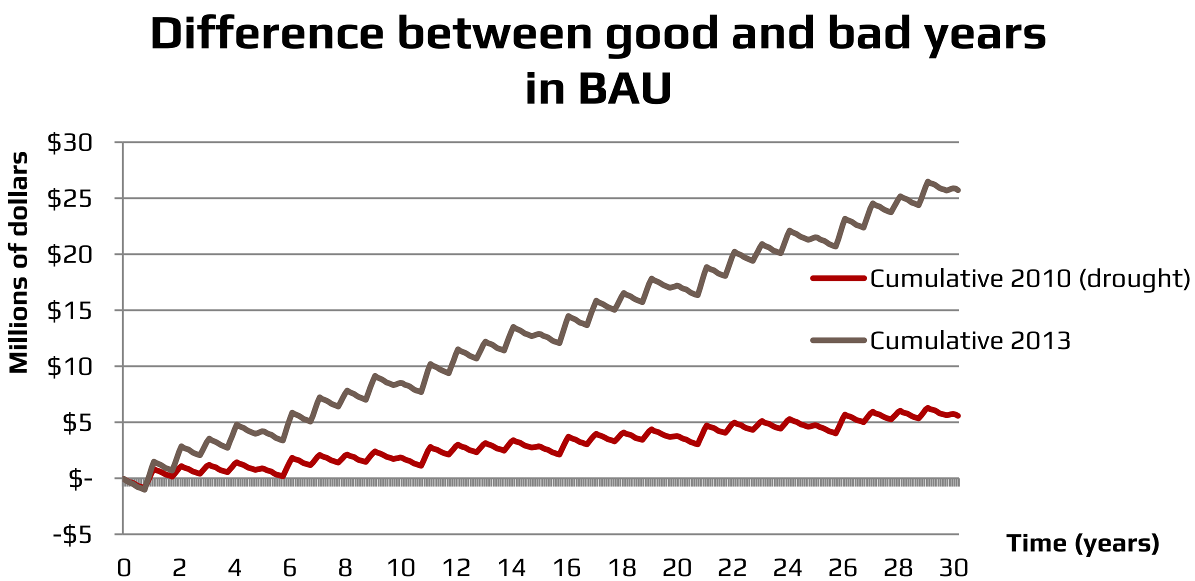
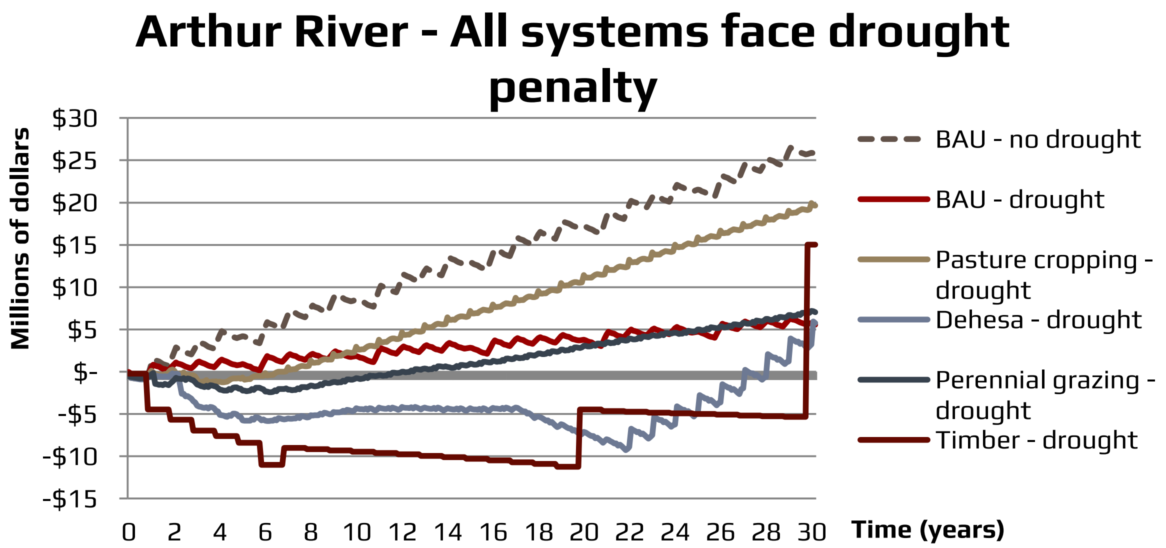


Figure 24 - Comparison of different industrial cropping (BAU) input data at Arthur River; 2013 numbers (good year) and 2010 numbers (drought year)

This shows the variability that industrial croppers in the Wheatbelt currently face. Diversified ecological farming systems have been proven to be more resilient against climate change (Lin, 2011), amongst others due to the buffering of temperature, moisture and wind and the improved water holding capacity of the soil. This prevents the water from flowing away as surface runoff or evaporate, keeping it available for plant use in dry spells.

To explore the theoretical differences between farming systems in reaction to periods of drought of both scenarios some new model runs were performed. One model run was done with an equal relative yield penalty for all scenarios as a result from drought, one run was done with a drought penalty for BAU alone. The former specification may be too pessimistic for ecological agriculture because of the higher resilience and water storage capacity, the latter specification may be too optimistic because ecological farming systems will still suffer from droughts to some extent. The real extent is impossible to measure at this point, so these two specifications provide the bandwidth in which the realistic situation may lie. Figure 27 shows the results from both model runs. The analysis will continue with the latter specification.



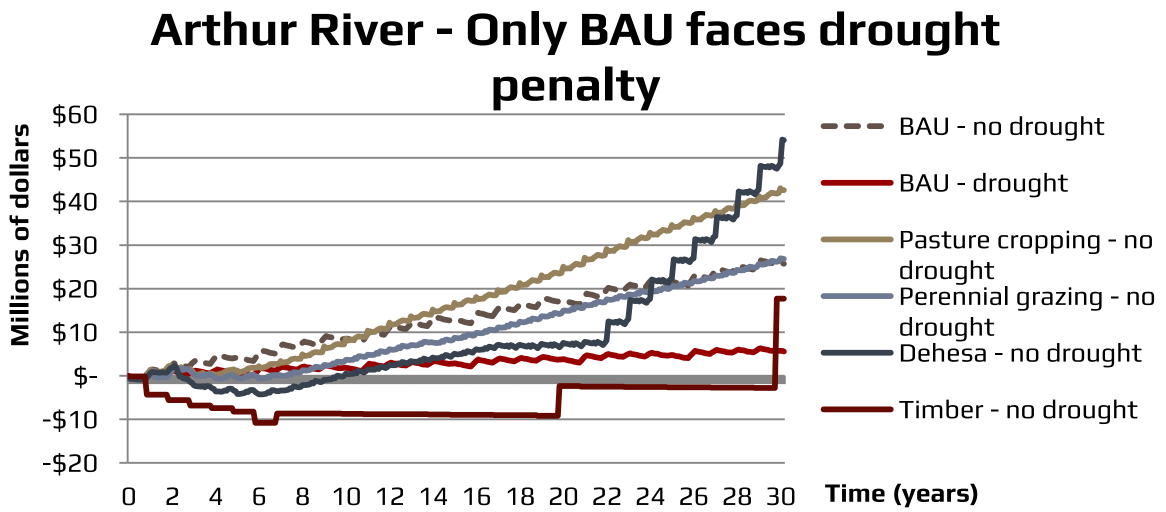


Figure 25 - Modelling results showing the effects of drought years on the results. The first graph calculates an equal yield penalty for all scenarios; the second calculates a yield penalty for BAU only

No ecological scenario is able to surpass the 2013 BAU level under the full yield penalty. However, all scenarios still do better than BAU under drought conditions, even though dehesa and perennial grazing only just cross the BAU line at the end of the 30-year period. Pasture cropping now is the most profitable alternative. However, without a drought penalty for ecological scenarios all ecological systems are significantly more profitable than continuing business-as-usual. The actual long-term averages for both the industrial and the ecological scenarios will probably lie somewhere in between the 2010 and 2013 figures, but at least some ecological farming systems seem to be always more profitable than industrial cropping.

This all remains rather hypothetical because no trials or measurements have been done comparing these systems on their capabilities to withstand periods of drought. It is based on the observations of increased subsurface water infiltration and storage in ecological systems. However, it does show the extent of the effect these regular drought years can have on farmers in the Wheatbelt, and that trials or research comparing drought resilience of different farming systems is needed. This section continues using the model specification of BAU as the only scenario receiving a yield penalty for drought.

Another point that was made in the introduction is the trend of increase in input costs that is not resulting in increased yields. This trend could not be quantified for the region of the Wheatbelt in this study, so this section resolves to using a (conservative) estimate of 1% increase in input costs per year (figure 28). After thirty years this amounts to a total cash flow which is about 10% lower compared to the basic specification.

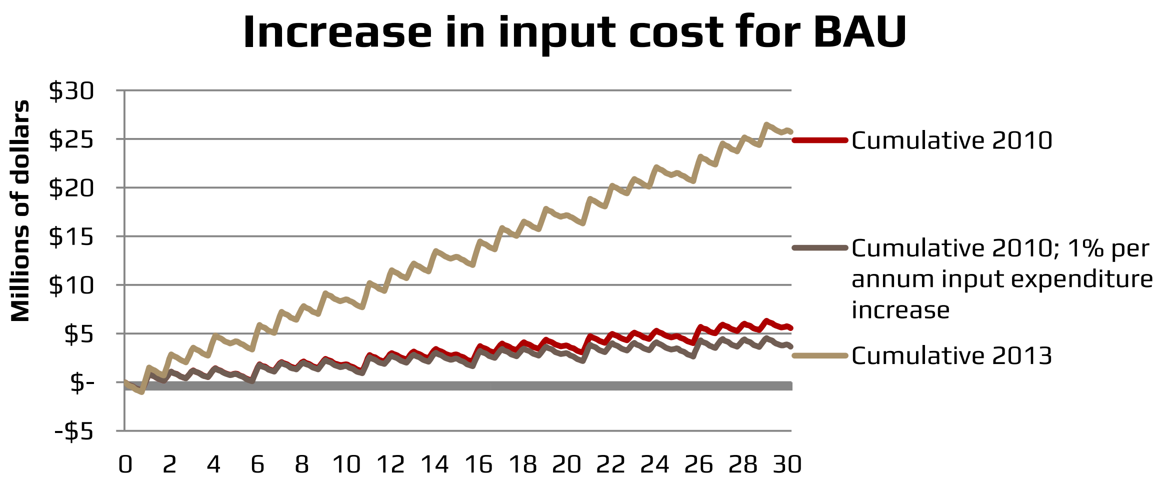


Figure 26 - 1% increase in the cost of inputs to maintain yields, compared to stable costs for a drought year and a good crop year

Apart from adding the trend of increased input costs for industrial cropping to the model specification, other input variables were analysed as well. Two key variables for the results prove to be the acorn price and yield. These make for the relatively enormous income from the dehesa from age 20. However, for dehesa to not be the most financially sustainable scenario these variables would have to be set to only a fraction of the values from literature. This was not deemed realistic. For the dehesa scenario, an expected future reduction in cork price due to the replacement with plastic bottle stoppers may play a role, but did not have a significant effect on the total cash flow of the dehesa system. Other variables, such as livestock value and pasture productivity in all scenarios involving livestock, were looked into as well, but overall the results proved robust.

The results from a model run as specified above are presented in figure 29.

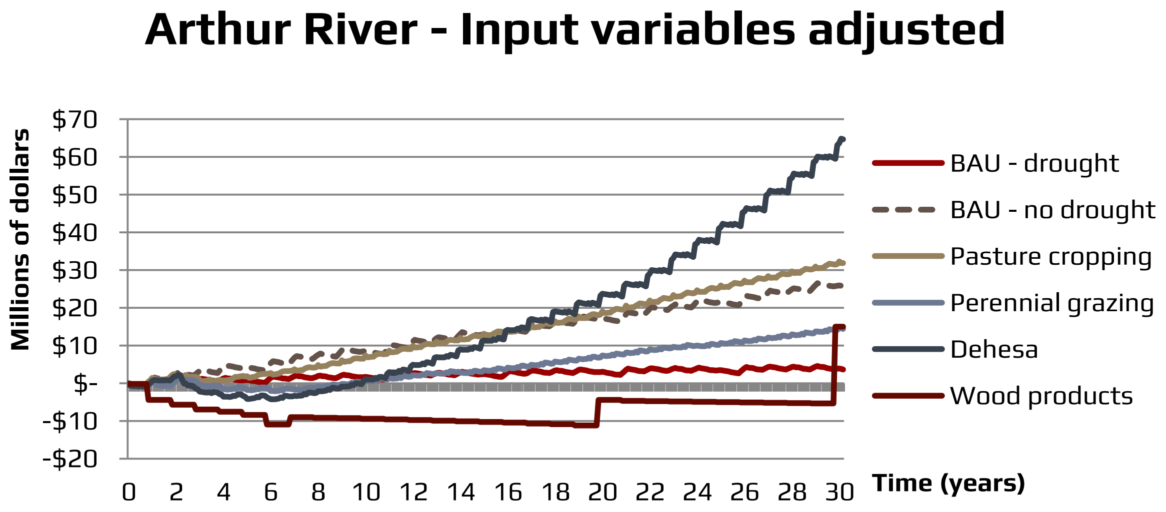


Figure 27 - Several variables in ecological scenarios adjusted for realism. Long-run averages for the BAU scenario are expected to be somewhere in between *BAU - drought* and *BAU - no drought*

Up to this point no carbon revenues have been included in any of the scenarios, while some of these farming systems may have the potential to sell rights for carbon stored in soils, in bushes, in oaks or in other trees. The reason for excluding carbon is to keep a level playing field for all scenarios: carbon is a realistic add-on for only some of the scenarios considered here. However, as mentioned before, the wood products scenario in Arthur River was adapted from an existing business plan in which the sales of carbon rights were a core revenue stream. To assess to what extent the inclusion of carbon right sales can influence the results, carbon revenue was added to the Wood products - Arthur River scenario (see figure 30).

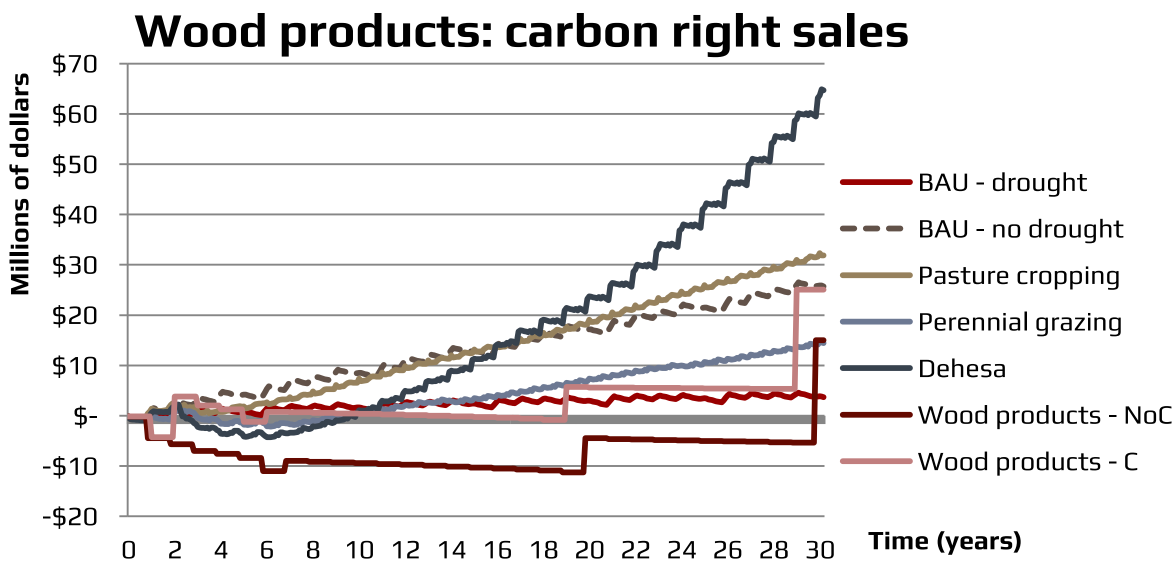


Figure 28 - Results showing the difference between including the sales of carbon emission rights as revenue stream at Arthur River

Carbon rights are sold in year 2, which adds around $8M and significantly reduces the time this system spends carrying a debt. It also means it is on par with BAU 2013 numbers, which makes it a more than competitive alternative for industrial cropping in the long run. It cannot compete with pasture cropping and dehesa, but the inclusion of carbon right sales does make a significant difference.

So far, interest has been left out of all of the scenarios. However, in reality, businesses will have to finance their transitions in some way, and if they have to lend money to do that interest will have a major influence. This is especially so because of the long earn-back times in some scenarios. Three interest rates were used to explore what effect can be expected with different interest rates. The average interest rate since 1990 was 4,8%, with a high of 17,5% in 1990 and a low of 1,5% in 2016. The model was run with a low interest rate (1,5%), medium interest rate (4,8%) and high interest rate (8%). The results are presented in figure 31 on the next page. The wood products scenario from Buntine was added to the analysis because it is so different in characteristics from the Arthur River one.

Earn-back time	Arthur River	Buntine
BAU	0.9 yrs	1,0 yrs
Pasture cropping	0.8 yrs	4.2 yrs
Perennial grazing	1.8 yrs	7.6 yrs
Dehesa	9.9 yrs	9.0 yrs
Wood products	30 yrs	15 yrs

Table 6 - Earn-back time without interest

The dehesa scenario is still the most financially attractive alternative, but pasture cropping comes close as interest rates rise. Where the wood products scenario at Buntine (Sandalwood) is the second best scenario with low interest rates, but has to make way for the BAU, pasture cropping and perennial grazing scenarios with high interest rates. High interest rates do not favour scenarios which require a large up-front investment in combination with a long earn-back period (table 7), in this case wood products, and favours scenarios that do not require a loan such as pasture cropping.

Another indicator which is often used to evaluate the financial attractiveness of different investment opportunities is Net Present Value (NPV). A positive NPV means an investment will be more profitable than keeping the money in the bank; a negative NPV means the money is better kept in the bank. Examining the results in table 8 it is noted that the wood products scenario without carbon right sales at Arthur River is a loss at all interest rates. The best investment across all interest rates is the dehesa system, but the second most attractive scenario (for Buntine) changes from wood products to pasture cropping. In Arthur River pasture cropping always comes second.

Scenario	1,5 %	4,8 %	8 %
BAU	$ 4.059.584	$ 8.772.504	$ 17.725.599
Pasture cropping	$ 37.972.399	$ 61.645.006	$ 101.698.452
Perennial grazing	$ 14.424.864	$ 20.512.646	$ 28.040.902
Dehesa	$ 68.509.647	$ 91.325.743	$ 120.243.401
Wood products - AR NoC	-$ 3.338.729	-$ 37.069.373	-$ 124.536.346
Wood products - AR C	$ 19.055.139	$ 3.247.630	-$ 54.309.020
Wood products - B	$ 42.834.370	$ 26.291.268	-$ 29.469.342

Table 7 - Net Present Value of each scenario under different interest rates

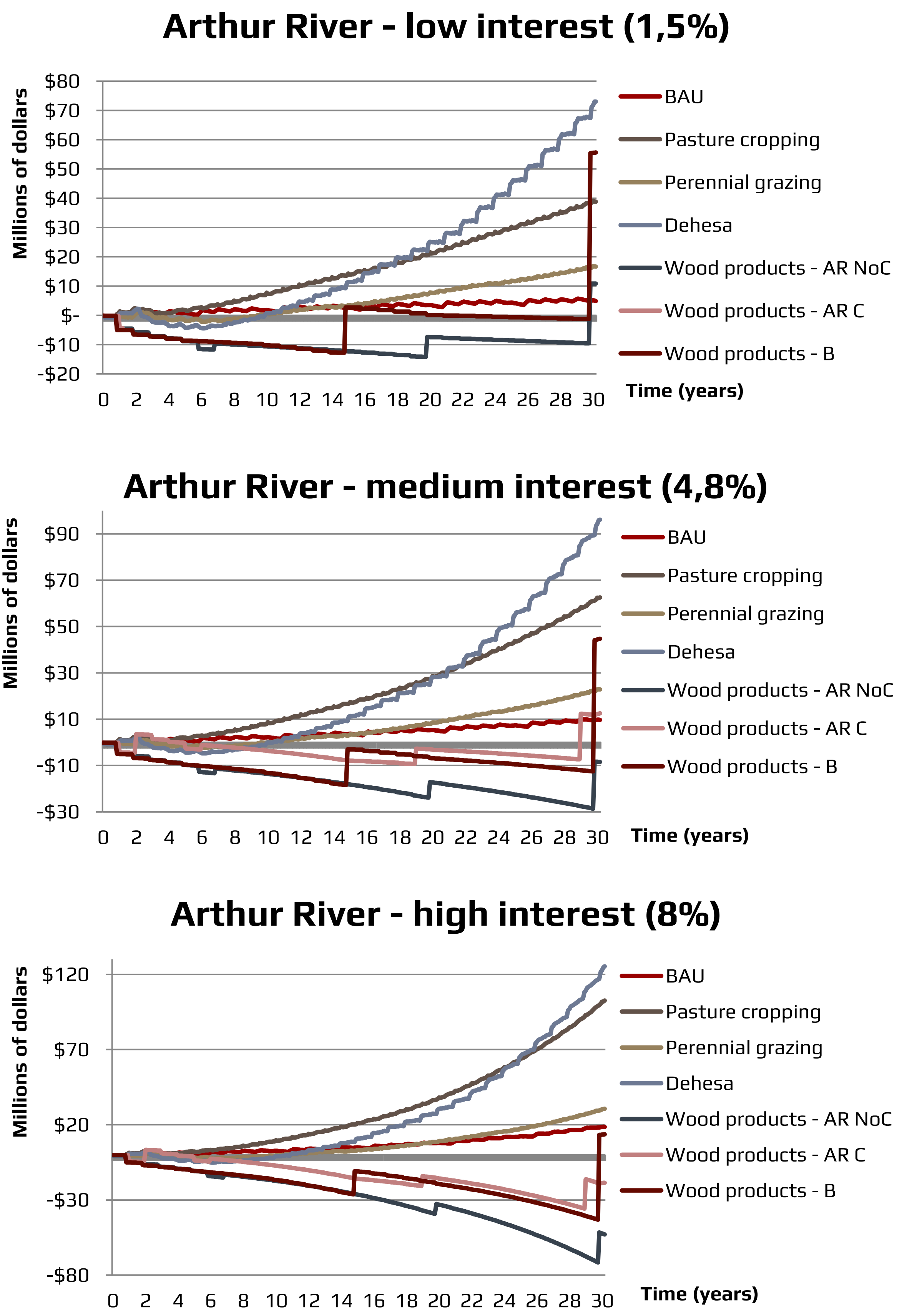


Figure 29 - Comparison of the effects of different interest rates on modelling results

4. DISCUSSION

Before discussing and interpreting the results presented above, the upcoming section will discuss the validity of those results. Uncertainties that arise from certain choices in methodology or assumptions will be mentioned, and ways in which these uncertainties have been mitigated will be explained. The choice for the methods used in this study will be evaluated as well. Section 4.2 will focus on answering the research questions, and selecting the scenario which performs best on all sustainability criteria. Section 4.3 describes a small extension research that was carried out to indicate what obstacles to adoption of this preferred scenario can be expected in the region. Section 4.4 then goes into the broader implications of this study for the future of the Wheatbelt region and comparable contexts elsewhere in the world.

4.1 VALIDITY OF RESULTS AND METHODS

As mentioned before, this study was an explorative exercise. Due to the hypothetical nature of the farming systems, the relatively small amount of data that were available from real-world cases in the Wheatbelt, and the long timescales at which predictions were made in this study, significant uncertainties with respect to the results were inevitable. Measures were taken in the process to minimise them, but uncertainties remain and the results of this study should be investigated further to be confirmed.

First of all, the methodology involving whole-farm modelling involves uncertainties inherent to trying to capture reality in a model. A robustness analysis was performed to counter this to some extent. Another important source of uncertainty is the timeframe which was used for the modelling, i.e. 30 years into the future. However, the intent of the modelling exercise was not to predict 30 years, but merely to gain insights into the long-term functionality of the different farming systems under consideration. The uncertainty as a result of from the long timeframe was therefore not considered a problem for the study.

A relatively small sample population was used to gather data from the field to feed the models, which made the financial sustainability analysis especially vulnerable. A small sample population could result in models which are based on data that are not representative of the whole population, and bias the results to show a better case for ecological agriculture than could be achieved in reality. The first measure taken to prevent this bias was to compare the data from the field with data from scientific or industry literature, and judge whether the field source was likely to overstate their success. The second measure was to take input variable estimates conservatively for all ecological scenarios, despite many of the farmers interviewed stating they felt they could still significantly improve their systems. Data ranges were constructed using the literature and data from the field, and only the lower values from those ranges were used as inputs for the scenarios. Input variables for industrial agriculture were taken from the higher end of data ranges, which themselves were based on large sample populations. Through this approach the study is more confident that some of the ecological farming systems are indeed more (financially) sustainable than the baseline scenario.

The scenario definition is another source of uncertainty. There is no guarantee that the systems discussed here are the best examples of ecological agriculture in the Wheatbelt. Many more variations can be thought of, which may be more environmentally sustainable, provide more jobs or be more profitable than the ones discussed here. However, the fact that (some of) these scenarios already (without optimisation) seem more sustainable than conventional agriculture, even without selecting the optimal form of ecological system, perhaps even strengthens the message that ecological agriculture is the better option.

Although having served their purpose, the methods used in this study do have some disadvantages. One disadvantage is the data-hunger of each method. The whole-farm modelling approach requires a profound insight in the interaction of different components of a farming system. This is a multi-disciplinary field of which soil science, hydrology, ecology and agronomy are only some components. The financial modelling selected as method for the financial and social sustainability analysis requires a large amount of data on productivity, costs, and prices as input for the models, and the environmental impact assessment method used for the environmental sustainability analysis also requires insights and data from various disciplines in research. Gaining these insights and gathering these data is not only time-consuming, it is also difficult because of the (currently) relatively small amount of sources of information available in the field. Selecting methods like these for an exploratory research such as this study has the advantage of providing detailed insights into the long-term functioning of different potential solutions while not being bound to what has already been done in the field.

The environmental analysis in this report is only a very broad and brief one. This has to do with the fact that within the scenarios there are many opportunities for a farmer to tweak their land management, thus improving on or detracting from the environmental score each scenario received here. The analysis was included to provide an indication of how the systems are positioned in relation to one another, and may be deepened in future research.

This study is to be a starting point for further, more specific and more detailed analyses in the Wheatbelt (and perhaps other places). It is therefore more general in character than most studies. Future research will dive deeper into certain aspects of this study. Recommendations for future research are given in paragraph 5.2.

This study has provided insights into the functioning of some hypothetical ecological farming systems that should work in the WA Wheatbelt, into how the timescale of investment assessment influences the financial profitability of ecological farming systems, and into how ecological systems compare to industrial systems on environmental, social and financial sustainability. It has shown that ecological agriculture may provide a long-term, sustainable solution for many of the problems that the WA Wheatbelt currently faces.

4.2 THE MOST SUSTAINABLE SCENARIO

This study set out to find an indication of what farming system, suitable to Wheatbelt conditions, can be expected to be the most sustainable option for the future. In the previous chapter three analyses were carried out to find how each of the five farming scenarios constructed for this study performed on the three pillars of sustainability.

The results of each of the three analyses are summarised in table 9. The relative position of each scenario is shown for each analysis, as well as a summation that gives the total score. No weighting has been applied. The scenario with the lowest score can be interpreted as the overall most sustainable scenario.

Scenarios	Environmental sustainability	Social sustainability	Financial sustainability	Total
BAU	4	4	3	**11**
Pasture cropping	3	2	2	**7**
Perennial grazing	2	3	3	**8**
Dehesa	2	1	1	**4**
Wood products AR	1	5	5	**11**
Wood products B	1	5	3	**9**

Table 8 - Relative position of each scenario in each analysis and overall most sustainable scenario (*total* column): lowest score is best. Financial sustainability based on results using average interest rate (4,8%)

Out of the systems explored in this study, the dehesa system is the most sustainable scenario. This is due to its good score on social and financial sustainability, despite its relatively high initial investment, and its environmental performance. Pasture cropping and perennial grazing follow, then come both wood products scenarios and the baseline scenario. It seems, then, from this exploratory research that indeed some ecological systems in the Wheatbelt are more sustainable than the baseline industrial scenario.

There is quite a wide range of scores between the different ecological systems in this study. The dehesa system for example scores well on environmental sustainability, and best on social sustainability and financial sustainability. Despite having a relatively high up-front investment the system starts earning back the investment reasonably quickly, is able to achieve a medium earn-back time (~9 years) and produces excellent revenue once the oaks are mature and start producing. The wood products scenarios on the other hand do extremely well on environmental sustainability, but their high investment, long earn-back time and low employment result in a position close to the baseline scenario.

Key factors determining the sustainability potential of a farming system seem to be, based on these results:

- High diversity of (complementary) farm enterprises
- Low initial investment and/or short earn-back time
- High employment

This provides guidelines for the future design of ecological farming system. For example, the systems assessed in this study could be made to score better by spreading out the transition of the farm over multiple years, rather than transforming the farm all at once. Several strategies are possible; transitioning fully, but only one section of the farm at a time, or transitioning the whole farm but only slowly adding enterprises as time progresses. This should have a large influence on the size of the up-front investment and the earn-back time.

Another guideline could be integration of these ecological farming systems. This can be done both laterally and vertically. An example of lateral integration is zoning the farm; a farmer could decide to put one part of the farm under dehesa, reserving another part for pasture cropping, while reforesting a third section of the farm under the wood products system. An example of vertical integration would be combining several systems on the same part of the farm; building a dehesa system with fodder shrubs in the understory and leaving room for rows of pasture crops in between the trees. Well-planned integration and spread-out transition may result in a reduction in earn-back time and up-front investment, while increasing long-term profitability, employment and resilience through the diversity of (complementary) farm enterprises.

Integration can be done using the farming systems from this study, but many more systems could be designed which are suitable to Wheatbelt conditions. Oil mallees for biofuel, native fruits like Quandongs (Santalum Acuminatum), intensive orchards (such as are sometimes created in permaculture systems), on-farm aquaculture with freshwater crayfish and (native) tubers such as youlks are just a few examples that have shown potential over recent years. Aboriginal knowledge may prove a rich source of inspiration. More research is necessary into which systems work best, and it may be that there is no one system best suited to Wheatbelt conditions, but many.

Some final design imperatives follow from ecological agriculture's basis in ecosystems thinking. Animals perform vital work in an agricultural ecosystem. These can be livestock, but can also be wildlife native to the region. They manage vegetation and contribute to quick build-up of organic matter in the soils through grazing, they feed soil biology with their manure and can control pests and parasites. Without these animals an ecosystem is not a functioning unit, so all ecological farming systems in the Wheatbelt should include animals.

4.3 IMPLICATIONS FOR THE WHEATBELT

For the region of the Wheatbelt this study indicates that a different approach to agriculture is not only possible, but preferable over current, industrial systems. Whether a large-scale adoption of ecological farming systems which employ more people in rural communities will be able to stop the trend of scale increase in farming, rural flight and concurring social decline in rural communities will have to be proven by real-world trials, but at first glance it does seem possible.

After all, some of the ecological farming systems in this study, without optimisation, were able to employ over ten times as many people as the baseline industrial system could, while being more profitable in the long run. As stated in the introduction, the Goldschmidt hypothesis indirectly connects land management to the well-being of communities through the scale of operations of the surrounding farms. The increase in farm employment may allow a decrease in the scale of farm operations, increasing the well-being of rural communities. More people can be employed on the same farm area, meaning that communities can grow, or that large tracts of land are no longer necessary for employment and can be allocated to restoration and permanent conservation of natural areas.

This statement not only connects to the Goldschmidt hypothesis, but to the on-going discussion of land sparing versus land sharing as well. This discussion originates from the notion that with a growing world population and increasing prosperity more food is necessary in the future, while on the other hand fertile agricultural land is decreasing in surface area. This means more food will need to be produced; however the general consensus is that this should not go at the cost of natural ecosystems. The discussion is about two solutions: land sharing, which consists of wildlife friendly farming assumed to reduce farm yields, meaning more land is required for food, or land sparing sacrificing certain pieces of farmland to high agricultural intensification thus freeing up/sparing land elsewhere for conservation (Green, Cornell, Scharlemann & Balmford, 2005). The results from this study suggest that the two do not necessarily oppose each other, but they can be combined: an increase in agricultural yield does not have to go at the cost of biodiversity. Farmland may be intensified in an agro-ecological manner, sharing this intensified farmland with natural flora and fauna an at the same time freeing up other farmland to be revegetated and set aside for conservation purposes. The land sharing versus land sparing debate is based on the underlying assumption that wildlife-friendly farming always produces less yield than industrial farming (Grau, Kuemmerle & Macchi, 2013), and in the case of ecological agriculture this assumption may not always hold.

A more sustainable way of farming in the WA Wheatbelt, which revitalises rural communities while restoring the environment, seems possible. However, if ecological agriculture is indeed such a win-win-win scenario, this begs the question why more farmers are not employing it. As a first step towards identifying which obstacles currently prevent farmers from transitioning to ecological agriculture, a small extension research was performed.

Figure 30 - A diverse cover crop near Arthur River

4.4 OBSTACLES TO ADOPTION

For this research a methodology of qualitative interviews was chosen. This type of interview, as opposed to e.g. a quantitative survey, has the disadvantage of greater statistical uncertainty because of the small sample size. However, the advantage of the comparatively enormous information density outweighs that disadvantage in this stage of research (Weiss, 1995). For this study, 18 farmers and 8 ((ex-)government) researchers were interviewed. There was no standard interview protocol; questions on obstacles to adoption were asked during appointments and during the farm visits which were undertaken to understand the farming systems (see section 2.1.3). The questions were asked in an open, non-suggestive manner, an example of which is 'what do you feel is holding farmers back from switching to regenerative agricultural practices?'.

These interviews did provide a range of obstacles to adoption of regenerative or ecological farming practices. The results of the interviews are summarised and grouped into three themes below. Although these results are not statistically representative for the whole population of the Wheatbelt, they may give direction to future research on the topic.

4.3.1 Awareness & Knowledge Base

Perhaps the most obvious obstacle to adoption of ecological farming is that farmers may not know of its existence, of how to employ it or of where to obtain such knowledge. Ecological agriculture seems to still be a rather rare approach to farming in the Wheatbelt region, which could cause such a lack of awareness amongst farmers. There is still much room for innovation and optimisation in ecological agriculture because it can be seen as a relatively new and unexplored form of agriculture, especially in the context of the Wheatbelt. The fact that there are still many unknowns gives rise to uncertainty amongst practitioners about the merits of ecological agriculture. Another point that was made during the interviews is that most mainstream farmers will only adopt an innovation if they have seen it work in person. Without full-scale demonstration it may prove difficult to convince the bulk of conventional farmers to transition to ecological agriculture.

4.3.2 Finance and Transitions

Some farmers indicated that financing the transition proves difficult. Banks seem reluctant to finance ecological farming practices, which may be explained by their perceived high-risk. As demonstrated in the previous chapter, some of the scenarios in this study involve a significant up-front investment. If this cannot be acquired, the farmer is forced to enter a slow transition process, only transitioning parts of the farm at a time, or only adding farm enterprises to the system as time progresses. Currently, the transition period often involves periods of reduced or insecure income and requires learning and experimenting because of the fact that knowledge on how to transition a farm to sustainable practices is not readily available. A slow transition may not be the most efficient transitioning strategy in the long run, and it may not be an attractive process for the farmer.

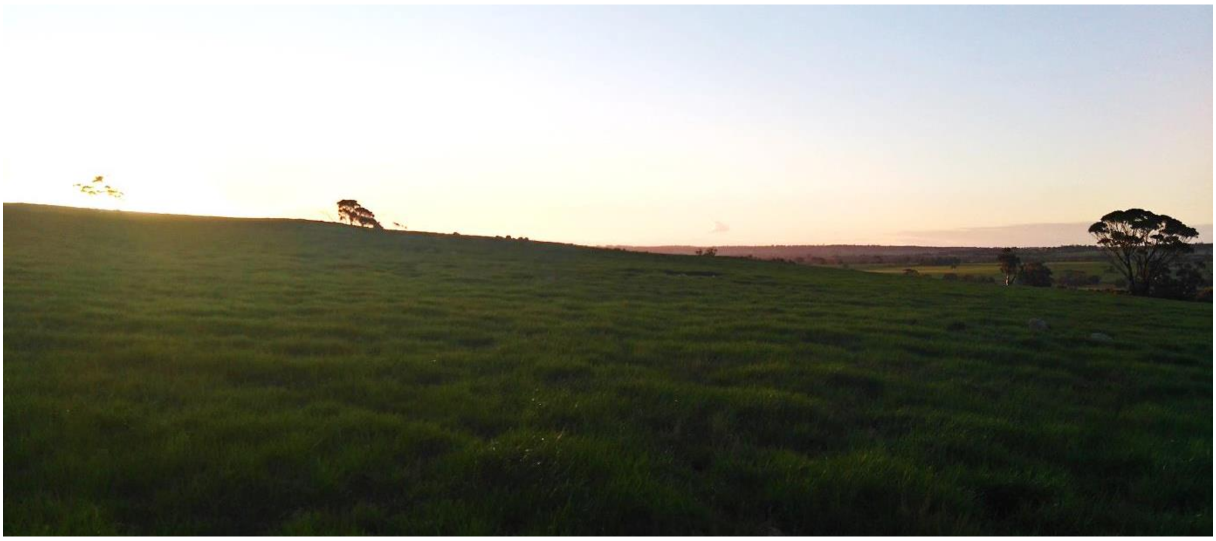


Figure 31 - A paddock which is under rotational grazing management with sheep near Arthur River

4.3.3 Social pressure

Social pressure is another reason interviewees gave why many farmers are not considering a transition towards a different approach to agriculture. The exact reason(s) why there is such social pressure remains unclear, but rural communities seem to not appreciate fellow farmers deviating from the status quo. Some refer to it as the 'tall poppy syndrome'. Some of the interviewees found themselves ostracised from their local community after acquiring organic certification. In rural communities which are already quite small and far apart, such social and intellectual isolation can be difficult to cope with.

4.3.4 Implications for diffusion strategy

Although these results are not statistically significant, they do indicate that a strategy for wide-scale adoption of ecological agriculture will have to be multi-faceted to remove the range of obstacles that appear to exist. It should also be noted that policy or regulations were not mentioned as obstacles, but that does not necessarily exclude them. Future research may point out whether there are more obstacles, and how important these are for the farmers of the Wheatbelt.

4.5 IMPLICATIONS FOR OTHER REGIONS

Although this study has been focusing on the Western Australian Wheatbelt, its implications may reach further. The problems and processes which the Wheatbelt is currently facing are not unique to the Wheatbelt. Other parts of the world where industrial agriculture has been the dominant approach to agriculture face similar problems, of environmental degradation, increasing farm size and dwindling communities. One example is the state of South Dakota in the United States of America. This state shows similar patterns of the loss of thousands of farms between the 1970's and the 2000's with total farmed area remaining the same, while the standard of living and the number of people living in rural communities both dropped significantly; there as well the link between land management and the health of rural communities has been made (Medlin & Medlin, 2004). Not only are the two farms in this report case studies for the Wheatbelt, the Wheatbelt can be considered a case study for the world. There is increasing awareness that the methods that define industrial agriculture are causing a variety of problems, but much more research is necessary to find agro-ecological ways of intensification if the world is going to answer to large challenges such as food security, climate change and extinction of species. In general, the full effects of the way in which farmers manage their land have received little attention from research, while there are indications that they are affecting hundreds of millions of people.

5 CONCLUSION & RECOMMENDATIONS

5.1 CONCLUSION

This report summarises an exploratory, brushstroke study into sustainable agriculture as a possible solution for many of the problems the WA Wheatbelt currently faces. These problems include soil constraints, decreasing farm profit margins, increasing farm scale and the resulting loss of jobs and loss of family farms leading to declining rural communities. Attempts at solutions for these issues have so far mostly been of a technical nature and proven unable to solve the problems sustainably. This study puts forward that the way agricultural land is managed may be the root cause of many or all of the problems mentioned above. From that link it is reasoned that if current land management is the source of the problems, a profound change in land management may be the solution. In this report the following main research question was addressed: how can agriculture in the Wheatbelt be performed in an environmentally, socially and financially sustainable manner?

A scenario-based approach of whole-farm modelling was selected for this study; comparing four ecological farming systems to one conventional (industrial) system on the three pillars of sustainability: environmental, social and financial sustainability. Detailed whole-farm models were built for each farming system, and run for two case study locations. The purpose of this exercise was to gain insight in the long-term functioning of each of the farming systems, and select the one which seemed most promising as a long-term sustainable solution for the Wheatbelt's problems. Due to the hypothetical nature of the scenarios and the methods used in this study some uncertainties remain, however measures were taken to minimise those.

In terms of environmental sustainability it is clear that all ecological scenarios performed significantly better than industrial agriculture. The wood products scenarios seem to provide most environmental benefits, but they are closely followed by dehesa and perennial grazing, and then pasture cropping. Ecological agriculture shows great potential to solve many of the environmental problems in the Wheatbelt.

For social sustainability on-farm employment was used as an indicator. Most of the ecological scenarios are significantly more labour-dependent than industrial agriculture. This results in some farming systems employing over ten times as many people as a similar-sized industrial farm would. This may indicate that farm size could shrink in a future with ecological farming systems, which, according to the Goldschmidt hypothesis, would have beneficial effects for the health of rural communities. The tenfold increase in on-farm employment may be expected to have an important effect on the local economy in rural towns. The pasture cropping and dehesa systems are, out of the systems examined, able to provide most jobs, and may therefore be the best option to revitalise rural communities.

The financial sustainability analysis showed that the timeframe at which farming system profitability is assessed has a large influence on which system performs best. Ecological systems generally take some investment and generally take some time to mature. In the short run, industrial cropping is by far the most profitable option; it is only after five or more years that ecological systems surpass industrial cropping as the most financially attractive option. At 10 years, pasture cropping is the most profitable option, dehesa being the most attractive option at 30 years due to the long wait before the oaks start producing acorns and cork. After adjustments for drought periods, interest on loans and other factors, dehesa performs best on financial sustainability.

Overall, out of the systems examined in this study, dehesa seems the most sustainable alternative. Key characteristics of high potential ecological systems appear to be high diversity of (complementary) farm enterprises, low up-front investment and/or short earn-back time and high on-farm employment. The ecological farming systems here were in no way optimised, which means that there may be even more attractive ecological systems to be designed. Lateral or vertical integration of farming systems, such as the ones considered in this study or other ecological systems, could prove a strategy to design successful ecological farms. On top of that, all ecological designs should have animals, either livestock or wildlife, performing services in the agricultural ecosystem.

So, although no one ideal ecological system could be appointed in this report, it can be stated with reasonable confidence that ecological farming systems are a very promising pathway for providing long-term solutions in the Wheatbelt. And, if the main effects and principles of industrial and ecological agriculture prove to be similar throughout the world, ecological agriculture may also provide such a promising solution for environmental and social decline in industrial agricultural regions elsewhere in the world.

However, despite being such a promising alternative, only few farmers in the study area are farming ecologically at the time of writing. Preliminary research during this study indicated that the reason for this low level of diffusion may be in lack of knowledge or awareness amongst farmers and researchers, but other factors, such as social pressure, lack of finance for the transition, and lack of knowledge and experience sharing amongst practitioners, may play an equally important role. These obstacles to (wide-scale) adoption of ecological agriculture should be researched further and removed; this would perhaps require a multi-faceted approach involving a variety of actors, including practitioners, researchers, policymakers and finance.

Ecological agriculture for now remains a relatively new and unexplored field of both study and practice, but it seems promising in its capabilities to contribute to solving a host of different problems throughout the world. Through applying ecological farming principles farmers potentially not only contribute to revitalising their businesses, their environment and their communities, but also contribute to solving water availability problems downstream, food security issues in their region, regional and global climate change problems and to reducing the use non-renewable resources. It still seems a ‘win-win-win’ scenario for society and the environment, and should therefore receive more attention in future research. Healthy communities start with healthy soils.

5.2 RECOMMENDATIONS

Recommendations following from this study are not only directed at future research, but also at other actors. This section will present recommendations for each group of actors; finance, policymakers, practitioners and researchers.

5.2.1 Research

This study was meant to remain of a brushstroke nature and give direction to future research. There are several directions future research should follow..

First of all, the findings of this study need to be tested in a broader setting for more confidence. This could mean trialling the hypothetical farming systems as they have been designed in this study to test whether the productivity and profitability numbers indeed represent the reality of what is achievable, as well as their capabilities of restoring soil constraints and whether they are able to provide the jobs that they are expected to provide. The scenarios explored in this study were not optimised, so optimisation research may prove whether more gains in sustainability may be achieved, perhaps by integrating some of the systems in this study into one new system, or by reducing or increasing farm size.

A second line of research that follows from the results of this preliminary study is the obstacles to adoption. The discussion mentioned that practitioners, researchers and government officials indicated certain barriers that currently may prevent farmers from transitioning to a more sustainable farming system. Not enough data were available however to fully explore these obstacles in this report; but some literature has appeared on barriers to adoption of sustainable practices and on innovation systems or the diffusion of innovations in agriculture. Future research may compile a list of these obstacles and send out a large sample population survey throughout the Wheatbelt to identify which obstacles there are, and which are perceived most powerful. Based on this information a detailed and well-informed strategy for implementation may be developed.

In general, ecological agriculture is a relatively new and unexplored field of study, especially in the Wheatbelt. The farming systems explored in this study were only examples of systems, many more are possible. More research, perhaps participatory research, is necessary into the overarching principles of design for ecological farming systems, the results of which should be extended in usable form to farmers in the region. These principles may take on the form of a framework of principles, within which there is enough room for the farmer's own creativity and preferences to create his or her own system. The effects that a transition from an industrial farm to an ecological farm has on the environment, communities and farm profitability should be monitored.

Another angle future research could take is to explore the link between land management and decline of rural Wheatbelt communities more. In this study the link was made, and there is enough qualitative evidence to be reasonably confident about this link, but it proved difficult to find quantitative data to size e.g. the increase in farm expenditures, the decrease of farm profit margins and their correlation with rural depopulation. A future study could look into collecting population dynamics for rural Wheatbelt towns and collect data on farm profitability and farm foreclosures (or farm size) from the farms surrounding them.

In the light of climate change, ecological systems seem to have another advantage. They may prove to be more resilient to climate change than industrial systems. They may even, similar to forests, be able to influence climate change through more evaporation and through the microclimates they create. The resilience against and influence on climate change of different ecological farming systems should be looked into. In the decades to come the climate in the region is expected to warm, and winter precipitation is expected to decrease (Intergovernmental Panel on Climate Change, 2007). This has already occurred over recent decades (figures 34 and 35), and the trend is expected to continue.

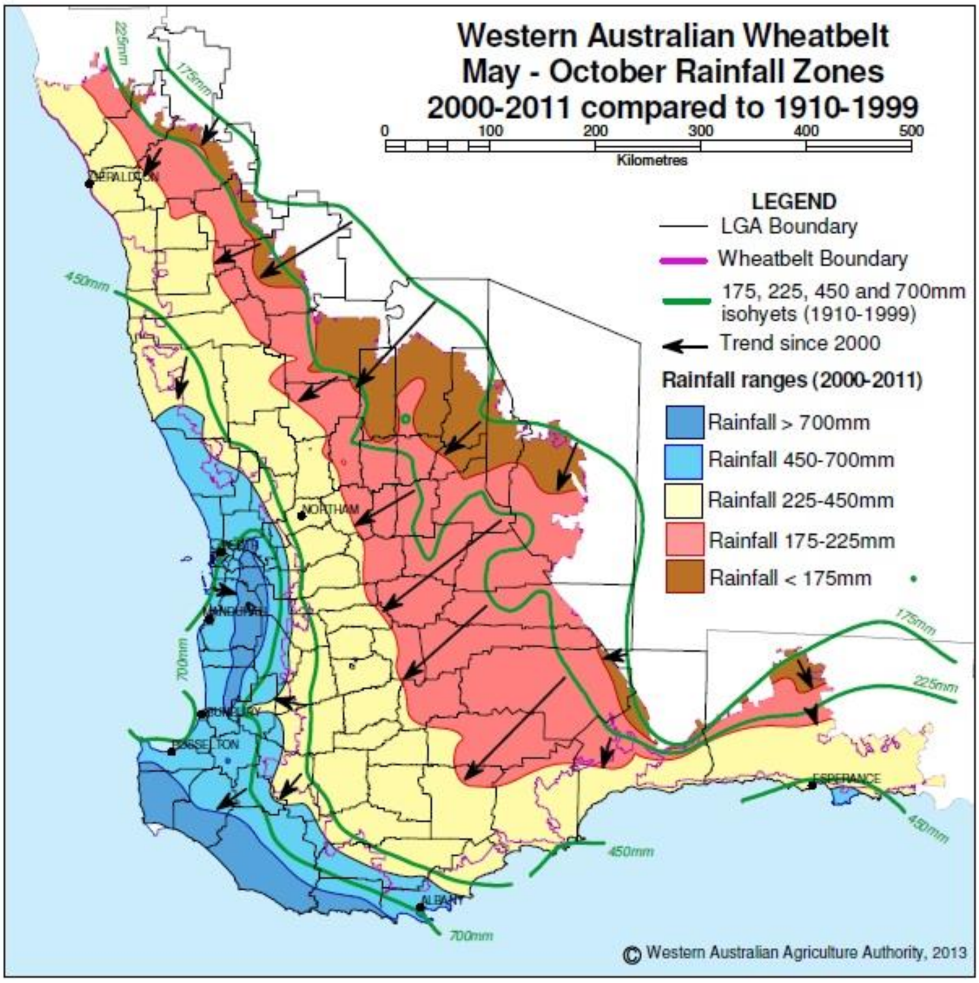


Figure 32 - Rainfall isohyets moving, showing the extent of climate change that has already taken place. Source: Department of Agriculture and Food, WA (2013).

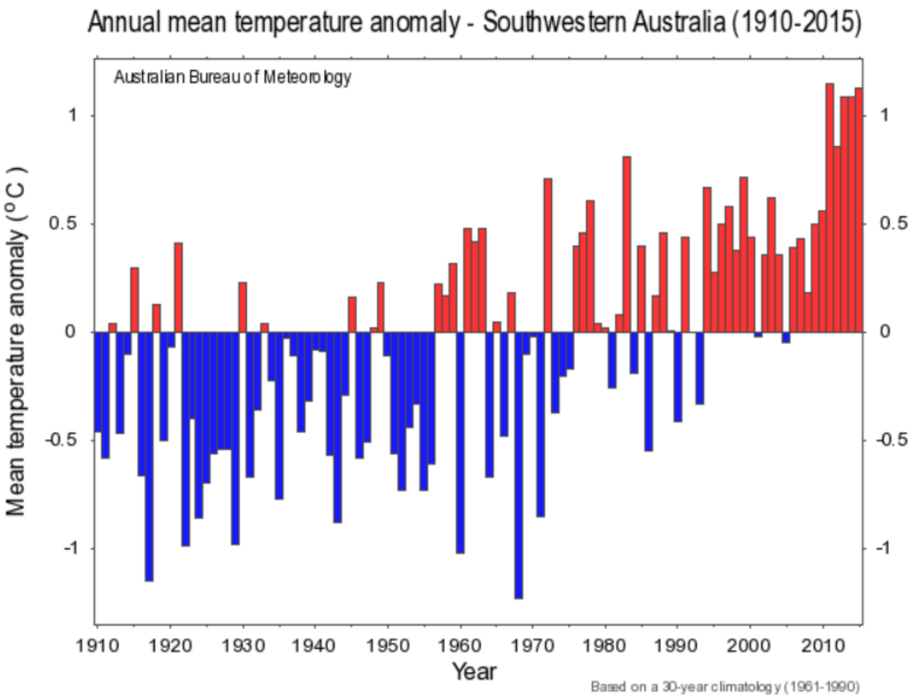


Figure 33 - Average temperature in south-western Australia, demonstrating climate change that has already occurred. Source: Australian Bureau of Meteorology (2015)

5.2.2 Practitioners

Few practitioners in the Wheatbelt seem to be aware of the existence and potential benefits of ecological agriculture, and even fewer know how to apply it. This is a major obstacle to adoption of ecological agriculture. Information currently is available on the principles of ecological agriculture, but improvement of region-specific information and awareness-raising may be advisable to improve the spread of knowledge. The merits that ecological agriculture can have in the Wheatbelt should be explored and documented more.

From the results of this research there is, at the time of writing, no best practice of ecological farming in the Wheatbelt yet. Farmers should therefore remain creative in their application of ecological agriculture. This means adopting the principles as a framework for farming, but experimenting within that framework which enterprises can be combined well. In enterprise selection diversity appears key in successful ecological agriculture; both diversity in 'stacking' different complementary enterprises on the same pieces of farmland, as spatial variation in the types of systems applied (i.e. zoning of the farm in different farming systems), as diversity in the species used (i.e. no monocultures). Local/Aboriginal knowledge on native ecosystems and farming systems may prove very useful on this quest. Diversity seems to improve both economic and ecological resilience.

In this exploration of ecological agriculture one observation is that one has to move the farming system 'all the way' to ecological agriculture to be successful. It seems that systems which are halfway between conventional and ecological farming provide the benefits of neither system and may not produce the expected results. A complete change in mind-set is required, which can be difficult. Farmers may experiment and practice with ecological agriculture on small portions of the farm first; transitioning the rest of the farm once they have mastered the principles and gained confidence that the new farming system will provide more benefits than the conventional model.

There are different ways of transitioning that may be explored, which are trade-offs between the size of up-front investment and time required for the transition, being:

1. transitioning the whole farm at once, establishing all new farm enterprises simultaneously
2. establish all new farm enterprises simultaneously, but only on certain sections of the farm at a time
3. transitioning the whole farm at once, but one farm enterprise at a time, slowly adding enterprises to the system as time passes

The first strategy may require the largest financial investment; the last may not be efficient from both an ecosystem and a farm business perspective.

Ecological agriculture in the region is still quite new and untested. In exploring its rules and merits, it could prove helpful if it went hand in hand with knowledge sharing and perhaps some coordination of trials. This would prevent people from making potentially costly mistakes that colleague farmers have already made before, and would allow for a trialling/research programme in which a great array of different systems, methods and technologies can be tested. This may increase the efficiency of the exploration of ecological agriculture possibilities in the region and may make progress in the knowledge of this approach to farming happen more quickly.

5.2.3 Finance

The agricultural finance sector, too, may need to take action. It has proven difficult for some of the interviewed farmers to obtain finance for their farming systems. Ecological agriculture currently may be perceived as a higher risk investment than conventional, industrial agriculture because it is such a new area. Secondly, the time horizon for repayment of investments may be less favourable for investors in ecological agriculture, due to the fact that ecological systems may take years to mature and enter full production.

However, as has been stated elsewhere in this report, industrial agriculture seems to become an increasingly vulnerable and decreasingly profitable system. Therefore to keep investing in industrial agriculture may, in the end, prove more risky than investing in ecological farming. The main risk in ecological agriculture currently may be the lack of knowledge. If finance would invest in knowledge and capacity building in ecological agriculture, particularly knowledge on the transition stage, this obstacle may be removed.

The comparative risk of ecological systems and industrial systems in the context of the Wheatbelt and the time period at which farm loans need to be repaid should be explored more. Lack of funds currently stops farmers from transitioning to ecological systems which are more sustainable and in the long run may be significantly more profitable. If ecological farming is to be adopted throughout the region this needs looking into.

5.2.4 Policymakers

This study has not looked into policy as a factor in the spreading of ecological agriculture. There may be policies and incentive structures currently in place that incentivise farmers to choose industrial systems over ecological systems, or even prevent farmers from employing practices which are part of ecological agriculture. This must be looked into. Considering that ecological agriculture may have significantly higher benefits for society in the WA Wheatbelt than industrial systems, policymakers should reassess which system they want to incentivise. Another option is to level the playing field; enabling practitioners to choose which approach to farming they want to employ, but some policies or regulations may need to be altered or lifted to allow them to do so. Policymakers may need to change policies, regulations and incentive systems to create the enabling environment required for large-scale adoption of ecological agricultural systems throughout the region.

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Appendix: Farming System Description & Establishment

This appendix describes each of the farming systems and the establishment strategy used for the modelling in this study in more detail.

A.1 Business-as-usual

Croppers generally crop canola, wheat, barley, oats, lupins and field peas in rotation. Cropping happens over the wet winters, in summer most crop fields are left fallow. As a response to severe wind erosion events in the sixties and seventies more than 90% of farmers nowadays use no-till techniques (Llewellyn & D'Emden, 2014). The average farm size ranges from about 4000 hectares in the southwest to more than 6000 hectares in the northeast, and farms are generally managed by only one or two people. If necessary, contractors are hired to perform certain activities; this generally occurs during harvest or sheep shearing time. Many Wheatbelt farms have become 100% cropping enterprises only over the last two decades, before that a mix of cropping and sheep, and sometimes cattle, was quite common. The cropping businesses are very machinery and chemical intensive. The WA climate is highly variable and occasional periods of drought, which may last up to 10 years, have led to crop failures and loss of income ever since the land was cleared.

A.2 Perennial native grazing

This scenario is a grazing-only system and is based on perennial plant species that are native to the region. Perennial pastures are intercropped with blocks of fodder shrubs. Perennial grasses have demonstrated to be much faster at building black soils than annual pastures, and have the added benefits of an extended growing and a cost saving from not needing to sow them. The fodder shrubs in this system provide another means of keeping green feed during periods of low growth, and provide other nutrients to livestock than the pastures do. They also provide habitat for beneficial insects and small birds and create a protective microclimate. On top of all that their deep root systems transport water and nutrients from depth and deposit them at the surface where they are within reach of the pasture.

Best practice in livestock management is considered to be low stress, successional rotational cell grazing. The low stress component is important because it reduces the amount of infrastructure needed and increases the willingness of livestock to try feeds that they are not used to. Rotational grazing is much better suited to perennial pastures than set stock grazing; set stock grazing does not allow recovery and the most palatable species are removed by natural selection, leaving a very poor pasture. Rotational management allows little selectivity on the grazer's side and allows the pasture to recover. Livestock is kept in high density on small areas for a short time, followed by a long rest period for the pasture. This way of grazing on perennial pastures has been found to reduce weed pressure, increase pasture species diversity and pasture productivity and accelerate soil building. Adding more livestock species to the mix is an improvement from an economic and ecological perspective.

Different types of livestock show different grazing patterns and can actually be quite complementary. Cattle for instance do very well as a first grazier, but leave large clumps of grass behind. Chickens only eat grasses as part of their diet and need grains to supplement their diet, but they also eat pest larvae and parasites that settle in the cow dung. Their nitrogen-rich manure sparks a quick regrowth of grass. Then the sheep come in, being nature's lawnmowers they eat the grass almost right down. When the sheep move out the pasture is left for at least three to four months to recover. More species can be used but for the sake of simplicity only these three species are considered for this study. The cattle operation is a beef cattle breeder operation, the sheep are mixed lamb/wool with own breeders and the poultry are chickens for eggs that house in 'chicken tractors'; mobile hen houses. This type of livestock management is used for all scenarios involving livestock.

Establishment

Transitioning from an industrial cropping system to this scenario was designed roughly as follows. The industrial farm will most likely be faced with soil constraints. These constraints will limit the root growth of perennial pastures and shrubs as much as they would normal crops. An approach for establishing pasture (or healthy crops) that has been proven in practice in the Wheatbelt focuses on establishing and feeding soil life. Soil microbes are spread out and fed using a mix of biological sprays. Barley has been found a vigorous crop that can establish in difficult soils, and its roots will host the microbes for the first two years. In principle, no pesticides, herbicides or fungicides are used.

This initial soil life will quickly start building soil organic matter and start removing the soil constraints. After about two years, the conditions at the surface will have been improved to an extent that native seeds that are still in the seed bank will germinate. Management then switches from crop to grazing, livestock will have to be acquired, and the intense grazing followed by extended periods of rest will allow the pasture to develop itself within a couple of years to a diverse, native mix of annual and perennial species. Their thick root mass will extend down into the soil and start breaking down the salinity, the acidity and the compaction. They will start to build organic matter, and water infiltration and retention will improve significantly. The shrubs will be planted in the second year of crop, a choice which is a balance between allowing the soil to improve before putting in shrubs and the time at which livestock can enter the system without destroying the shrubs by overgrazing them because they are too small. After these initial years of establishment livestock numbers can slowly be increased as the paddocks become healthier and carrying capacity increases.

A.3 Pasture cropping

Pasture cropping is a collection of practices where crops are planted into pasture paddocks. In some cases the paddocks are partially or wholly sprayed out before the crop is sown, in other practices the farmer seeds straight into the pasture. In the chosen scenario the farmer sows straight into perennial pasture. This scenario is based on data from no-kill cropping, a stream within pasture cropping. No-kill croppers crop straight into pasture and do not apply any chemicals or fertilisers. No-kill croppers are generally yielding about one fifth of industrial croppers, but the costs are only about one tenth (Bruce Maynard, personal communication). However, these paddocks do provide feed from the pasture and that makes overall biomass production in these paddocks about 30-40% higher than in industrial paddocks. Main advantages over industrial cropping are permanent ground cover, reduced weed, pest and disease pressure and quick soil building; perennial grasses are amongst the quickest ways to build soil organic matter because of the depth and volume of the root mass.

Establishment

For establishment a similar method to the perennial grazing scenario is used; two years of traditionally sown barley crops with biology sprays to get soil life re-established, followed by leaving all paddocks fallow to give the seeds in the seed bank a chance to germinate. It is estimated that after two years of grazing the pastures will have established themselves to a point where weed pressure is no longer a factor for the crops, so in year five the first crop is planted following no-kill principles. All paddocks need regular grazing to improve and maintain pasture health, which means that part of the farm needs to be set aside each season to maintain the livestock during the cropping season. Two-thirds of the property is reserved for this. We assume normal crop prices; i.e. no premium price for organic produce.

A.4 Dehesa

The system originates from Spain, where it was developed over the last six thousand years under very similar conditions to those in the Wheatbelt. The dehesa system has not been set up in WA on a significant scale; only one instance of a dehesa system in the state is currently known (dehesa analogue). The dehesa is a man-made ecosystem that can be described as an oak woodland or oak savannah, and has been created and maintained using livestock (sheep, cattle, pigs and goats) and fire (Alagona et al., 2013) as tools. The advantages of a savannah type system over a single-layered pasture landscape are those of microclimate (temperature, evaporation and moisture control, wind speed buffering), deep nutrient cycling and added productivity (fodder, cork, acorns). Pigs are grazed in the dehesas and subsequently finished on the dropped acorns in fall. Evidence suggests that the trees positively influence the pasture productivity in their direct neighbourhood (Moreno et al., 2013).

Establishment

The 'classic' Spanish dehesa design was chosen for these locations. The basis of the dehesa is a perennial pasture. This will be established in the same way the previous two scenarios are. A mix of cork oaks, holm oaks and carobs will be direct seeded in year 3. They will be seeded at a density of 36 stems per hectare. Stem spacing will be about 16.5 metres, with crown diameters of 7-8 metres. To establish every tree three seeds will be planted in close proximity, with added compost and tree guards to protect them from livestock, kangaroos and parrots. After three years the most vigorous of each group of three saplings will be selected, the other two removed if not already deceased. To speed up initial growth the trees will be irrigated occasionally during the first eight years. Tree guards will be removed once the trees have become large enough to not be harmed by livestock.

A.5 Wood Products

This scenario does not employ livestock but rather focuses on timber and timber-related products. The scenarios are not identical for both case study locations. In the south, the scenario is one of native, biodiverse reforestation with some species for timber. The timber species are Red Ironbark, Sugargum, and Swamp and Rock Sheoak. These will be seeded along with endemic Jarrah, Marri, Yate and Wandoo with their natural understory. The production trees will be partially removed at years 7 and 20, followed by a final felling at age 30. After this the land is put under conservation.

These timber species will not grow quickly enough in the north of the Wheatbelt without irrigation, which was deemed too expensive. On top of that there are also no sawmills anywhere near the northern case study location, which would make transport prohibitively expensive. A different model was developed which is based on sandalwood nut and wood production. Sandalwood is planted in rows that are accessible to harvesting machinery, and surrounded by a diverse mix of hosts. The nuts will be harvested and sold from year 5 onwards, the sandalwood will be harvested at age 15 (partial) and 30. There is potential for selling some of the hosts for timber, posts or firewood.

Establishment

Establishment for both locations is reasonably similar. Before seeding the soil will need to be prepared by pulling rip lines in which to sow. The southern timber scenario will be partially direct seeded, partially hand planted, with form pruning in years 2, 3, 4 and 5, thinning in year 6, felling at age 20 and 30. The northern sandalwood scenario will be completely direct seeded, with pruning in years 2, 3, 4 and 5, thinning in year 15 and harvest at age 30. Both will be fertilised during the first couple of years.