Integrating Climate Change Mitigation and Adaptation Options into Farms in the Southwest of Western Australia

by

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I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

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Abstract

This research reviews existing climate change literature and quantifies the climate change mitigation and adaptation potential of specific agricultural diversification activities at an individual farm level. It comprises modelling and simulations of net emission reductions and discounted market values of a range of small-scale renewable energy and carbon sequestration projects. The research aim is to enable private agricultural entities and governments to compare alternative investment options for both climate change mitigation and adaptation in the southwest of Western Australia. The research includes an analysis of ten small-scale renewable electricity systems and a range of sub-scenarios. In addition, six forestry sequestration projects are modelled, and one analysis of displacing fertiliser by using biochar are assessed.

The results indicate that privately-owned, small-scale, grid-connected renewable energy systems were not competitive adaptation options for private entities relative to sourcing electricity from centralised renewable electricity generators connected to the network. The total discounted capital and operating costs, and the relatively minor mitigation potential of the small-scale energy systems resulted in very high mitigation costs. The overall discounted values of the systems were relatively insensitive to the magnitude of the existing subsidy mechanisms, either capital subsidies or feed-in tariffs.

The forestry sequestration project results for the higher rainfall region show large differences in total discounted project costs over time. These costs were highly dependent on the project financing arrangements, while the tree species selection, and the previous land use were primary determinants of the biomass growth and the total carbon sequestered. The results indicate that the most productive agricultural lands in the region might be permanently retired from food production and replaced by single species tree plantations, although the viability of this option is dependent on future carbon market eligibility rules and carbon values. The biochar sequestration modelling results indicate that a reduction of phosphorus fertiliser use in low-rainfall cropping regions was possible when applying large quantities of biochar to the soil. The cost-effectiveness of using biochar in cropping systems was found to be insensitive to phosphorus fertiliser price or carbon market values. In contrast, the commercial viability of this option was highly dependent on the price paid for biochar, rather than the carbon price.

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List of Acronyms

CBA	Cost-benefit analysis
CCIAV	Climate Change Impacts, Adaptation and Vulnerability
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalent
COMAP	Comprehensive Mitigation Assessment Process
COP	Conference of the Parties
DSM	Demand side management
DCF	Discounted cash flow analysis
ENSO	El Niño / Southern Oscillation Index
GDP	Gross Domestic Product
GSP	Gross State Product
Gt	Gigatonne
GWP	Global Warming Potential
Ha	Hectare
IAM	Integrated Assessment Model
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal rate of return
kJ	Kilojoule
KP	Kyoto Protocol
kW	Kilowatt
kWh	Kilowatthour
MC	Marginal cost
MJ	Megajoule
MW	Megawatt
MWh	Megawatthour
MP	Marginal price
NPC	Net present cost
NPV	Net present value
RDC	Research and Development Corporation
REC	Renewable Energy Certificate
R&D	Research and development
RD&E	Research, development and extension

SGU	Small generating unit
SRES	Special Report on Emission Scenarios
SW	Southwest
SWIS	Southwest Interconnected System
tC	Tonne of carbon
tCO_2	Tonne of carbon dioxide
tCO_2-e	Tonne of carbon dioxide equivalent
UNFCCC	United Nations Framework Convention on Climate Change
WA	Western Australia

Glossary

Adaptation: initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. The various types of adaptation include: anticipatory and reactive; private and public; and, autonomous and planned (Intergovernmental Panel on Climate Change 2007).

Adaptation benefits: the avoided damage costs of the accrued benefits following the adoption and implementation of adaptation measures (Intergovernmental Panel on Climate Change 2007).

Adaptation costs: costs of planning, preparing for, facilitating, and implementing adaptation measures, including transition costs (Intergovernmental Panel on Climate Change 2007).

Adaptive capacity: the whole of capabilities, resources and institutions of a country or region to implement effective adaptation measures (Intergovernmental Panel on Climate Change 2007).

Afforestation: planting of new forests on lands that historically have not contained forests (for at least 50 years).

Barrier: any obstacle to reaching a goal, adaptation or mitigation potential that can be overcome or attenuated by a policy, programme, or measure (Intergovernmental Panel on Climate Change 2007).

Barrier removal: includes correcting market failures directly or reducing transaction costs in the public and private sectors by e.g. improving institutional capacity, reducing risk and uncertainty, facilitating market transactions, and enforcing regulatory policies (Intergovernmental Panel on Climate Change 2007).

Baseline: reference for measurable quantities for which an alternative outcome can be measured (Intergovernmental Panel on Climate Change 2007).

Biomass: the total mass of living organisms in a given area or volume; recently dead plant material is often included as dead biomass. The quantity of biomass is expressed as a dry weight of as the energy, carbon, or nitrogen content (Intergovernmental Panel on Climate Change 2007).

Climate change: refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. The United Nations Framework Convention on Climate Change (UNFCCC) defines climate changes as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (Intergovernmental Panel on Climate Change 2007).

Co-benefits: the benefits of policies implemented for various reasons at the same time, acknowledging that most policies designed to address greenhouse gas mitigation have other, often at least equally important, rationales (Intergovernmental Panel on Climate Change 2007).

Complementarity: the inter-relationship of adaptation and mitigation whereby the outcome of one supplements or depends on the outcome of the other (Klein et al. 2007).

Deforestation: conversion of forest to non-forest (Intergovernmental Panel on Climate Change 2007).

Discounting: a mathematical operation making monetary (or other) amounts received or expended at different points in time (often years) comparable across time. The operator uses a fixed or possibly a time-varying discount rate (>0) from year to year that makes future value worth less today (Intergovernmental Panel on Climate Change 2007).

Fossil fuels: carbon based fuels from fossil hydrocarbon deposits, including coal, peat, oil and natural gas (Intergovernmental Panel on Climate Change 2007).

Greenhouse gas: those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect (Intergovernmental Panel on Climate Change 2007).

Gross Domestic Product (GDP): is the monetary value of all goods and services produced within a nation (Intergovernmental Panel on Climate Change 2007).

Implementation: describes the actions taken to meet commitments under a treaty and encompasses legal and effective phases. Legal implementation refers to legislation, regulation, judicial decrees, including other actions such as efforts to administer progress which governments take to translate international accords into domestic law and policy. Effective implementation needs policies and programmes that induce change s in the behaviour and decisions of target groups. Target groups then take effective measures of mitigation and adaptation (Intergovernmental Panel on Climate Change 2007).

Kyoto Protocol: the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1997 in Kyoto, Japan, at the Third Session of the Conference of the Parties (COP) to the UNFCCC. It contains legally binding commitments, in addition to those included in the UNFCCC. Countries included in Annex B of the Protocol agreed to reduce their anthropogenic greenhouse gas emissions by at least 5% below 1990 levels in the commitment period 2008 to 2012. The Kyoto Protocol entered into force on 16 February 2005 (Intergovernmental Panel on Climate Change 2007).

Land-use: refers to the total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction, and conservation, etc.) (Intergovernmental Panel on Climate Change 2007).

Land-use change: refers to a change in the use or management of land by humans, which may lead to a change in land cover. Land cover and land-use may have an impact on the surface albedo, evapotranspiration, sources, and sinks of greenhouse gases, or other properties of the climate system and may thus have a radiative forcing and/or other impacts on climate, locally or globally (Intergovernmental Panel on Climate Change 2007).

Mainstreaming: the integration of policies and measures to address climate change in ongoing sectoral and development planning and decision-making, aimed at ensuring the sustainability of investments and at reducing the sensitivity of development activities to current and future climate conditions (Klein, Schipper, and Dessai 2005), as cited by (Klein et al. 2007).

Measures: technologies, processes and practices that reduce greenhouse gas emissions below anticipated future levels. Examples of measures are renewable energy technologies, waste minimisation processes, and public transport commuting practices, etc. (Intergovernmental Panel on Climate Change 2007).

Mitigation: technological change and substitution that reduce resource inputs and emissions per unit of output. Although several societal, economic and technological policies would produce an emissions reduction, with respect to climate change, mitigation means implementing policies to reduce greenhouse gas emissions and enhance sinks (Intergovernmental Panel on Climate Change 2007).

Mitigation Potential: the amount of mitigation that could be – but is not yet – realised over time (Intergovernmental Panel on Climate Change 2007). Studies of market potential can be used to inform policymakers about mitigation potential with existing policies and barriers, while studies of economic potential show what might be achieved if appropriate new and additional policies were put into place to remove barriers and include social costs and benefits. The economic potential is therefore generally greater than the market potential (Intergovernmental Panel on Climate Change 2007).

Net market benefits: climate change, especially moderate climate change, is expected to bring positive and negative impacts to market-based sectors, but with significant differences across sectors and regions and depending on both the rate and magnitude of climate change. The sum of the positive and negative market-based benefits and costs summed across all sectors and all regions for a given period is called net market benefits. Net market benefits exclude any non-market impacts (Intergovernmental Panel on Climate Change 2007).

No behest option: when the benefits of an activity equal or exceed both the costs to the private investor and the society, excluding the benefits of avoided climate change (McHenry 2011).

No regrets option: when the benefits of an activity equal or exceed costs to society, excluding the benefits of avoided climate change (Intergovernmental Panel on Climate Change 2001).

Non-market impacts: are impacts that effect ecosystems or human welfare, but that are not easily expressed in monetary terms, e.g., an increased risk of premature death, or increases in the number of people at risk of hunger (Intergovernmental Panel on Climate Change 2007).

Opportunities: circumstances to decrease the gap between the market potential of any technology or practice and the economic potential, or technical potential (Intergovernmental Panel on Climate Change 2007).

Policies (in terms of the UNFCCC): are taken and/or mandated by a government, often in conjunction with business and industry within its own country, or with other countries, to accelerate mitigation and adaptation measures. Examples of policies are carbon and other energy taxes, fuel efficiency standards for automobiles, etc. (Intergovernmental Panel on Climate Change 2007).

Portfolio: a coherent set of actions to achieve a particular goal. A climate policy portfolio may include adaptation, mitigation, research and technology development, as well as other actions aimed at reducing vulnerability to climate change. By widening the scope in measures and technologies more diverse events and uncertainties can be addressed (Klein et al. 2007; Intergovernmental Panel on Climate Change 2007).

Projection: a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions in order to emphasize that projections involve assumptions concerning, for example, future socio-economic and technological developments that many may not be realised, and are therefore subject to substantial uncertainty (Intergovernmental Panel on Climate Change 2007).

Reforestation: planting of forests on lands that previously contained forests but that have been converted to some other use (Intergovernmental Panel on Climate Change 2007).

Region: is a territory characterised by specific geographical and climatological features. The climate of a region is affected by regional and local-scale forcings like topography, land-use characteristics, lakes etc., as well as remote influences from other regions (Intergovernmental Panel on Climate Change 2007).

Resilience: the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity

for self-organisation, and the capacity to adapt to stress and change (Intergovernmental Panel on Climate Change 2007).

Scenario: a plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combines with a narrative storyline (Intergovernmental Panel on Climate Change 2007).

Sensitivity: is the degree to which a system is affected, either adversely or beneficially, by climate variability or climate change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise) (Intergovernmental Panel on Climate Change 2007).

Social costs and discount rates: reflect the perspective of a society. Social discount rates are lower than those used by private investors (Intergovernmental Panel on Climate Change 2007).

Tax: a carbon tax is a levy on the carbon content of fossil fuels. Because virtually all of the carbon in fossil fuels is ultimately emitted as carbon dioxide, a carbon tax is equivalent to an emissions tax on each unit of CO_2-e emissions. An energy tax – a levy on the energy content of fuels – reduces demand for energy and so reduces carbon dioxide emissions from fossil fuel use. An eco-tax is designed to influence human behaviour (specifically economic behaviour) to follow an ecologically benign path. An international carbon/emissions/energy tax is a tax imposed on specified sources in participating countries by an international agreement. A harmonised tax commits participating countries to impose a tax at a common rate on the same sources. A tax credit is a reduction of tax in order to stimulate purchasing of or investment in a certain product, like greenhouse gas emission reducing technologies. A carbon change is the same as a carbon tax (Intergovernmental Panel on Climate Change 2007).

Technology: the practical application of knowledge to achieve particular tasks that employs both technical artefacts (hardware, equipment) and (social) information ("software", know-how for production and use of artefacts) (Intergovernmental Panel on Climate Change 2007).

Technology transfer: the exchange of knowledge, hardware and associated software, money and goods among stakeholders that leads to the spreading of technology for adaptation or mitigation. The term encompasses both diffusion of technologies and technological cooperation across and within countries (Intergovernmental Panel on Climate Change 2007).

Tradable permit: is an economic policy instrument under which rights to discharge pollution – in this case an amount of greenhouse gas emissions – can be exchanged through either a free or controlled permit-market. An emission

permit is a non-transferable or tradable entitlement allocated by a government to a legal entity (company or other emitter) to emit a specified amount of a substance (Intergovernmental Panel on Climate Change 2007).

Trade-off: a balancing of adaptation and mitigation when it is not possible to carry out both activities fully at the same time (Klein et al. 2007).

Uncertainty: an expression of the degree to which a value (e.g., the future state of the climate system) is known. Uncertainty can result for lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures, for example, a range of values calculated by various models, or by qualitative statements, for example, reflecting the judgement of a team of experts (Intergovernmental Panel on Climate Change 2007).

United Nations Framework Convention on Climate Change (UNFCCC): the Convention was adopted on 9 May 1992 in New York and signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries and the European Community. Its ultimate objective is the "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". It contains commitments for all Parties in Annex I (all OECD member countries in the year 1990 and countries with economies in transition) aim to return greenhouse gas emissions not controlled by the Montreal Protocol to 1990 levels by the year 2000. The Convention entered into force in March 1994 (Intergovernmental Panel on Climate Change 2007).

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Publications Arising from Thesis

Published Peer Reviewed Journal Articles:

M. P. McHenry (*in press*) How farming and forestry converge: enhancing the interface between agricultural production and tree biomass systems to improve farm-scale productivity in Western Australia. Australian Forestry.

M. P. McHenry (2012) Small-scale (≤6 kWe) stand-alone and grid-connected photovoltaic, wind, hydroelectric, biodiesel, and wood gasification system's simulated technical, economic, and mitigation analyses for rural regions in Western Australia. Renewable Energy 38 195-205.

M. P. McHenry (2012) A technical, economic, and greenhouse gas emission analysis of a homestead-scale grid-connected and stand-alone photovoltaic and diesel systems, against electricity network extension. Renewable Energy 38 126-135.

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M. P. McHenry (2011) Integrating climate change mitigation and adaptation: Refining theory for a mathematical framework to quantify private and public cost-effectiveness, and carbon emissions for energy and development. Renewable Energy 36(4) 1166-1176.

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Published Edited Book Chapters:

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M. P. McHenry (*in press*) Practicalities of establishing forestry carbon sequestration projects in the agricultural sector: a technical and economic analysis with implications. In Carbon Sequestration: Technology, Measurement Techniques and Environmental Effects. Ed. TBA, Hauppauge, New York. ISBN TBA.

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M. P. McHenry, M. Schultz, & K. O'Mara (in press) Wholesale electricity markets and electricity networks: balancing supply reliability, technical governance, and market trading in the context of Western Australian energy disaggregation and marketisation. In: Advances in Energy Research, Volume 5. Ed. A. R. McAdams. Nova Science Publishers, Hauppauge, New York. ISBN 978-1-61761-897-0.

M. P. McHenry (2009) Synergies between conventional soil organic carbon, farm productivity, soil sequestration and soil carbon market risk in Australia. In: No-Till Farming: Effects on Soil, Pros and Cons, and Potential. Ed. E. T. Nardali. Nova Science Publishers, Hauppauge, New York. ISBN 978-1-60741-402-5.

Relevant Journal Publications:

M. G. Borines R. L. de Leon, & M. P. McHenry (*in press*) Bioethanol production from farming non-food macroalgae in Pacific island nations: Chemical constituents, bioethanol yields, and prospective species in the Philippines. Renewable and Sustainable Energy Reviews.

M. G. Borines, M. P. McHenry, & R. L. de Leon (2011) Integrated macroalgae production for sustainable bioethanol, aquaculture and agriculture in Pacific island nations. Biofuels, Bioproducts and Biorefining 5(6) 599-608.

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Prologue

Our family have been farming in Western Australia for over 110 years. I grew up on the family farm, went to school in the local public schools until year 12, and moved to Perth for part-time work and a tertiary education. In Perth I met my wife Julia, and we now are both undertaking our PhD's while running part of the farm with dad, mum, my brother, and his wife. After some years in Perth, we plan to build and live on the farm.

We are both committed to the future of rural and regional areas, which is clear from our research. Currently, Julia is undertaking an Australian Research Council funded PhD titled "Arts and Social Wellbeing in Rural Communities". Her honours topic was similarly focussed: "An Exploratory study of Arts Participation and Wellbeing in Regional WA – A Quantitative Study Of Denmark in the Great Southern Region". My own honours thesis was "Australian Agricultural, Energy & Climate Change Policies & Trends in Performance of Stand-alone Power Supply Systems in Pastoral Western Australia".

The primary reason I embarked on this PhD is because the existing information we required to integrate climate change adaptation and mitigation options on our farm, and the policies with some influence over our on-farm planning, were insufficient for our purposes. Expanding my academic research on carbon markets, climate change mitigation measures, renewable energy systems and policy into agricultural production system integration, was based on the principle that incremental and iterative integration was required in this sector – reflecting the incremental evolution of Australian farming over the last few decades. This contrasts with "overly-available" information regarding, in my opinion at least, drastic land-use change policy proposals derived from "top-down" approaches, rather than from a rigorous assessment from those with a reasonable grasp of the modern agricultural sectoral systems.

By collating farm-scale micro-environmental data, manufacturer specifications for energy technology performance, emission factors for new mitigation

options, software tools, existing economic policy and market values (etc.), I was able to undertake feasibility analyses and scenarios to quantify the cost effectiveness and mitigation potential of incorporating some new technologies and practices into farming operations to a finer resolution, specific to the SW of WA.

This research was undertaken on the premise that there is much speculation and under-informed assertions regarding the performance and cost-effectiveness of new small-scale technologies used to mitigate on-farm emissions. Without a balanced commitment to quantify the market value to landholders, policymakers, or the actual mitigation that is possible relative to existing technologies, resultant choices are likely be sub-optimal.

I have aimed to make the information in this thesis relatively simple when compared to my scientific journal article submissions. This was a purposeful attempt to contribute to a body of knowledge more widely read than journal articles, to enable a straightforward review of technology choices for both on-farm and policy decision-makers. As we and many others in our region would like to remain productively farming, I hope this work will be useful to folks exploring potentially viable options to increase our productivity while reducing environmental footprints and vulnerability to climate-related impacts.