Sustainable Development of Catchment Land-use for Multifunctional Agro-ecological Landscapes under a Changing Climate

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The IAFOR International Conference on Sustainability, Energy & the Environment – Hawaii 2017
Official Conference Proceedings

Abstract

Incorporating the likely impacts of climate change into regional and rural planning is vital to accommodate their profound effects on anthropogenic systems such as agriculture that interact with, or are directly dependent on, natural environments. In Australia, adaptation is already occurring at local and regional levels through regulatory shifts, new resource management strategies, and land-use change, both voluntary and forced by regional policies and strategic priorities. Agricultural land-use has been undergoing a transformation. The continuous optimization and direction of adaptation activities provides regional authorities with the opportunity to ensure that economic and environmental benefits are maximized.

This paper outlines research assessing potential land use changes over a long planning horizon (to 2070), by looking at impacts of climate change on agricultural sector of Regional Victoria. The modelling indicates that a transition to intensive horticulture would be biophysically possible and economically feasible. Phasing out livestock farming and replacing it with optimally diversified horticulture would enable largescale protection of existing carbon stocks and guide further carbon sequestration efforts. Well managed land-use would also increase overall resilience, while ensuring its contribution to a less carbon-intensive future of the industry.

This research will develop new framework assessing land suitability of rural areas under rapid change by analyzing both biophysical and socio-economic factors. The proposed strategic foresight scenarios will take into account risks and opportunities presented by projected land-use shifts in the context of local economy.

Keywords: Climate change impacts, adaptation, land-use optimization, strategic foresight, spatial modelling

I. Introduction

Climate change is a serious threat to the world economy, environment and communities, with profound impacts on many systems, particularly agriculture (Meadows et al. 2006; IPCC 2014). The world faces a great challenge to continue producing enough food for a rapidly growing population during an era where natural resources (arable land, water) are scarcer and where the biophysical environment is becoming increasingly unfamiliar to farmers. The key to addressing this challenge is a focus on building adaptive capacity to ensure currently productive regions remain so, and to increase the resilience of farming systems to ensure they remain viable despite the inevitable climate-shocks associated with extreme weather. These can be anything from technological advances, to development of new methodologies that incorporate existing frameworks to ensure successful adaptation of rural regions to climate change and resilience building. Significant economic, social and environmental opportunities can be capitalized on by communities with well-established strategic foresight and planning for the projected climate changes in their regions.

This paper outlines a framework that focuses on bio-physical as well as socio-economic components necessary for a successful regional development planning, with agriculture at the forefront of the development efforts. This framework is applied in the state of Victoria, Australia. The economy of the State of Victoria makes up a significant part of Australian economy. Agriculture formed 21% of national production total gross value in 2014-2015 (ABS 2016). With 60% of the state's land area used for agriculture, its rapid transformation caused by environmental and socio-economic stressors show the great importance of robust planning and decision making (Sposito et al. 2010). Many Victorian regions are known as the 'food-bowl' of Australia and capitalize on their favorable soil and climate conditions as well as close proximity to major ports connecting the state to emerging markets in Asia. Driven by growing middle class, especially in China and India, the Asian-Pacific markets generate demand for a large portion of crop and livestock production, making up a fifth of the national export value (Van Dijk et al. 2013; Faggian et al. 2012; Hatfield-Dodds et al. 2015; Sposito et al. 2010; Beyond Zero Emissions 2014).

All the outlined changes in environmental conditions as well as economic opportunities for regional branches of Victorian agricultural sector indicate a strong need for a better planning across farm, community and regional scales. Planning is generally concerned with reducing the likelihood of failure (for example, by systematically addressing risks, and can therefore be linked to climate change adaptation). This paper will introduce a number of governmental schemes designed to help the Victorian agricultural sector, regional economies, and also the climate change mitigation/adaptation efforts. A number of which have failed due to the lack of foresight in the early planning stages. When compared with planning, foresight techniques are more concerned with proactively shaping events over a long time horizon by developing knowledge about possible futures (and can therefore be linked to building climate resilience). Pro-active along with pre-active approaches advanced by foresight help linking the anticipation of a planning scheme or a regional strategy to the action (Godet 1994) of particular farmers and communities by implementing proposed land-use changes.

The scenario-based crop-yield models generated at this stage of the project will be presented to local farmers and regional government and other planning organizations. Some of which will use the generated information to inform their own conceptual models of their system of interest (be it a farm, a food-production system or a region), which in turn will inform how they think about, and implement, actions that contribute to climate adaptation and resilience. For instance, a farmer may look at the aforementioned models and decide to diversify their production system by introducing a new variety or species. This action, along with the farmers subsequently increased knowledge of the biophysical environment and the plant interactions with it, will contribute to their resilience. The same modelling will have different (complimentary or perhaps competing) implications at higher levels of abstraction (regional-level, food-system level, etc.), which will shape the next stages of the project.

The framework presented throughout this article helps to determine challenges along with opportunities necessary to be included in planning schemes, strategies and policies. Firstly, a *Land Suitability Analysis (LSA)* methodology working with bio-physical variables in a GIS environment will be introduced. The analytic approach will then be followed by a set of climate projections for Victoria, which have to be taken into account when developing all future scenarios and recommendations for the state's regions. Subsequent discussion on the development potential of Regional Victoria analyzes a number of historical shocks and past government programs, looking at their primary incentives as well as outcomes, with the aim of informing future planning decisions. The last section introduces *Strategic Foresight* as a decision making support tool with the aim to increase transparency of regional decision making process and bridge the gap between strategy formulation and implementation.

II. Methods

Land Suitability Analysis (LSA) evaluates a biophysical quality of an area by determining the potential of an optimal land use or cover. This depends on the environmental requirements of targeted commodities to reach an optimal yield without compromising vital attributes such as fertility and biodiversity (Ferretti & Pomarico 2013; Malczewski 2004; Romeijn et al. 2016). Even though this approach is predominantly analytical, it also incorporates expert opinion of specialists and farmers to reflect their knowledge in the evaluation stages of the commodity models and output maps. The early participation of regional stakeholders contributes to an overall transparency, making projects truly regional and tailored to the needs of local communities. The expert involvement increases robustness of the environmental models, ensuring an appropriate representation from specialists in fields integrated in the land-use and managed ecosystems science. To further enhance the relevance of our research findings and their translation into plans, strategies and policies, this framework proposes a further use of both experts from local institutions, commercial bodies and individual farmers to account for the uneven distribution of information (Farmer & Foley 2009) and diverse perspectives of the involved parties. Their evaluation and the resulting consensus between scientific expert and local knowledge is critical to form pertinent decisions about future land use and the role of agriculture in local economies.

Land Suitability Analysis

Multiple Criteria Analysis (MCA, or Evaluation MCE) is a commonly utilized methodology used to develop the aforementioned mathematical suitability models. It uses suitability as a proxy for crop yields that determine values of all underlying environmental attributes (Sposito et al. 2013; Romeijn et al. 2016). It considers 3 main variables: *Climate, Soil* and *Landscape*, with assigned weights depending on their influence on commodity growth and subsequently yield. Those variables are subdivided into several other attributes, whose value ranges are set to meet the optimal yield, with indexes ranging from 0.0 to 1.0 depending on the agricultural potential of 0% to 100% suitability. The attributes with their criteria are analyzed using an *Analytical Hierarchy Process (AHP)* developed by Saaty (1987) an example of which can be found in Figure 1.

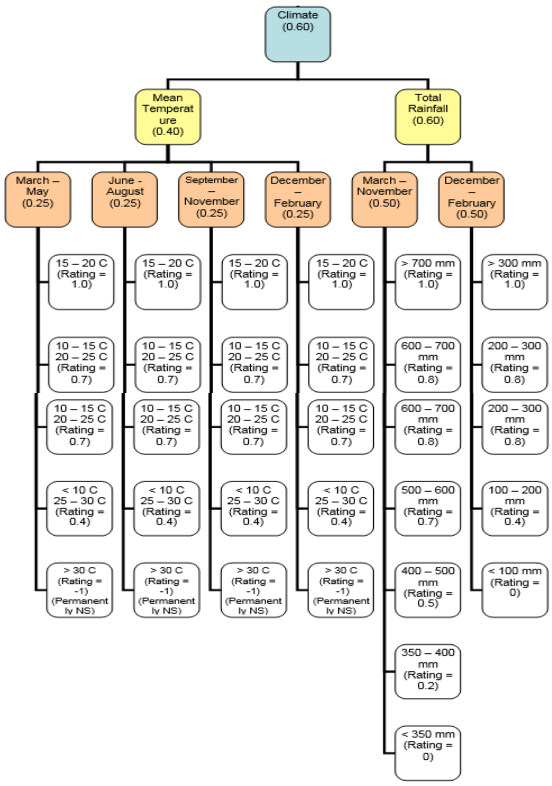

Figure 1 – Land Suitability Model: Climate Hierarchy

Both MCA and AHP are widely used in LSA studies and are embedded in a GIS environment, producing a spatial representation of outputs by using a weighted overlay of all the attributes and their extremities (Ferretti & Pomarico 2013; Malczewski 2004; Dujmovic et al. 2009; Bathrellos et al. 2013). The models are developed for multiple timeframes, the first one being a climate normal, or a baseline, and future projections. The baseline represents a current climate by averaging values of measured historical data from a period of 1960-1990. The projections are modelled for years 2030, 2050 and 2070.

Climate Projections

The baseline climate data has been derived from an averaged overlay of SILO and WorldClim datasets. SILO data has a resolution of 5 km^2 and provides historical climate data (precipitation; maximum, minimum and mean temperature) from Australian Bureau of Meteorology (Department of Science, Information Technology and Innovation 2016). WorldClim data has a resolution of 1 km^2 and was created by interpolating average monthly values by combining data from a number of global as well as local Australian databases (Hijmans et al. 2005). The output baseline layers have a 1 km^2 resolution, to be comparable with the projection datasets. Values for 2030, 2050 and 2070 have been derived using a 1 km^2 ACCESS 1.0 global climate model developed for Australia by CSIRO-BOM (Ramirez & Jarvis 2008). The projection models represent the most recent Representative Concentration Pathways (RCP) scenarios (IPCC 2014).

Foresight Framework

The study will use *Framework Foresight* developed by Peter Bishop and Andy Hines, presenting a standardized method that promotes supplementation from other techniques at various steps (Hines & Bishop 2013). It assesses their strengths and weaknesses, making it easier for foresight practitioners to determine which methods suite their objectives the best within different phases of the foresight analysis. The use of this particular well-established framework increases the potential for the land-use framework to be adopted as a tool for a strategic regional land-use planning by involved parties without the need for a scientific intermediary. Following three scenario techniques have been selected to be best suited to complement the Framework Foresight and promote community-based decision making.

Incasting works with scenarios created ahead of time. Those scenarios are often global in nature (such as those created by Shell and IPCC, or as in the case of this project more localized such as CSIRO Natural Resource Management scenarios used in the context of Victoria (CSIRO and Bureau of Meteorology 2015; Grose et al. 2015)). The Incasting method can be used with groups of stakeholders that are presented with a number of alternative future pathways as determined by the general scenario (Schultz 2003). The participants are then encouraged to determine the impacts each of the scenarios would have on different domains within their region (often from the STEEP categories of Social, Technology, Environment, Economics and Political). It is based on judgement and is logistically quite simple, since the scenario kernels are already provided (Hines & Bishop 2013; Hines & Bishop 2015). Incasting promotes stakeholder participation and engagement which can increase acceptance of the resulting strategies formulated on the basis of the scenario analysis (Mrazova et al. 2016).

Backcasting starts with multiple visions of the future and works backwards, creating a new set of scenarios based on the stakeholder input (Bishop et al. 2007; Kröger & Schäfer 2016; Börjeson et al. 2006). This approach aims to break away from the historical trends and encourage creative thinking, balancing between the realms of plausible and possible (Börjeson et al. 2006). Backcasting has a number of different techniques, all of which are better suited for medium to long term time horizons. Similarly to the incasting techniques, all of them are based on judgement and can be participatory (Bishop et al. 2007).

La Prospective as developed by Godet and his team created a number of tools focused at strategy formulation and scenario analyses in regional context. It seeks large participation, encouraging information exchange and strategic dialogue between community leaders, representative and the public. As in the case of incasting, it explains global trends in a local context. Godet and Durance (2011) state that 'the external influences such a globalization, technological change, climate change, external constraints are not to be seen as obstacles to be overcome but rather opportunities to be seized,' promoting change as an opportunity, which could lead to a positive change of attitude. As a methodology, the prospective approach is rather complex and resource intensive, but the computer programs developed by Godet and his team can be complementary to the Framework Foresight, providing well established tools for phases such as stakeholder analysis carried out by the Micmac software.

III. Climate Change

Australian climate is characteristic by its high natural variability. If coupled with the projected impacts of climate change, primary industries such as agriculture and forestry are likely to face more severe changes with an earlier onset than the rest of the world (Beyond Zero Emissions 2014; CSIRO 2015; Grundy et al. 2016). The climate models that are visualized in Figure 3 and Figure 4, are accompanied with large uncertainty due to the aforementioned natural volatility of Australian weather. Accounting for the uncertainties, the possible environmental shifts are alarming, as they are *'likely to affect all aspects of Australian food production'* (Beyond Zero Emissions 2014). The following sections cover environmental as well as socio-economic impacts of projected climate change on agricultural sector of Victoria. The contribution of the primary industries to greenhouse gas emissions, pointing out the potential for climate change mitigation along with sequestration possibilities will be covered in the discussion.

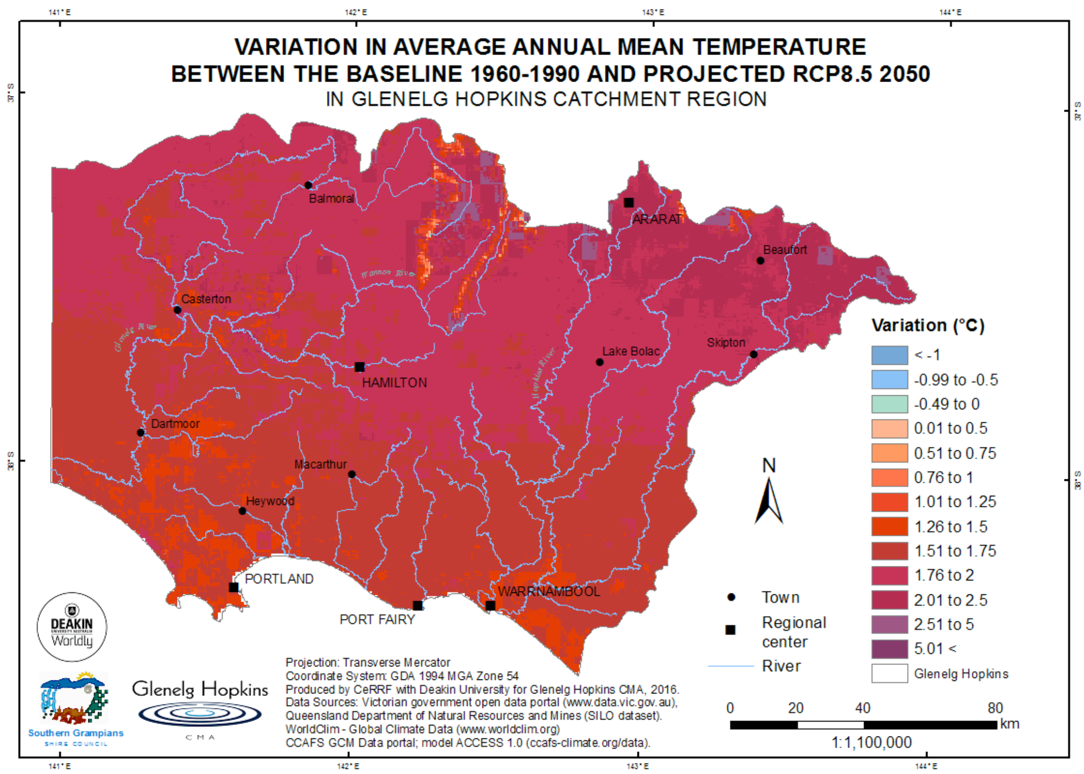

Figure 2 – Projected change of annual mean temperature averages between baseline 1960-1990 and RCP 8.5 values for 2050

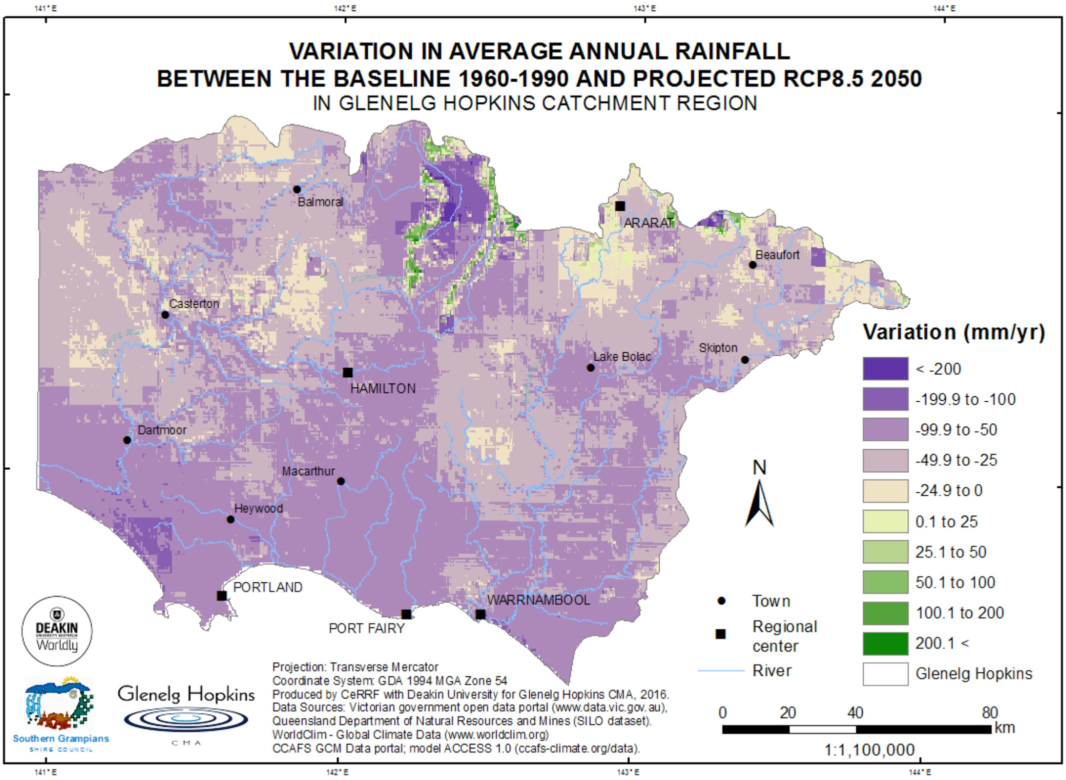

Figure 3 – Projected change of annual precipitation between baseline 1960-1990 and RCP 8.5 values for 2050

Environmental impacts of projected climate change

As apparent from Figure 1 showing an example of an AHP model, climate is a variable with the highest influence on agricultural commodities. The projected increase in average mean temperature accompanied by less accumulated frost days has the potential to severily hinder growth of some commodities (such as desidious fruit trees) that require a certain number of accumulated chilling units (consecutive days of negative temepratures) to ensure a long enough dormant stage vital for a healthy development of their buds (Sposito et al. 2013; State Government Victoria 2013). A long enough period of colder temperatures are beneficial for temperate crops in general to minimise spread of certain diseases and pests that thrive under warmer conditions (Altieri et al. 2015).

More heat days of temperatures above 35°C coupled with a reduced average rainfall and consequently stream flows also negatively impact on many commodities suffering from the lack of available soil moisture and increasing erosion. Less frequent but heavier rainfall during winter months that is already being recorded around Victoria (most recently in September 2016) results in floods, causing depleted soils to waterlog and damage winter crops before harvest. Water shortages as well as the lack of infrastructure engineered to accumulate flood water for use in dry summer months cause droughts, that together with bushfires threaten summer crops. (State Government Victoria 2013; The State of Victoria Department of Environment and Primary Industries 2013)

South East Australia has faced three major droughts in the recorded climate history, *Federation* (1895–1902), *WorldWar II* (1937–1945) and the most recent *Millennial*

Drought (1997–2010) that is the most severe drought since European settlement at the end of 18th century (Verdon-kidd & Kiem 2009; Cai et al. 2014; Kiem 2013; Heberger 2012). The study by Verdon-kidd & Kiem (2009) determined that *'the three droughts differ in terms of severity, spatial footprint, seasonality and seasonal rainfall make-up. This diversity arises due to the fact that the droughts are driven by different climatic teleconnections with the Pacific, Indian and Southern Oceans'*. High variability of Australian weather and climate forcings coupled with uncertain impacts of climate change potentially exacerbating the already existing volatility, therefore makes forecasting of droughts rather difficult, but vital for the survival of dry-land agriculture typical in Victorian regions. Van Dijk et al. (2013) calculated that the Millennium Drought caused an amplification of wheat crop yield decline by a factor of 1.5-1.7. Offset of some of the long-term negative impacts of the drought caused by increased water use efficiency, although significant, was overshadowed by several non-linear responses and accumulating impacts on the hydrological system. Consequential lower yields and higher costs put the Victorian farmers and environment under stress for over a decade, emphasizing the importance of timely and comprehensive adaptation efforts (Van Dijk et al. 2013; Heberger 2012; Kiem 2013).

The above mentioned environmental impacts of a warming climate create challenges as well as opportunities for Victorian regions. Given that the soil erosion is kept to the minimum by employing low or no-till sowing, crop rotation, improved irrigation and soil fertility management practises, heat or drought-resistant crops present lucrative alternatives. (Sá et al. 2016; Bryan et al. 2014; Glenelg Hopkins CMA 2015; Beyond Zero Emissions 2014; Heberger 2012; Cassman & Wood 2005) The high resistance plants as well as commodities suited for warmer climates are ideal for diversification, increasing resilience of the region's agriculture, with a potential to create jobs supporting regional communities and their growth.

Socio-economic impacts of projected climate change

As mentioned above, agriculture constitutes a large portion of many regional economies across Victoria. Due to the significant portion of produce being exported to Asian-Pacific region, it also plays an important role in global food security. The projected growth of Asian population and middle-class along with modelled climate change impacts, Victoria's and even Australia's position on the global food market can be weakened and consequently threaten its contribution to food security (Qureshi et al. 2013; Fischer et al. 2014; Smith et al. 2016; Vermeulen et al. 2012; Challinor et al. 2014; Altieri et al. 2015; Kpadonou et al. 2017).

Qureshi et al. (2013) calculated a total mean expected agricultural production for a *climate normal* based on historical average and alternative scenarios based on the amount of available rainfall. For the dry climate projection of 2030 consistent with findings of the above presented models of Victorian rainfall, the research estimates an average decline in total production of 29%. The rest of researched commodities and their estimated values are in Figure 5, showing the largest decline for staple crops and smallest for horticulture and viticulture. Diversification of existing agriculture by introducing intensive horticulture and viticulture to suitable land has the potential for a higher economic feasibility than continued use of land for cereals and pasture that can be seen across the state.

Commodity	Climate normal expected mean production (1000 tonnes)	Climate dry production (% change)
Cereals	594	-25
Rice	625	-71
Pasture related activities	8470	-31
Horticulture	1488	-15
Viticulture	1403	-18
Total	12,579	-29

Figure 4 – Total mean expected production (tonnes) in climate normal and percentage change in alternative dry scenario (Adapted from: Qureshi et al. 2013)

Close cooperation with Victorian Regional Councils, Catchment Management Authorities and farmers as well as the outcomes of an inaugural conference on *Rural and Regional Futures organized by Planning Institute Australia* in November 2016 suggest that demographic pressures such as aging and overall population decline together with a shortage of skilled workforce present other challenges faced by Regional Victoria and Australian regions in general. Lack of facilities further impedes any demographic incentives by regional governments to attract younger generations (Spataru et al. 2016).

IV. Discussion

It is essential for Australian regional communities as well as the agricultural sector to build resilience to be able to face shocks caused by environmental and socio-economic pressures highlighted in the previous sections. The recent history in rural Victoria has seen a number of significant disturbances such as the failure of chickpea crop in recent years due to the extended drought (Siddique & Sykes 1997) and the collapse of the wool and hardwood industries. The Australian Government has had a number of incentives to support agriculture as a vital part of regional economies and more recently as a possible carbon sequestration tool in climate change mitigation. Success of such government programs can often be undermined by frequent changes in leading political parties with different agendas and priorities combined with insufficient long-term project planning.

For example, the economy of southwest Victoria was underpinned by wool production for 150 years. The industry boomed in the 1980's due to a highly favorable climatic period and high commodity prices. However, in the late 1980's, the collapse of the *Australian Wool Reserve Price Scheme* (due to falling international demand) saw the local wool industry collapse (Bardsley 1994). Farmers proudly identify themselves as a type of producer (for example, a 'wool producer'). It seems, for some, that diversifying production is too high a cost as it dilutes their claim to 'wool producer' status and therefore diminishes their identity in the farming community, even if the alternative is financial hardship. Similar trends can be observed with cattle and dairy farmers alike.

The *Managed Investment Schemes (MIS) was* another governmental incentive addressing the deficit in Australian trade in wood products in the 1990s that has also proven to be insufficiently planned and executed. Allowing income tax deductions for investors in timber plantations caused agricultural land prices in southwest Victoria to artificially grow due to increased demand. Hardwood plantations of Bluegum trees required a large upfront investment that first time investors often did not have, with an average growth period of 10 to 15 years (NewForests Asset Management Pty Limited

2015). The economic downturn precipitated by the 2008 financial crisis caused many individuals and businesses to default on their hardwood plantation loans. The affected plantations were subsequently sold off to larger companies or reverted back to agricultural use. The decline in land prices that followed has resulted in land-use transition back to agriculture in many places, but at a price of up to AUD 2,000 per hectare to remove tree stumps and rehabilitate pastures (Beyond Zero Emissions 2014; NewForests Asset Management Pty Limited 2015; Schlesinger 2014). Also, low prices for hardwood and high labor costs mean it is often too expensive to harvest the timber in plantations. As a result, many plantations established under Managed Investment Schemes have effectively been abandoned – not only have they locked up potentially productive agricultural land, but they also pose a significant fire hazard in the landscape. Of course, global economic crises or shocks (such as the 2008 Financial Crisis or the Great Depression) are very difficult to predict. Including foresight analyses in the process of articulating governmental incentives resulting in large scale land-use change are vital in order to increase resilience of the branches of primary industries already under stress from bio-physical drivers of change

The most recent governmental schemes for the agricultural sector are the *Carbon Farming Initiative* and the *Emissions Reductions Fund* launched in support of farmers wishing to introduce carbon offsetting as a part of their farming system, in exchange for tradeable carbon credits. Bryan et al. (2015) modelled the potential of carbon and environmental plantations (such as the aforementioned Bluegums) for emissions abatement, and adoption rates of new land-use practices. Their results indicate an average lag of new land-use implementation of 16 years, determined by a range of hurdle-rates using profitability as the driver of land-use change rather than bio-physical factors. The study calculated that *'plantings-based land sector abatement has the potential to supply between one third and one half of Australia's total abatement potential from 2031–2050, assuming substantial abatement of direct emissions from other sectors',* and proposed Bluegums as the fastest growing type of carbon plantations, offering the highest sequestration rates (Bryan et al. 2015, p.31). The slow adoption rates, and more importantly, the aforementioned problems with forestry in South West Victoria suggest that there is sometimes a significant gap between research (that informs policy) and reality.

Robust decision making with strategies based on historical trends as well as sound future scenarios built on challenges and opportunities are important to achieve desired, yet well-planned change in regional communities (Sposito et al. 2010). There is a number of decision support tools for local governments or farmers (Kerselaers et al. 2015; McCown 2012) that seek to influence seasonal planning, whereas the framework proposed by this research focuses on long term decision making, influencing the overarching direction of the agricultural sector and consequently the regional economy structure. The framework structure is shown in Figure 5. Reactive planning common in the current practice proves to be insufficient when attempting to tackle complex issues such as climate change and regional development. Pro-active and pre-active approach is proven to be better, allowing for a foresight component ensuring longevity of vital projects. Small scale foresight projects designed for specific communities and their circumstances are essential, with a notable example of the regional scenario development of irrigation futures for the Goulburn Broken Catchment in Victoria that showed large participation and positive outcomes in terms of transparency and project commitment (Wang et al. 2007).

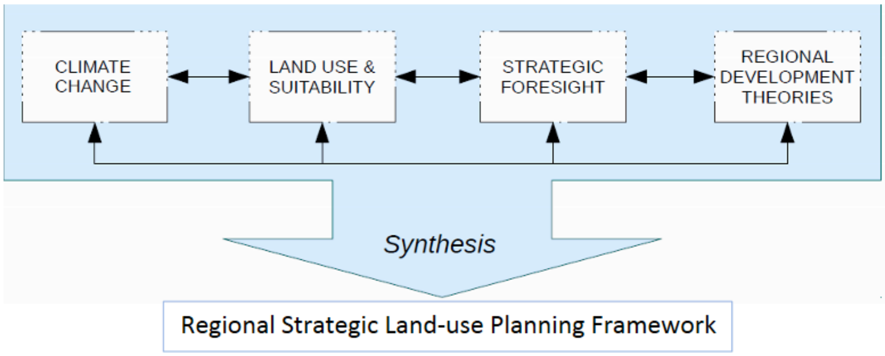

Figure 5 – Regional Strategic Land-use Planning Framework

Foresight is a useful decision support tool for interdisciplinary projects involving stakeholders from various backgrounds. Kröger & Schäfer (2016) have used scenario techniques to facilitate cooperation and communication between an interdisciplinary research team focusing on sustainable land-use. The apparent lack of foresight expertise and project design (shown by insufficiently chosen objectives as well as foresight methods, and lack of transparency of the underlying foresight decision about main drivers, storylines and used techniques observed by the participants) apparent from the publication shows the difficulty of interdisciplinary work involving scientists alone. Successful engagement of stakeholders of varying backgrounds and positions is equally or perhaps more challenging, and can be further hindered by the aim of the presented research to create a transformative change of agriculture, known to be among the most traditional and conservative sectors of primary industries, but also the most threatened by the projected bio-physical and socio-economic changes.

Future research will therefore focus on developing a holistic regional development framework that uses modelling of bio-physical attributes as a bases for land-use optimization and a specifically tailored strategic foresight methods to guide regional councils along with their communities to a sustainable future of agricultural sector as a significant contributor to local employment and income.

V. Conclusion

Climate change is a phenomenon containing significant uncertainties and requires a long-term view, while farming as well as political planning horizons are rather short (e.g. the next cropping season or election period). Long-term decision making, essential when tackling climate change, therefore tends to be overshadowed by operational, short-term planning. Australian agriculture has been faced with, and adapted to, more sudden shocks, such as deregulation of the economy, the collapse of the Australian Wool Reserve Price Scheme and subsequent local wool industry downfall, the rise and fall of the MIS scheme or the millennial drought. Long-term transformational decisions concerning land-use optimization are needed, but unfortunately hindered by ill-planned government incentives on one hand and deeply imbedded preconceptions against innovative agricultural techniques, reinforced by community pressures to conform to traditional agricultural practices on the other.

The aforementioned observations demonstrate how vital, yet difficult engagement of all stakeholders is in successful strategy formulation and execution. A successful introduction of foresight scenarios into planning has the potential to bridge the gap between stakeholders, and between strategy formulation and implementation. It is also likely to improve the resilience of impacted systems and overcome the challenges presented by uncertainty. The resulting maps of land suitability for particular crops and an overall versatility (coupled from all the target commodities) are transparent and easily comprehensible outputs for the community, planners and decision-makers alike. Assessment of an impact of climate change on overall versatility is vital, but the comparison between current and future suitability for individual crops allows for long-term yet specific path to be taken toward a shared regional vision. A desired future built on resilience and sustainability, which does not compromise the region's natural resources and stays profitable by capitalizing on intensification as well as diversification of its agricultural sector.

Using expert opinion and evaluation as an input throughout the various stages of the study, embodied in the design of the future output framework is vital in order to ensure transparency and decrease the inequality of access to information across the community. It aims to provide the decision makers with adequate tools and unbiased data relevant in the regional context to form long-term vision and ensure its successful implementation.

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