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# Developing frameworks to assess impacts of multiple drivers of change on grassland system

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**Abstract.** Grassland systems face many simultaneous pressures including market and policy compliance that operate from local to global scale. The ability to adapt to these pressures against a background of constrained natural resources and inputs is vital to the continued success of the grassland livestock industry and all those dependent on its outputs. New Zealand and Uruguay collaborators have been developing a suite of tools and processes embedded in an “innovation platform” to enable farmers, agribusiness and policy planners to engage and collectively learn about the impact of their interacting individual decisions and strategies. We describe the generic framework and demonstrate examples of the tools and processes used and their applicability across scale in both New Zealand and Uruguay.

**Keywords:** Grassland systems, collective learning, social-ecological systems, strategic planning.

## Introduction

Grassland based livestock systems are complex socio-ecological systems that are reliant on the feedback between farmer behaviour, the farm’s natural resources and its biological systems to generate a range of services necessary for human well-being (food, income, lifestyle *etc.*) while sustaining ecosystem integrity (water quality, soil integrity *etc.*). Farmers, although key decision-makers, do not act in isolation but are embedded within a value chain that integrates local to global scale pressures that drive behaviour across the chain. These many simultaneous pressures that include: market (*e.g.* accreditation, product price, input costs, land values, skilled labour), societal (*e.g.* consumer perception) and policy factors (*e.g.* environmental regulation) (MAF 2007) also occur in a world with finite natural resources (Parliamentary Commissioner for the Environment 2004) offering both risks and opportunities in shaping industry growth and direction. These drivers do not operate independently, but interact to produce complex and uncertain system behaviour both on- and off-farm, adding to the complexity of the challenges facing the sector and its multiple stakeholders.

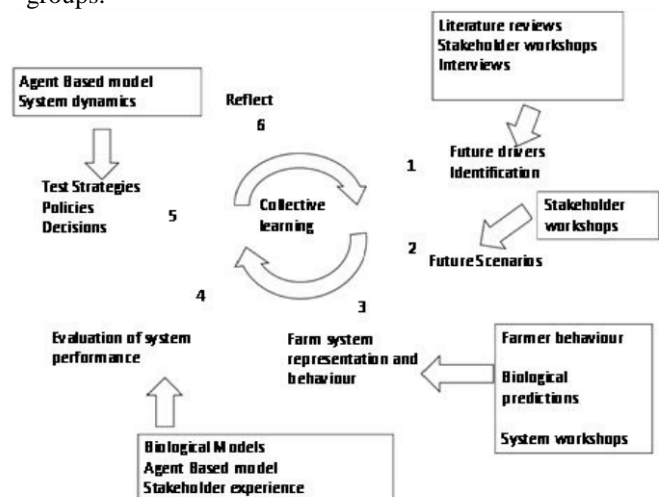
New means of enabling farmers’ and other stakeholders’ to learn and collectively develop innovative solutions in response to complexity are required if the grassland livestock industry is to continue to exist and thrive in the future. Research in New Zealand and Uruguay has developed a framework and embedded it in an “innovation platform”, to address this challenge. Innovation platforms bring together multiple stakeholders in the pastoral value chain to identify, through dialogue, challenges and opportunities in the production and policy environment. The platform participants then identify and implement solutions through the value chain (van Rooyen and Homann 2013).

We have used an integrated and participatory approach requiring the application and development of system dynamics and thinking methodologies suited to dealing with complexity. The strength of the approach is in integrating human behaviour into our biological systems modelling to encompass the social context (Holling 2001, Bawden 2007). This paper describes the generic framework and demonstrates examples of the tools and processes used and their applicability across scale in both New Zealand and Uruguay.

## Results

### Description of the framework

The framework (Fig. 1) is designed as a multi stake-holder “innovation platform” to enable collective learning, although it can also be used by individual stakeholder groups.



**Figure 1.** Framework for exploring futures through collective learning. Numbers 1 – 6 refer to the steps in the text

**Step 1 Future drivers identification:** Identification of future drivers at global and local scale can be informed by literature, market analysis and stakeholder intelligence. Given that drivers do not operate in isolation it is important to develop an understanding of their relationships to allow identification of those that have a strong influence and can act as system leverage points, where a small change in one thing can produce big changes in everything (Meadows, 1999).

**Step 2 Future Scenarios:** Drivers identified in *Step 1* can be used to develop scenarios for guiding the design of future farm scale systems and also regional scale land use.

**Step 3 System representation and behaviour:** The specific characteristics of a future farm system that might exist under the scenarios are identified by the stakeholders and are used as the basis for evaluating the impact of simultaneous drivers on system performance.

**Step 4 Evaluation of system performance:** Different models and expert opinion are used to evaluate the performance of future farm systems. Ideally, the system is evaluated financially, socially and environmentally requiring an integrated approach and a multidisciplinary team.

**Step 5 Testing strategies, policies and decisions:** Stakeholder groups are provided the opportunity to participate in “live” interactions with modelling tools to ask “what if” questions associated with future scenarios and to observe the impact of their strategies and policies before they are implemented.

**Step 6 Reflect:** Building reflection time into the framework is important to allow the stakeholder group to pause and consider the repercussions of their activities and to continue their iteration within the framework.

### The cases

This framework has been used in a variety of cases ranging in scale from farm (both New Zealand and Uruguay) to catchment and region (New Zealand) (Table 1). All of the cases have a future focus on the farm system and associated outputs related to the individual need and preference of the farmer and public good environmental outcomes. The framework has been used to organise constructive exploration of the future with multiple stakeholder participants. Participants have ranged from farmers only (Uruguay); to farmers, agribusiness, policy and extension (farm scale New Zealand), plus recreational groups and NGOs and regional and district policy at the catchment and region scale (New Zealand). The selection of participants is critical in order to have stakeholders with a range of world views to encourage a diversity of thinking

### Tools and Processes

Table 2 outlines the potential tools and processes that can be applied at each step.

### Lessons from cases

#### Step 1: Future driver identification

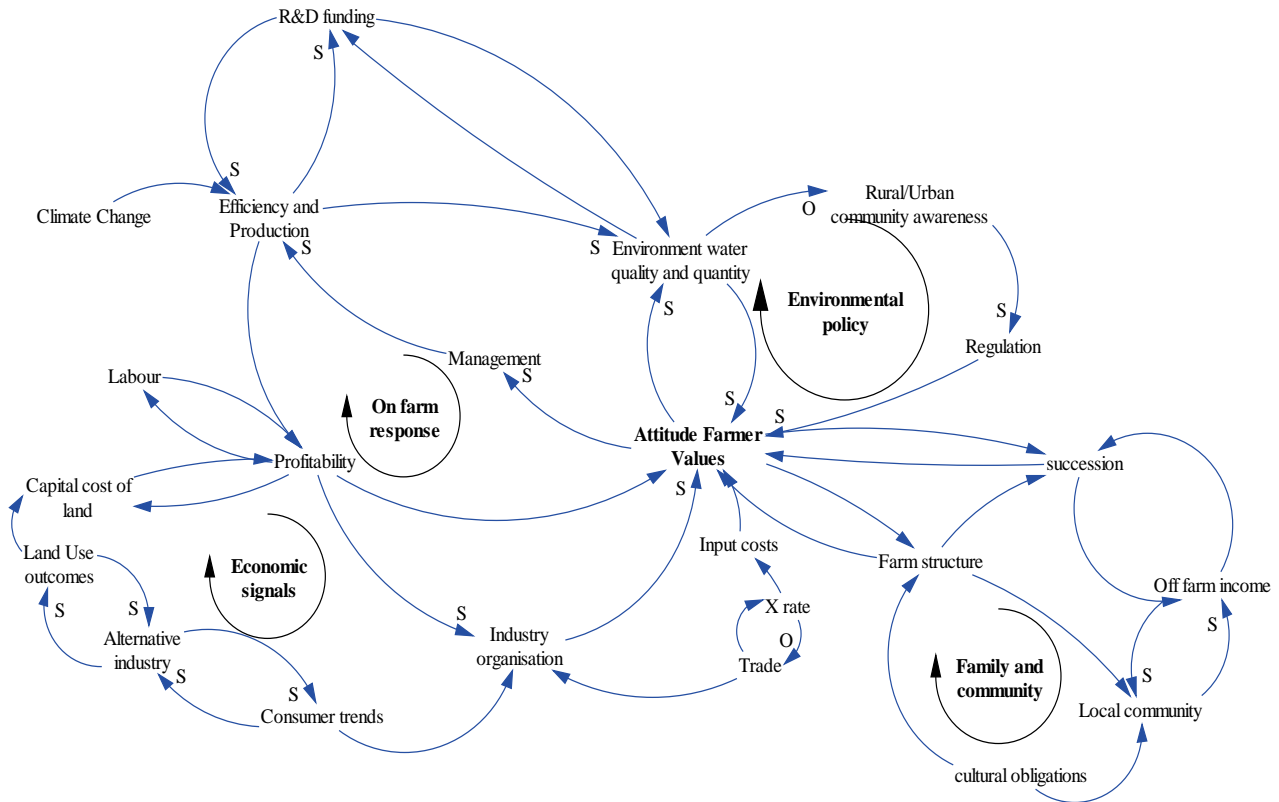
The farm cases in New Zealand and Uruguay identified very similar drivers and sub systems (Fig. 2), through the application of systems thinking tools such as Causal Loop

**Table 1. Description of cases where the framework has been applied**

Scale	Case descriptor
Farm	<b>Uruguay Beef and Sheep;</b> Basaltic region; Owner operated; Effective area 500ha Grassland production 3864 kg DM/year <b>New Zealand Sheep and Beef;</b> Horizons region; Owner operated; Effective area 800 ha; Fertiliser N kg/ha 25; Lambing % 125; Beef yearling 320kg <b>New Zealand Dairy;</b> Horizons region; Owner operated; Effective area 250 ha; Fertiliser N kg/ha 250; Imported feed kgDM/cow 450; Stocking rate 2.8 cows/ha; productivity kgMS/cow 950
Catchment	<b>Selwyn Te Waihora Canterbury New Zealand;</b> Regional councils have to work with catchment communities to set and manage to water quality and quantity limits. Land use interactions with water and the values that communities aspire in environment, economic, social and cultural outcomes inform the limit setting process.
Region	<b>Southland New Zealand;</b> A region where rapid land-use change from sheep and beef farms to dairying is occurring within natural resource constraints. The region's community organisations need to plan for these changes.

**Table 2. The potential tools and processes that can be applied at each step.**

Step in the framework	Tools and Processes
Step 1: Future drivers identification	Literature review of issues, drivers, shocks and wildcards (political, economic, social, technological) for the next 10-15 Years; Interviews and surveys of stakeholders; Systems thinking tools and processes (e.g. Causal Loop Diagrams, Bayesian Network analysis, Leverage point identification)
Step 2: Future Scenarios	Scenario narrative development
Step 3: System representation and behaviour	Interviews, surveys to inform segmentation of farmer behaviour e.g. place in their life cycle; decision making style; risk preference Farm system models: biological feasibility, financial, and environmental
Step 4: Evaluation of system performance	<b>Farm scale:</b> Farm system models e.g. FARMAX <sup>®</sup> Pro and Dairy, MEGanE and nutrient budget models e.g. OVERSEER <sup>®</sup> <b>Catchment, Region scale:</b> Multi Agent Simulation models e.g. SequiaBasalto, Hydrological models e.g. CLUES; Aggregate economic models and social impact assessments Collaborative, and deliberative processes
Step 5: Testing strategies, policies and decisions	As for step 4 with the addition of interactive simulations and visualisation techniques
Step 6: Reflect	Reflexive monitoring (van Mierlo et al. 2010)



**Figure 2. Systems map of the drivers and subsystems identified in the Horizon Case**

Diagrams (Maani and Cavana 2007). Four integrated subsystems were identified by workshop participants: (1) environmental policy; (2) on farm response; (3) economic signals; and (4) family/ community. In comparison to New Zealand, Uruguay had an emphasis on drought, while local environmental policy was not a driver. The leverage points identified in New Zealand were farmer attitudes and values, productivity and profitability, labour and staff skills, regulation, environmental constraints/limits and continued well being (survivability). Catchment and region cases all had land use and its relationship with natural capital, economics and community well-being as key drivers of future behaviour. Not all stakeholders found the building of a systems diagram as part of driver identification intuitive, and indicated a preference for being given a set of pre-prepared drivers. This could be due to the fact that thinking in feedback loops requires practice and is not obvious to many novice users of systems tools. The strength of the systems thinking approach was in making the linkages between the drivers transparent, and in demonstrating where particular drivers had key leverage throughout the system. This would not have been achieved with a simple list of drivers, and other research has shown that decision makers often miss the dynamics of complex issues (Senge 1991; Sterman 1989; Maani and Maharaj 2004).

The system map is a conceptual model that can be used as the basis for the development of interactive models that allow stakeholders to explore changes in system behaviour and the consequences across economic, environmental and social sub systems. This is the foundation for building new experiences and knowledge. Construction of the diagram also revealed stakeholder views of the world and their

attitudes and in a collaborative process this is essential for understanding the perceptions of others and building trust.

*Step 2: Future Scenarios*

Given that farming is not an isolated activity it is important to view future farming systems in the context of what the regional community sees as its future. A number of scenario analysis have been done in relation to agriculture (Leon et al. 2004, Flanagan et al. 2008) and they have been useful in assisting with strategic planning for research and primary producer organisations by providing people with the time and environment to explore trends, patterns, wild cards (unexpected events, like a new technology) and relationships and to use this foresight to position their own business. In the Southland region case, we presented participants with a fictitious newspaper headline in 2030: “3<sup>rd</sup> New Rural School open in Southland this year”, and asked them to describe the conditions required for that headline to be feasible, with special emphasis on the implications for the pastoral sector.

*Step 3: System representation and behaviour*

The characteristics identified by the New Zealand stakeholders prominent among dairy and sheep/ beef farms within their region in the 10 years to 2020 included: no change to owner operator status; an increase of 33% in dairy and in 200% sheep and beef in the use of applied N; 440% increase in dairy related bought in feed; a stocking rate increase of 0.3 cows for dairy and 1su /ha for sheep and beef and productivity gains of 30% in dairy and 10% in sheep and beef. Even with exposure to the drivers, the groups focus within a 10 year horizon was very much on an expansion of the current business-growth model rather than

transformative future farm systems.

In contrast the Uruguayan case had a focus on a future where climate variability would be more frequent resulting in more and longer drought periods. To improve adaptation to drought, past effects of droughts were modelled to understand the dynamics, basic mechanisms and effects at the farm level. To represent the production systems and their functioning two contrasting farmer strategies were modeled, taking into account some previous results and a survey of 65 farmers during the 2005/2006 drought (Bartaburu *et al.* 2009). Each strategy differed in the information used to make decisions during the year. The first (PRO) characterizes farmers who use grass height to decide about management and typically use a lighter stocking rate mainly in winter. The second (REA) characterizes farmers who focus on cattle body condition and a higher stocking rate and did not react to drought until the animals had already lost body condition. These types of management styles and the corresponding models were discussed with farmers in a set of participatory workshops. The farmers easily understood the sequence of actions and its logic within the model, and also were able to identify actual farmers represented by the typology of strategies. They also gained sufficient knowledge of the model's functioning to allow them to experiment with a series of modifications such as changing the maximum stocking rate with which the simulated strategies began each winter.

#### *Step 4: Evaluation of system performance*

The 2020 New Zealand future farm systems characteristics identified in step 3 were evaluated using farm system optimising tools FARMAX<sup>®</sup> Pro, and FARMAX<sup>®</sup> Dairy and OVERSEER<sup>®</sup> a nutrient budget model. Discussion from the group generated considerable debate about how well the base farm models would represent the "average" farmer in the region in 2020. Many of the farm parameters, *e.g.*, stocking rate, MS per cow and per hectare, were not significantly pushed beyond the current top performing farms in the region in 2010. There was general agreement that it may be reasonable to expect that in 10 years' time the "average" farmer would continue down a business-as-usual-pathway, shifting to a position that reflected the current top 10% of the industry.

In Uruguay, a multi agent simulation model (MAS) named "SequiaBasalto" ([CORMAS http://cormas.cirad.fr/fr/applica/sequia.htm](http://cormas.cirad.fr/fr/applica/sequia.htm)) was built to evaluate the Uruguayan system defined in Step 3. The SequiaBasalto model was able to show the seasonal time step for decision making, showing that sheep performance was not affected by drought. Other topics illustrated by the model and discussed in the workshops with stakeholders were: live weight gain on livestock, and how reproductive performance was affected by stocking rate, grass allowance, grass consumption and body condition score.

In both the catchment and regional cases farm systems representing business as usual were set up and modelled. The information from the farm analysis was then integrated into a catchment model (CLUES) and the cumulative impact of land use on water, economics and social outcomes was analysed by researchers and used to inform community choices of where the water limit should be set.

#### *Step 5: Testing strategies, policies and decisions*

In New Zealand, traditional models of farm feasibility and environmental impact are usually run by consultants and scenarios for the farm presented to the farmer as a series of spreadsheets. If questions arise there is usually a time delay as the consultant re-runs the models and returns with the analysis and interpretation. In contrast the cases noted here used live simulations of FARMAX<sup>®</sup> Pro and FARMAX<sup>®</sup> Dairy interactively with the stakeholders and this gave them the opportunity to ask the "what if" questions and gain instant feedback on the consequences of farmer decisions on farm productivity and financials. This approach has also highlighted the importance of tools to allow participants to meaningfully visualise the outputs. Typically there was a significant proportion of the exercise taken up by debating the farm parameters, having these numbers displayed well and demonstrating the trade-offs between outputs is critical to stimulate debate. This is an important part of the process as the participants must be confident in the model's capacity to represent a realistic future farm system. Many of the outcomes were consistent with the users' expectations, others generated debate *e.g.* how a farm might respond to labour shortage and automation.

In recent years, multi-agent-based simulation (MAS) models have become a popular method of modelling complex real world systems in the land based sector. MAS models are intended to capture emergent properties of complex systems that are not amenable to equilibrium analysis and they are beginning to see some use for analysing agricultural systems. New Zealand and Uruguayan colleagues view these models as an objective tool to assist strategy and policy setters to learn about the behaviour of this complex socio-economic/biophysical system before they intervene, and thus form a key component of an innovation platform. The New Zealand Rural Futures MAS model describes the strategic decisions and behaviours of individual model farmers in response to changes in their operating environment, and links to the production, economic and environmental impacts of their management. It models the behaviour of representative farms on a landscape defined using data from actual regions, such as Southland. The model farmer-agents are subjected to drivers and shocks like drought, price changes, and new policies, and their reactions produce outputs from the model. The model is operated interactively with stakeholders and has a visualisation component.

In Uruguay, the MAS "SequiaBasalto" model was used to understand the long-term dynamics of Uruguayan livestock farms under different climatic scenarios. Only one strategy was tested, where simulation was made using the "PRO" producers decision scheme with the main management strategy tested being the decision to adjust the carrying capacity of pastures and animal demands using the winter stocking rate. The model was run interactively with groups of farmers and a range of outputs tested including annual gross income.

In catchment related work in New Zealand, different water target scenarios were explored using the outputs from a range of farm scale and catchment scale models. The

outputs from the models were assessed by the community stakeholders for their acceptability in line with their social, economic, cultural and environmental values. There has been an emphasis on the models that deliver quantifiable impacts however this information has to be translated into language and units that are relevant and meaningful for the community. This required the embedding of science based information within a collaborative process to make transparent the impact of land use on community values and for the community to identify the trade offs and unintended consequences of land use meeting a particular water target.

#### Step 6: Reflect

Although identified as a distinct step in the process to make it transparent, in practice reflection occurs at each step. All cases demonstrated the value of building reflection and iteration into the process. For example, the questioning by stakeholder participants of the outputs from the models generated debate around their accuracy and relevance. This in turn led to a recognition of the impact of drivers on total system behaviour *e.g.* the impact of the lack of skilled labour when having to manage a farm that has to perform within an environmental cap and these reflections led to a re running of the models to take these factors into consideration.

#### Conclusions

Grassland farming cannot be isolated from the catchments, communities and global value chains they are an integral part of. Farmers therefore have to plan and make decisions based on not only their own farming preferences but also the signals they receive from the value chain and local environmental policy compliance. There are a number of tools and processes not traditionally used in agriculture that when brought together in a framework, that is used within processes that allow stakeholders to learn in a collective manner, can allow exploration of the behaviour of future farm systems to enable strategic planning. The framework can be used at farm to catchment to region scale enabling participants to gain a greater understanding of their fit within the wider system. Through the processes applied in the framework; stakeholder perceptions and attitudes, trade offs within and across scale and intended and unintended consequences of actions are all made transparent. The selection of participants is therefore critical in order to have stakeholders with a range of world views to enrich discussion and encourage a diversity of thinking. The innovation platform offers a route for biological science to integrate with decision making and inform agribusiness and policy strategic planning. Traditional farm productivity, profitability and environmental models, for exploring options, when used in an interactive way are very useful for exploring impacts, however they are not enough; if we recognize that farmers are not economic rationalists and we need to take into account other factors that influence decisions *e.g.* ease of labour, and farmer age. The agent based models profiled in the case studies reported in this paper are examples of the role that the next generation of tools will play in building stakeholder understanding of the emergent properties, behaviours and unintended consequences of farm systems. There has been an increase in the demand for these types of models because they integrate

human and biological behavior and demonstrate emergent properties that may offer counter intuitive means of addressing issues. Taking a systems approach to exploring the impact of drivers has been useful in directing where attention and resources can be focused.

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