Review of new agricultural methods for use in scenario modelling of the Australian food system.

Abstract

The purpose of this paper is to review a range of existing and emerging agricultural methods in the context of the Australian food system that could potentially address issues surrounding adequate, nutritious future food production. It forms part of a larger project that will use scenario modelling and the Australian Stocks and Flows Framework (ASFF) on a national scale to identify priority policy interventions to help protect Australia's food security in the face of environmental sustainability challenges. The land a resources issues that could be address by each method have been discussed and the changes required in the ASFF to incorporate these methods have been identified.

1. Introduction

1.1 The Problem

Food security is commonly defined as "a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (World Food Summit, 1996). One of the four main dimensions of food security is food availability, defined as "sufficient quantities of food of appropriate quality supplied through domestic production or imports" (FAO, 2006, p. 1). Although not sufficient in itself to ensure overall food security, it is important when considering the supply side of the issue and is determined by the level of food production, stock levels and net trade. The emphasis on nutrition in the definition of food security and supply aspects for food availability, indicate that a stable supply of nutritious food is an essential part of being food secure.

Australia's domestic production is important to local food security. Overall it is in surplus, but it doesn't meet requirements for some foods.

Currently, Australia is considered to have sufficient food available. At present, Australian farmers produce 90% of the fresh produce consumed by the population and export enough to feed an additional 40 million people in other countries (DAFF, 2013). Domestic production of most major food groups equals or exceeds domestic consumption (DAFF, 2013).

However, a sufficient supply of 'food' does not ensure a sufficient supply of the right foods for a nutritious diet. Findings from the a previous project by the same research team found that local fruit and vegetable production is currently insufficient to meet the requirements for a healthy diet as defined by the Australian Dietary Guidelines (Larsen et al., 2011).

Furthermore, increasing population, resource scarcity (land, water, energy) and climate change are issues that have been highlighted as having implications for future food production (Sobels et al., 2010; PMSEIC, 2010; Garnaut, 2008). The fact that a large proportion of food demand is met with domestic production suggests that it is relevant in investigations of future food availability.

1.2 This Project

In order to deliver evidence that supports strategic planning and policy, assessments of the global food supply increasingly combine 'what if' scenarios that explore multiple possible futures for food security with quantitative modelling (Erb et al., 2009; Reilly and Willenbockel, 2010). Recent research by Larsen et al. (2011) developed a scenario modelling methodology for linking land and resource use to the availability of a nutritious diet for the Victorian population. The project engaged a broad group of stakeholders in the development of scenarios for the future of the food system, and demonstrated the feasibility of using the CSIRO's Australian Stocks and Flows Framework (ASFF) model to assess and understand the implications of these scenarios. Although the research was undertaken within strict time and resource constraints and the analysis limited, significant tensions were identified between food availability, emissions and resources such as land, water, fossil fuels and phosphorus.

Areas recommended for future investigation include further development of the physical model, more detailed analysis of key tension areas and evaluation of resilience issues. ***More detailed and diverse modelling capabilities are particularly necessary in the area of primary food production***, which only included conventional broad-acre methods for crops and animals with varying levels of intensity and implications for fertiliser, irrigation and fossil fuel inputs.

This project has been initiated to use the methodology developed by Larsen et al. (2011) and expand the scenario modelling to a national scale to identify priority policy interventions to help protect Australia's food security in the face of environmental sustainability challenges. The main objectives of this project are to:

- refine and extend the ASFF model's capability as a robust tool for assessing the implications of environmental sustainability challenges for Australia's food supply;
- define the impacts of environmental sustainability challenges on food availability, accessibility and affordability in Australia;
- specify policy and other interventions for planning and managing resource allocation and food system transformations to reduce food supply vulnerabilities in Australia and;
- prioritise policy and other interventions to inform Australian decision-makers in adapting to environmental sustainability challenges to protect food security.

1.3 Sustainable Intensification

This paper commences the investigation of methods to be explored in analysis of Australia's future food production. Globally, food availability is recognised as a pressing issue and a significant focus of prominent research is on *sustainable intensification*, namely producing enough food to feed the growing population without adverse environmental impact and without the cultivation of more land (Foresight, 2011; Garnett et al., 2013; Godfray et al., 2010; The Royal Society, 2009). However, there are various interpretations about what this means in practice. Originally the concept was applied to developing countries and characterised by an agro-ecological perspective (Collette et al., 2011; Heinemann and IFAD, 2010), but has since evolved to include agri-industrial and biotech methods (Foresight, 2011; The Royal Society, 2009), as well as urban agriculture (Kirwan and Maye, 2012; Smit and Nasr, 1992; vanVeenhuizen, 2006). Due to the complexity of the food system and urgency of the food problem, Garnett and Godfray (2012) suggest that a combination of production methods will be necessary to ensure a sufficient and stable food supply and the Royal Society (2009) states that no techniques or technologies should be ruled out. Currently, a number of new food production methods are being investigated and practiced both here and overseas that could potentially address the issues described above and provide solutions in the Australian context. Although many of these methods have been studied in isolation, they have not yet been incorporated in a systematic way to explore their combined impacts on overall food availability and resource use.

This paper reviews a range of existing and emerging agricultural methods that could help respond to the emerging issues surrounding adequate food production. It does not attempt to identify or classify all possible methods, focusing on those that would require structural changes to ASFF to be considered in analysis in later stages of the project.

It clarifies terms, identifies complimentary characteristics and outlines how these methods could be incorporated into future food scenarios and the ASFF. This work will contribute to refining the model and addressing the first objective of the broader project. Similar papers are being prepared for other key areas, including food processing, transport and waste.

It is acknowledged that some of these methods are contentious and their evidence of their effectiveness in meeting environmental and productivity challenges is often lacking. This paper does not review evidence of effectiveness, nor seek to challenge or support particular claims. The focus is on physical characteristics that need to be modelled in ASFF if they are to be included in later analysis. The extent to which these methods meet these claims (and how much they could contribute) will be considered later in the project. All method descriptions in Section 4 should be read as *claims*.

In this paper the scenario modelling methodology (Section 2) and an overview of the ASFF (Section 3) will first be discussed to provide context for the review of the existing and emerging agricultural methods (Section 4). Following this, the structural changes that will need to be made to the model to incorporate the new agricultural methods will be presented (Section 5).

2. Scenario Modelling Methodology

Food systems are complex socio-ecological systems (Lawrence and Worsley, 2007) with a high degree of uncertainty. Food availability is closely linked to resource and land use, trade, unemployment and energy and water usage. Assessing or managing food availability requires a coherent assessment of the interactions of all these factors, and an awareness and incorporation of those that cannot necessarily be forecast from historical trends. There are a number of theories about how the future food availability problem might be addressed (Cribb, 2010; Glover et al., 2008; UN, 2011), but there is a lack of evidence to help identify and prioritise policy interventions and other approaches (Reilly and Willenbockel, 2010).

Dammers (1994) presented a typology for future research methodologies, using two variables: the number of theories and the number of facts that are available. This leads to four types of future research methodology, prognoses, projections, speculations and scenarios (Figure 1).

FACTS \ THEORIES	MANY	FEW
MANY	Prognoses	Projections
FEW	Scenarios	Speculations

Figure 1 – Typology for future research methodologies (based on Dammers, 1994).

The many theories and few facts available regarding the solution to future food availability suggest that scenarios would be a suitable methodology to analyse contributing factors and potential outcomes. Unlike prognoses and projections, scenarios present alternative images of the future instead of extrapolating current trends from the present. They represent alternative environments in which current policy decisions may be played out. In that way, they are not predictions but rather an exploration of different trajectories. The uncertainty of the future is taken into account by describing different possible futures, with the realisation of each of these futures being dependent on several factors. By describing the scenarios, these factors can be identified, thus giving clues on how to influence these factors (Snoek, 2003).

Scenario modelling is a combination of scenario analysis and systems modelling (Reilly and Willenbockel, 2010). Qualitative scenarios are first developed to reflect different strategic of policy approaches and are then translated into quantitative scenarios to enable computational analysis of key settings. The numbers, proportions and results are set to allow exploration of critical relationships. In practice, none of the scenario parameters are tightly defined and it is possible to adjust the value of some of those parameters so that outcomes are reduced or inadvertently increased, resulting in subsequent changes in other system functions.

Proposing several alternative scenarios underlines that there is not one pathway into the future and that it should not be expected that a scenario will emerge in a ‘pure’ form. Most scenarios are described in their extremes, thus underlining the different variables and their relation to each other. Based on the methodology developed by Larsen et al. (2011) three future food scenarios will be developed and used in conjunction with the Australian Stocks and Flows Framework (ASFF) to link land and resource use with the availability of a nutritionally adequate food supply.

3. ASFF Overview – current capabilities for primary production

For the purposes of this research, the Australian food system is being modelled using the Australian Stocks and Flows Framework (ASFF), a highly disaggregated simulation of physically significant stocks and flows in the Australian socio-economic system developed by the CSIRO (Poldy and Conroy, 2000). It simulates the physical processes of economic activity explicitly, based on the underlying thermodynamic constraint of conservation of mass and energy. It covers all the physical elements of each sector of the Australian economy that are significant from a thermodynamic perspective, including some service aspects. Natural resources (land, water, air, biomass and mineral resources) are also represented explicitly. The temporal extent of the ASFF is long-term: scenarios over the future are calculated to 2100, and the model is also run over an historical period from 1941. Such a capability could be generalised to other nations with suitable data.

The ASFF was developed to provide a quantitative modelling framework for identifying and exploring current and future environmental/ resource challenges facing Australia, and for transparently analysing potential solutions and pathways. When using the ASFF, solutions are constrained to be consistent with underlying physical (thermodynamic) constraints. This includes interactions across economic sectors or environmental compartments due to its comprehensive coverage (aiding integrated assessment) (Turner et al., 2011).

In this section, the existing structure of the ASFF with regards to primary food production will be presented. This includes the division of land use, land state, crop and livestock production, and fish farming.

3.1 Land use and land state

Currently, land stocks in the ASFF are divided broadly into Urban, Agricultural and Forestry. Within the Agricultural division, land use is specified according to the type of activity (various crops or livestock) and intensity according to broad-acre agricultural methods (high, low, fertilised, irrigated and feeding intensity).

For the agricultural land stock, land state is determined based on land vintage (how long land has been under cultivation) and history of land activity (crop + intensity). The change in land state over time is represented by landscape function measures of acidity, dryland salinity, irrigation salinity and soil structure. Currently all land activity categories except “fallow” and “idle” result in land degradation. The four landscape function scores are used to calculate four yield factors which are multiplied together to produce a single ‘landscape function yield factor’ for each vintage. This yield factor is the fraction by which yield is reduced due to loss in landscape function. The landscape function yield factors are then combined with a base yield and yield factors for other components of the agricultural system (genetics, irrigation, fertiliser) and the areas of different activities to calculate crop and pasture production in each statistical division.

3.2 Crop production

In the Crops and Land calculator, there is a procedure that determines the agricultural land activity for the proportion of agricultural land in each statistical division (SD). It incorporates different levels of intensity based on broad-acre farming techniques.

The agricultural land activity is determined based on the land activity share (the proportion of each SD's land under each activity), activity per period (the frequency per five years of the activity), crop type and level of intensity. The available crop types are cereal grain, legume grains, hay, silage and green feed, sugar cane, raw cotton, nuts, oil crops and fruit and vegetables. The levels of intensity are categorised as high only, high with fertiliser, high with fertiliser and irrigation, low only and low with irrigation. It is also possible to categorise agricultural land as fallow or idle. Subsequent crop yields are determined based on land activity and other factors such as weather and genetic factors, trophic response, fertiliser response and irrigation factors (where applicable).

Based on the land activity, the Agricultural Operations calculator then determines agricultural operations required and the subsequent energy, materials, water, fertiliser and labour required on a per hectare basis.

3.3 Livestock production

Livestock production is incorporated into the ASFF with the Animals calculator. Similar to the Crop and Land calculator, some variation of intensity is possible but is based on broad-acre farming methods. The proportion of each livestock type and the intensity are specified via exogenous inputs. The livestock types available include beef and veal, mutton and lamb, pigs, poultry and egg producing poultry and milk products, with the intensity parameter only incorporating feeding intensity.

The Animals calculator deals primarily with animal products production and feed required. The associated energy, water, materials and labour required are calculated in the Agricultural Operations calculator. Since it is based on broad-acre farming, this only includes labour required per animal and the energy, water, labour and machinery associated with milking machines per head of dairy cattle. Some additional resources are also accounted for in the production of crops for animal feed. Manure production is quantified and it is also possible to specify the proportion of diet provided from grazing or from feed grown on separate land.

3.4 Fish farming

The ASFF has a procedure in the Fisheries calculator called 'Fish Farming Operations' that is used to determine the inputs required to supply the given fish farm production (from exogenous input). The parameters *fish farm labour intensity, fish farm energy intensity* and *fish farm operating materials intensity* specify the people, tonnes of operating materials, and joules of energy required to produce a tonne of each fish kind. This gives fish farm labour and fish farm operating materials. The *fish farm energy share* then specifies which fuels provide what share of this energy, from the nine secondary energy types available. The fish farm energy conversion coefficient is used to determine the amount of fuel energy of each type required to supply the energy needs according to the conversion efficiencies for each fuel, giving the total energy for fish farms.

4. Review of Sustainable Intensification Methods

Although Australia's land area is significant, only 6% is arable land suitable for soil based agriculture such as cropping and grown pasture (ABARES, 2010). Most of this arable land is located on the coastal fringe of the continent, coinciding with major urban centres (ABARES, 2010). Since increases are occurring mainly in urban populations (ABS, 2013), coupled with expansion of urban areas (ABS, 2008), it is likely that tensions will occur between food supply and demand (Ramsey and Gallegos, 2011). The area of productive land in Australia is also diminishing due to various degradation processes (NLWRA, 2000; PMSEIC, 2010) and productivity of dryland farming, the majority of the Australian agricultural sector, is being impacted by the effects of climate change, particularly lower rainfall, higher temperatures and changes to the distribution and abundance of insect pests, pathogens and weeds (Gunasekera et al., 2007). Mitigation measures for climate change may also have further implications for land availability if it becomes necessary to transfer land from agriculture to forestry to offset emissions or sequester carbon (Keating and Carberry, 2010). Rising oil prices will also have a significant impact due to the fact that modern agriculture is heavily dependent on petroleum products for fuel, fertiliser and pest control (Dodson et al., 2008).

It is argued in global literature that the prime goal of sustainable intensification is to raise *productivity* (as distinct from increasing *volume of production*) while reducing environmental impacts. This means increasing yields per unit of inputs (including fertiliser, water, energy, capital and land) as well as per unit of 'undesirable' outputs (such as greenhouse gas emissions or water pollution) (Garnett and Godfray, 2012).

Although broad themes such as regenerative farming, intensive farming, agro-ecology and urban agriculture exist in current global literature, there is no coherent classification that identifies specific methods that belong to each one. Therefore, in this paper methods have not been grouped under specific themes, but instead have been discussed individually, with reference to how they relate to each of the broader themes. They are then presented in a visual metric/table linking methods, outcomes and characteristics to make it possible to see how these methods could contribute individually and in combination to potentially achieve an increase in productivity with lower inputs.

In this section, a range of methods will be presented that aim to address these issues in some way and could therefore contribute to sustainable intensification. These include technologies, practices and systems such as:

- new crop types developed with biotechnology techniques;
- precision agriculture that reduces the need for inputs;
- intensive animal raising e.g. feedlots and factory farms;
- agro-ecological methods that use strategic cycling of crops and/or animals to reduce inputs and increase production (polyculture cropping, crop rotation, rotational grazing, crop-livestock integration and permaculture); and
- urban agriculture – using urban waste streams and redundant resources to produce food.

NB. Urban agriculture is not so much a method or set of methods, but a methodology based on location. Different methods can be used to produce food in an urban setting, such as permaculture, hydroponics and aquaponics, however the aspects that are the most beneficial in relation to sustainable intensification are the production of food in close proximity to where it is consumed, the potential use of urban waste materials as inputs, such as water and organic waste (Barthel and Isendahl, 2013; Smit and Nasr, 1992), and the availability of local labour to offset/replace agricultural practices that consume large amounts of energy.

4.1 New crop varieties developed with biotechnology

Plant breeding with the assistance of molecular marker technologies and genetic modification has the potential to produce new crop varieties with traits that address some of the emerging food security issues. Claims include: increased yields through insect resistance, herbicide tolerance and drought resistance; reduced reliance on inputs via increased water-use and nitrogen-use efficiencies; and reduced emissions from animal excretions with the development of feed that can be digested more easily (Glover et al., 2008).

There are also a number of indirect benefits of new crop varieties. Increased land productivity from higher yields also has potential benefits related to greenhouse gas mitigation and biodiversity protection through land sparing in comparison to extensive agricultural methods (Burney et al., 2010; Phalan et al., 2011). Planting of insect resistant crops can reduce both the amount of insecticides required and fuel required for machinery used to spread the insecticides, and subsequently reduces overall farm costs (Acworth et al., 2008). Reducing the amount of fertilisers and insecticides can also reduce carbon dioxide emissions further up the production line. This includes reducing the energy required for their manufacture, which is particularly significant for nitrogenous fertilisers (BRS Workshop 2007, cited in Glover et al., 2008), as well as fossil fuel use in transporting the products. Herbicide tolerant crops also can be used in conjunction with conservation tillage practices (see below for further explanation) to reduce soil degradation and increase carbon storage in soils. Since the purpose of tillage is to remove weeds, no or low tillage methods are more reliant on costly herbicide based weed control systems. Herbicide tolerant crops allow a particular herbicide to be applied after the emergence of the crop, which reduces the need for pre-emergent herbicide applications. This reduces overall costs (Fawcett and Towery, 2002) and has potential benefits for biodiversity (Ammann, 2005).

4.2 Intensive animal farming – factory farms and feedlots

Conventional intensive animal production involves raising large numbers of animals on limited land and requires large amounts of food, water and medical inputs, and possibly infrastructure. Animal feed is grown intensively on separate land. It satisfies the need for increased land productivity, however, is also known to have adverse implications for the use of other resources and associated environmental impacts (Cassman, 1999; Matson et al., 1997; Subak, 1999). Production methods have much more in common with manufacturing processes and, as a result, large, highly intensive indoor livestock operations are commonly known as factory farming, while outdoor intensive farms are known as feedlots.

4.3 Precision agriculture

Precision agriculture takes advantage of highly technical spatial information and grain yield monitors to determine how inputs could be applied differently across different fields to match crop demands, in particular variable rate fertiliser application (Hochman et al., 2013; Matson et al., 1997). This is particularly applicable in Australian agriculture due the high variability of soil types across the country and large proportion of dryland farming dependent on variable rainfall. Variable application of fertiliser in these situations would allow a better match between nutrient supply and demand. This leads to a more efficient use of fertilisers, potentially higher yields and lower environmental impacts (Hochman et al., 2013).

4.4 Polyculture cropping

Polyculture cropping is a method where crops are grown in mixtures of species rather than single species (i.e. monocultures) (Raman, 2007, p. 10). This can increase yield as more than one harvest per product can be obtained from the same amount of land and the diversity of species (different heights and root patterns) can mean that they get more light and more efficient use of the soil. They also tend to limit the need for fertilisers and chemicals and have been shown to significantly reduce vulnerability to pests, pathogens and weeds. The use of perennial crops in polyculture cropping has additional benefits for soil structure by retaining cover over the soil and more extensive root systems. This reduces erosion, maintains soil carbon and increases water flow (Raman, 2007, p. 11), which improves or maintains landscape function and potentially improves yields. The use of trees within crops or pasture (agroforestry) or other perennial grasses and forage crops is being increasingly explored to gain these benefits.

4.5 Crop rotation

Crop rotation involves different crops being grown in succession in a carefully designed sequence on the same land. Crop rotations influence soil fertility and survival of soil pathogens, soil erosion and microbiology and biodiversity. When used in organic systems they are designed to build resilience to pests and diseases since crops of the same species or with similar pest and disease problems are never grown in succession (Raman, 2007, p. 13). Phase cropping is an example of crop rotation developed in Australia, where summer active Lucerne is rotated with a grain crop. The benefits of this method include improved soil structure and reduced infiltration to groundwater (reducing salinity) (Robertson, 2006, p. 12). It has also long been considered to be a sustainable and profitable means of maintaining organic fertility of cropping soils in southern and western Australia (Carter et al., 1982; Puckridge and French, 1983), potentially reducing the need for fossil fuel based nitrogen fertilisers depending on the length of the pasture phase in relation to the duration of the cropping (Peoples and Baldock, 2001).

4.6 Conservation tillage

Conservation tillage includes a number of methods designed to reduce disruption to the soil. It encompasses no-till and reduced tillage practices that restrict the amount of tillage, with crops sown through the stubble residue of previous crops into undisturbed soil. The benefits of such practices compared to conventional tillage include reduced soil loss from wind or water erosion; increased water infiltration; increased soil water storage efficiency; and increased soil organic matter (Doyle, 1983; Lyon et al., 2004; Papendick and Parr, 1997). These aspects have positive effects on soil fertility and crop yields.

Since soil disruption breaks down soil structure and releases carbon, no-till or reduced tilling practices can slow the rate of decomposition and lead to an accumulation of carbon in the soil and subsequent sequestration from the atmosphere (Crovetto, 2000; Dalal and Chan, 2001). The extent of carbon sequestration under no-till farming differs based on climate and soils. It has been suggested that the level of carbon sequestration through no-till practices may be limited in parts of Australia and will be much less than levels reported in the Northern Hemisphere. This is related to both Australia's dry and hot climate, and the naturally low levels of organic carbon in Australian soils (Wang et al. 2004; Grace 2007; Umbers 2007). However, even small increases in the amount of carbon sequestered would have environmental benefits.

4.7 Rotational grazing and Holistic Resource Management

Rotational grazing describes a method where grazing animals are limited to a small area for small periods of time, then repeatedly moved. Intensively grazing one area at a time allows the other areas to be rested in between grazing rotations, so that the plants are able to recover, grow and develop better root systems, which contributes to better soil health and reduces compaction of particular areas (Undersander et al., 2002).

Holistic Resource Management is a rotational grazing method developed in Zimbabwe by Savory and Parsons (1980) and involves intensive and rotational grazing of stock. This incorporates principles of rotational grazing but also cover cropping, since bare ground would be reduced, preventing erosion and water run-off and improving soil health. In combination with the added nutrients from animal waste in the soil, this supposedly allows for greater seedling success for regrowth, which leads to greater forage production and enables higher stocking densities.

4.8 Crop-livestock integration

Crop-livestock integration takes advantage of the complimentary nature of inputs and outputs from crop and livestock production to increase productivity, by farming more on the same land and reducing overall input requirements. Mixed –use farming has been practiced in Australia since the 1930s and still dominates the major cropping zones in the south (Henzell, 2007; Hochman et al., 2013). Two relatively recent methods being adopted in Australia demonstrate the capacity of crop-livestock integration to address the dual goals of increasing production and reducing environmental impacts: perennial pasture in cropping systems and dual purpose graze and grain crops.

4.8.1 Pasture cropping

The integration of perennial pasture in cropping systems, also known as pasture cropping, involves the strategic cycling of crops and livestock and the retention of ground cover. Large herds are grazed in a time-controlled manner to manage weeds, create litter and mulch, and prepare the land for cropping. Crops are then sowed using a direct drilling method amongst the existing pasture, which has been grazed to a sufficiently low height so that it does not hinder the growth of the emerging plants (Seis, 2006a). Despite the fact that this method reduces the grain crop area, it has been suggested that the proportional increase in livestock production is sufficient to outweigh this loss and overall farm productivity is increased (Hochman et al., 2013). Trials have shown that using this method it is possible to run the same number of livestock with significant reductions in costs related to pasture seed, labour, fertiliser and weed control, increasing profitability (Seis, 2006b). In addition to this, the retention of ground cover addresses on-site and off-site problems such as soil erosion and degradation, dryland salinity and nutrient leaching, and offers potential improvements in bio-diversity conservation (Bridle et al., 2009) and carbon sequestration (Dalal et al., 1995), reducing overall environmental impacts. Perennial pastures used in two to five year rotations with crops also provide benefits for subsequent crops by reducing weed seed banks (Doole and Pannell, 2008), improving soil structure (McCallum et al., 2004) and increasing soil fertility (Hirth et al., 2001), reducing reliance on external inputs such as herbicides and fertilisers.

4.8.2 Dual purpose grain and graze crops

Dual purpose graze and grain crops provide the opportunity to obtain additional grazing for livestock during early winter while maintaining or increasing grain production, allowing both crop and livestock production from the same land, reducing risk and increasing resilience. If the crops are grazed in the early stages of development, there is little or no effect on yields depending on the seasonal conditions in the recovery period (GRDC, 2009; Kirkegaard and Filmer, 2008). In fact, grazing is an effective defoliation method, an important part of canopy management that reduces water uptake in the early stages of growth and leaves a reserve in the soil to boost later yields (GRDC, 2009). Dual purpose cereals have been an integral component of mixed farming operations in medium to high rainfall zones of southern Australia for many years, and more recently oil crops such as canola have also been incorporated successfully (Kirkegaard and Filmer, 2008). Although there are production advantages for dual enterprises, they do sometimes require more infrastructure and equipment (GRDC, 2009).

4.9 Permaculture

Permaculture is an ecological and agricultural design philosophy that incorporates a whole system approach to farming focusing on meeting human needs while regenerating the land. The focus of permaculture is not on each separate element of a system but rather on the relationships between the elements and how they can be beneficial to each other. The techniques were developed by Bill Mollison and David Holmgren in the 1970s. They involve an integrated, evolving system of perennial or self-perpetuating plant and animal species useful to humans and consciously designed landscapes which mimic the patterns and relationships formed in nature and yield food, fibre and energy for provision of local needs (Holmgren, 2002) . They incorporate water sensitive design, waste recycling and aspects of crop rotation and crop-livestock integration. The fact that permaculture incorporates these aspects makes it particularly applicable in urban areas where waste water and organic waste are available for use. Since a both crops and animals are produced on the same land and potentially increase overall land productivity, permaculture can also be considered to be a form of intensive agriculture.

4.10 Protected agriculture - Hydroponics and Aquaponics, Aeroponics

Other farming methods developed to increase food production on limited land include growing crops in greenhouses or raising fish in farms, known as aquaculture. In both these cases, growing conditions are monitored and controlled to improve productivity. More extreme forms of greenhouse farming are hydroponics, a system of agriculture that utilizes nutrient-laden water rather than soil for plant nourishment (Bridgewood, 2003) and aeroponics, where the nutrient laden water is sprayed on the plant roots. Removing the soil eliminates risk of soil organisms causing disease and enables crops to be grown in locations where there is no soil. Aeroponic and hydroponic systems do not require pesticides, and it has been suggested that they require less water and space than traditional agricultural systems, and may be stacked (if outfitted with led lighting) in order to limit space use (also known as vertical farming) (Marginson, 2010). Along with the fact that they don't require soil, this makes them optimal for use in urban areas. Enabling food production close to consumers has positive implication for reductions in transport emissions, however typically, aeroponic and hydroponic systems have high energy costs because they incorporate lighting, pumping, and air moderation systems. Primary costs (aside from energy costs) include the purchase and purification of fertilizers and water.

Aquaponics refers to a combination of aquaculture and hydroponics, where the nutrient-rich waste water from the fish is used as the mineral solution for hydroponic plants. The water is effectively cleaned by the plants and can then be returned to the fish farm, reducing both water and fertiliser demand compared to hydroponics. For these reasons it is also considered to be a form of sustainable intensification (Klinger and Naylor, 2012).

4.11 Characteristics of Methods

As mentioned previously, the emerging issues related to future food availability in Australia are the availability and condition of arable land, availability of fossil fuels and associated fertilisers, pesticides and herbicides, water use, climate change mitigation through emissions reduction and carbon sequestration. To obtain an accurate picture of how these new agricultural methods contribute to addressing these issues, they have been presented alongside each other in Table 1. The '+' symbol indicates a positive change, while the '-' symbol indicates negative change.

It is clear from this information that no single method would be sufficient to address all issues related to the food system, therefore a combination of methods will be necessary to ensure food availability. Different combinations of methods will be used in each of the scenarios to explore the effect of different ideological approaches.

Table 1 – Metric showing how each new agricultural method addresses specific emerging issues related to food availability.

Desirable Outcomes	IR crops	HT crops	Drought resistant crops	Water use efficient crops	Nitrogen-use efficient crops	Easily digestable animal feed	Feedlots	Factory farms	Precision agriculture	Polyculture	Crop rotation	Conservation tillage	Rotational grazing	Pasture cropping	Dual purpose grain and graze crops	Permaculture	Greenhouses	Hydroponics	Aquaponics
Increased land productivity	+	+	+				+	+	+	+		+	+	+	+	+	+	+	+
Reduced fertiliser					+				+	+	+		+	+	+	+			+
Reduced pesticides	+										+					+		+	+
Reduced herbicides		+									+	-		+		+			
Reduced water use				+			-	-		+		+			+	+		+	+
Reduced fossil fuel use	+				+		-	-			+	-		-					
Reduced emissions	+	+	+		+	+			+	+	+								+
Carbon sequestration										+		+	+	+					

5. Proposed Amendments to ASFF

ASFF requires significant modifications to enable consideration and analysis of the methods outlined above. These include:

- increasing the range of crop and livestock intensities;
- modifying the land activity per period;
- changing the land state calculation and
- allowing for reductions in fertiliser and water use to be incorporated in aggregate totals.

Table 2 shows briefly the current model capabilities and the proposed model structural additions. These are also depicted in systems diagrams in Figure 2 and Figure 3, with the comments in black indicating existing capabilities and the comments in red illustrating the proposed changes or additions.

Figure 2 shows an example of how new agricultural methods will be incorporated as additional intensities in the model structure. Figure 3 shows how regenerative farming practices, urban farming and associated reductions in fertiliser and water use will be represented.

Table 2 – Current model capability and proposed changes.

Current model capability	***Proposed model additions***
Total land in each statistical division is divided into Urban, Agricultural or Forestry.	Proportion of land from urban areas can be added to total agricultural land and proportion of mixed use (agroforestry) land from agriculture can be added to total forestry land.
In the Crops and Land calculator, there is a procedure that determines the agricultural land activity for the proportion of agricultural land in each statistical division. It incorporates different levels of intensity based on conventional broad-acre farming techniques. There is currently no procedure incorporating crop production with greenhouses or hydroponics.	To incorporate new crop varieties and greenhouse/hydroponic production in the ASFF, changes would need to be made to both the Crop Production calculator and the Agricultural Operations calculator. Additional intensity parameters would also be required to differentiate between crops produced using broad-acre and each of the intensive methods since production rates and resource requirements for each method will vary.
In the Animals calculator, the proportion of each livestock type and the intensity (based on broadacre methods) are specified via exogenous inputs. Livestock types available include pigs, poultry and egg producing poultry, which are typically raised in factory farms. It is also possible to specify what proportion of feed come from grazing or other sources. The intensity parameter only incorporates feeding intensity, not other aspects of factory farming.	Only some changes would need to be made in the Animals and Agricultural Operations calculators to incorporate factory and feedlot farming. The existing model already incorporates the required livestock types and the possibility of feeding animals entirely via methods other than grazing, but additional intensity parameters would be needed to take into account the increased production rates, medication requirements, infrastructure and resource use.
The ASFF Fisheries calculator has a procedure called 'Fish Farming Operations' to determine inputs required to supply fish farm production (from exogenous inputs). The parameters *fish farm labour intensity, fish farm energy intensity* and *fish farm operating materials intensity* specify the people, tonnes of operating materials, and joules of energy required to produce a tonne of each fish kind. The *fish farm energy share* specifies which fuels provide what share of this energy. The fish farm energy conversion coefficient is used to determine the amount of fuel energy of each type required to supply the energy needs according to the conversion efficiencies for each fuel, giving the total energy for fish farms.	To reduce complexity, aquaponics could be incorporated through a combination of the existing fish farm procedure and the future hydroponics procedure. A certain percentage of the fish farm production could be allocated as aquaponics, represented by an aquaponics factor, which can then flow through to the Crop Production calculator to calculate the associated (additional) crop production via the hydroponics procedure. This factor would also be an input in the overall sum of water and fertiliser requirements, effectively acting as deletions to reduce overall water and fertiliser demand and contribute to resolving tensions.

Current model capability	***Proposed model additions***
In the Crops and Land calculator, the land activity per period currently involves sequential patterns of land use over each time step. Each land activity is represented as a proportion over the time period, with the total equal to one.	To incorporate the increase in production with crop-livestock systems, changes would need to be made to the land activity parameter in the so that land activity could occur in parallel and represent mixed use farming on the same land. The total land activity per period could equal more than one.
For the agricultural land stock, land state is determined based on land vintage (how long land has been under cultivation) and history of land activity (crop + intensity). The change in land state over time is represented by soil function measures of acidity, dryland salinity, irrigation salinity and soil structure. Currently all land activity categories except “fallow” and “idle” result in land degradation.	To represent improvements in land state due to crop-livestock integration, crop rotation and cover cropping, changes need to be made. Base land state would still be determined based on land vintage and activity history, but new land activity categories would be added with altered soil function measures to represent improvement. An additional soil function measure of soil carbon would also be required, and translated into overall emissions reductions.
Fertiliser requirements are currently associated with the land activity (crop + intensity) and the geographical location.	Fertiliser requirements would be altered to depend not only on land activity and location, but also on land state, to represent reduced fertiliser requirements for areas employing regenerative and precision farming techniques.

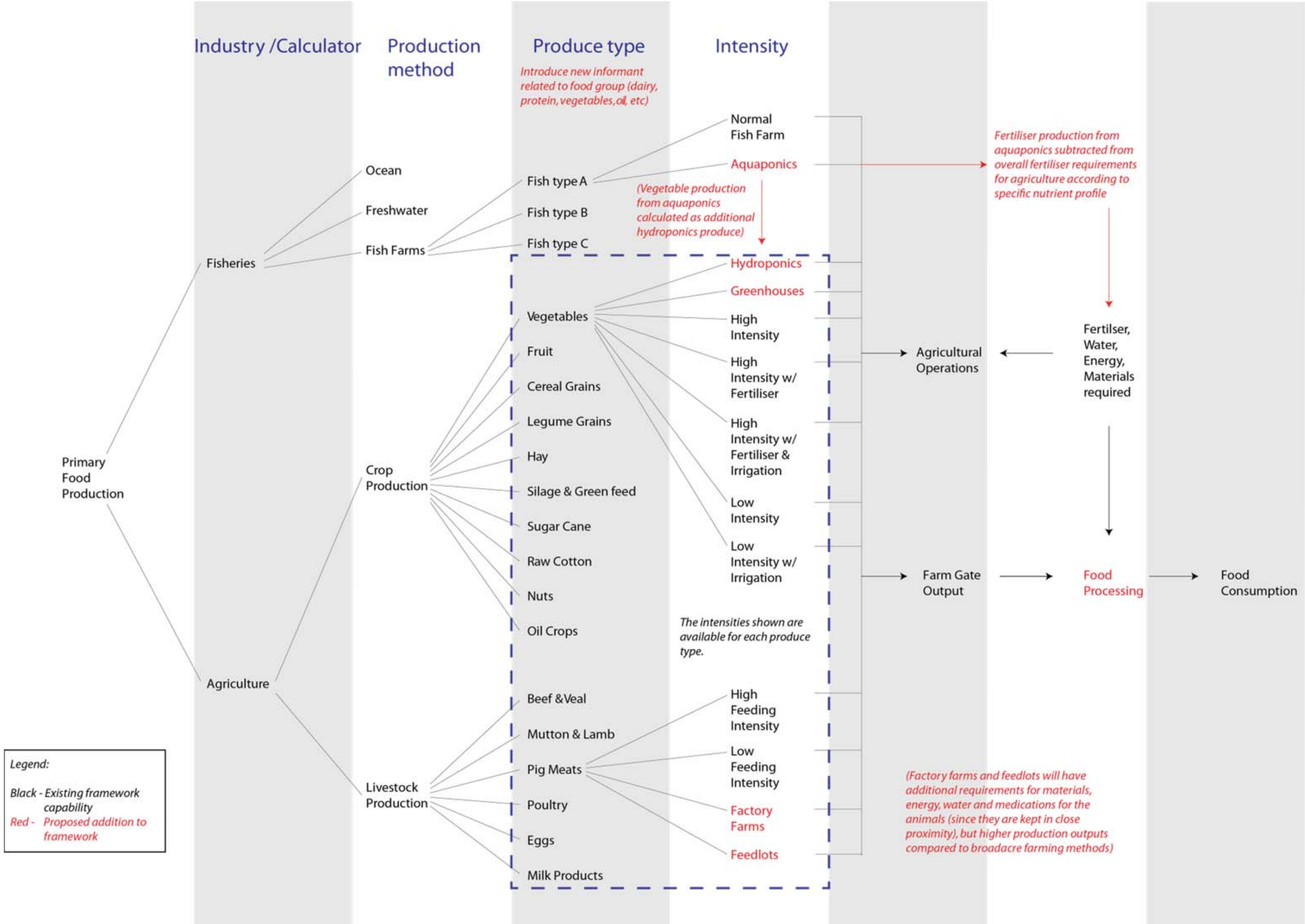

Figure 2 - Systems diagram of current model and proposed design changes incorporating new methods as additional intensities.

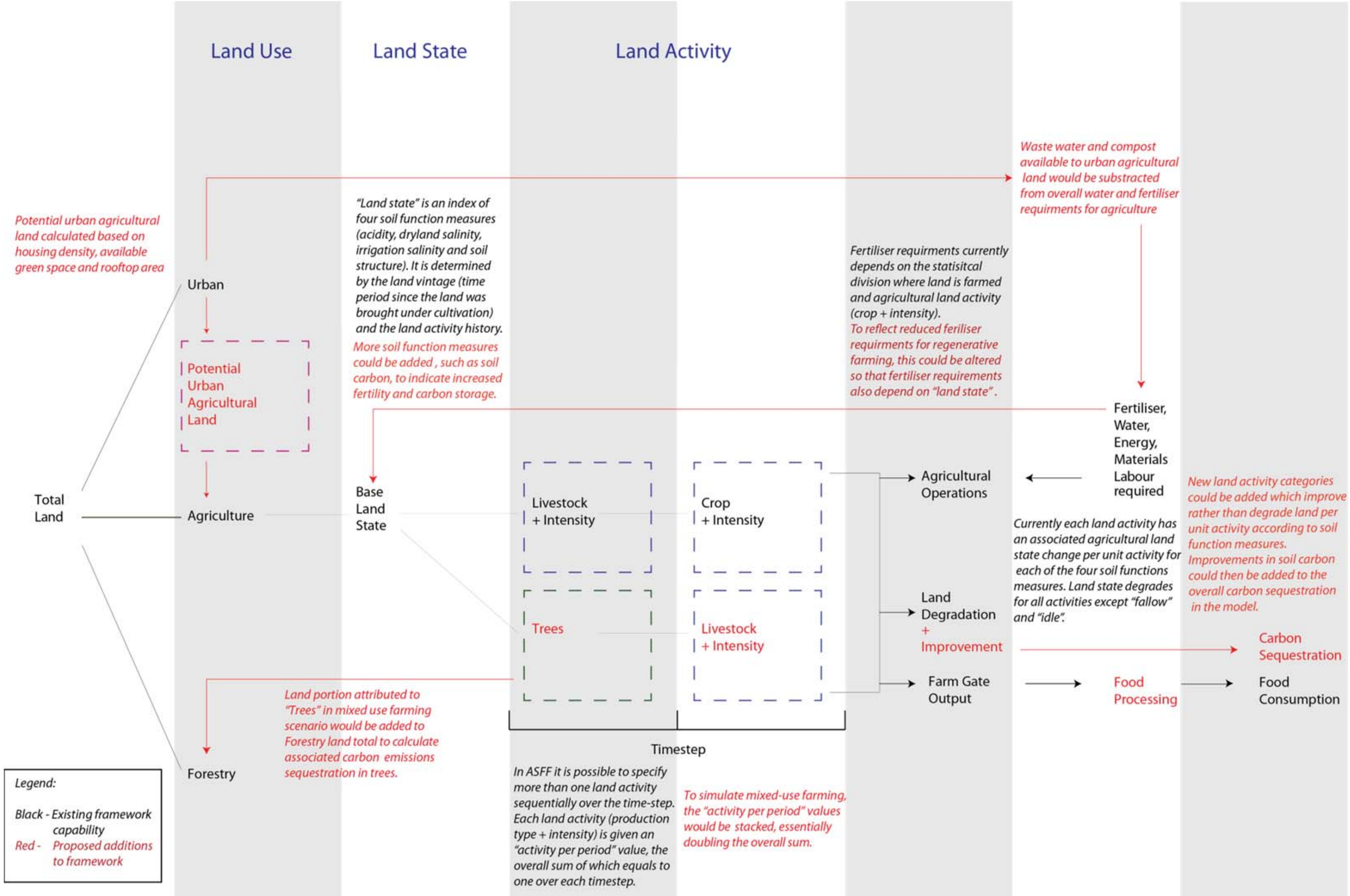

Figure 3 – Systems diagram of current model and proposed design changes to incorporate land regeneration, urban farming and associated reductions in inputs.

6. For Discussion

1. Are these methods and systems relevant to the analysis – worth investigating
2. Are there other methods or systems that should be considered? ***ONLY those that require additional structural change to the ASFF at this stage***

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