Targets for Sustainable and Resilient Agriculture (TSARA): Indicators and modelling for the Sustainable Development Goals

Ronaldo Vibart[1], Kelly A. Stirrat[2], William Kaye-Blake[2], Matthew J. Smith[2], Margaret Brown[1]

[1] AgResearch, Grasslands Research Centre, Palmerston North, New Zealand

[2]PwC, Wellington, New Zealand

Report prepared for AgResearch

Client Report Number: RE450/2018/045

āta mātai, mātai whetū

This report has been prepared for the TSARA Project within the Resilient Rural Communities (RRC) Programme, and is confidential to PricewaterhouseCoopers and AgResearch Ltd. No part of this report may be copied, used, modified or disclosed by any means without their consent.

Contents

1. EXECUTIVE SUMMARY

Targets for Sustainable and Resilient Agriculture (TSARA) is a European research programme that is investigating land uses and changes to land uses, their potential to support progress toward the United Nations (UN) Sustainable Development Goals (SDGs) and pathways from the current situation to defined future end states. To analyse these pathways, TSARA will use a complex land-use model developed by Rothamsted Research in the United Kingdom (UK). AgResearch is participating in the TSARA programme by using New Zealand as a non-European case study for additional modelling.

This report presents an overview of the progress made in the 2017-2018 fiscal year of AgResearch's collaboration in TSARA. It acts as a follow up to the AgResearch report on the first phase of this research published in June 2017. The project is conducting two parallel workstreams. The indicator workstream is identifying and evaluating indicators that are useful to researchers and policy-makers, and can be included in land-use modelling. This report outlines the process of collaborating with stakeholders to identify potential indicators that can be used to measure progress towards the SDGs and assesses the indicators identified. The modelling workstream is helping to extend the Rothamsted model so that it both models New Zealand agricultural land uses and contains the aforementioned indicators. The report describes the Rothamsted model and explains how it is being adapted for New Zealand conditions.

The TSARA research supports the aim of the Our Land and Water National Science Challenge to liaise with researchers, industry and government. The new knowledge being produced in TSARA is giving researchers a clearer picture of priorities and measurement issues to investigate further. It is giving the agricultural sector a better idea of the potential performance measures and the types of changes that could occur. It is providing government with practical assessments of potential indicators, lists of these indicators and initial views on the pathways toward achieving the SDGs.

This work is still in progress. We expect that the next year will involve significant collaboration with the TSARA modellers in Europe. We also believe that there is an important opportunity for collaboration here in New Zealand. The Treasury and Statistics NZ are undertaking work on well-being and the SDGs. Our research team has built considerable understanding of the SDGs in relation to agriculture. This understanding is based on collaboration with a wide range of stakeholders and careful review of the literature on indicators. We hope to contribute our understanding and expertise to the national conversation about measuring progress towards the SDGs.

2. INTRODUCTION

2.1 Background

Targets for Sustainable and Resilient Agriculture (TSARA) is a European research programme that investigates how different land uses can support progress towards achieving the United Nations (UN) Sustainable Development Goals (SDGs). The project aims to develop pathways from the current situation to defined future states. This part of the research programme uses a land use model to analyse the impact of different land uses and show a range of potential paths to achieving the SDGs. Later, the project will require an analysis of trade and international markets to examine how varying progress on the SDGs at a national level can be suitably aggregated at the transnational level.

As part of the research, TSARA will evaluate the trade-offs and synergies between agricultural practices and negative environmental outcomes such as impacts on air quality, water quality, greenhouse gas emissions and biodiversity. To do this, indicators for monitoring the sustainability of different farm types will be developed. The indicators are linked to specific Targets under the SDGs and different farm types are linked to agricultural practices. The research is focused on study sites both within and outside Europe. New Zealand was chosen as a non-EU comparison, in part to contrast different approaches to measuring progress towards the SDGs and as a country with a different land use profile.

While the SDGs are aspirational goals that countries are not bound to achieve, all 193 UN member countries have committed to work towards them. In order to measure progress towards achieving the SDGs, the UN Statistical Commission developed indicators for some of the SDG Targets in 2016. Some Targets, however, do not have any indicators, and each country is tasked with developing their own approach to tracking progress towards those Targets. In addition, due to each country's unique situation and priorities, not all of the UN indicators are equally relevant to every country.

Figure 1. United Nations Sustainable Development Goals.

New Zealand has to set for itself its indicators for measuring our own progress towards achieving the SDGs. The government elected in 2017 has affirmed the importance of the SDGs, and it is important that policy-makers are involved in developing indicators to help support New Zealand to achieve these goals.

The current research focuses on developing indicators that are especially relevant to New Zealand and its land uses and agricultural practices. In particular, this phase of the research is about linking indicators to specific SDG Targets and enabling them to be incorporated into the TSARA model for making land-use choices.

2.2 Agriculture and the SDGs

In 2015, UN member states adopted the 2030 Agenda for Sustainable Development, and along with it 17 SDGs. The aim is that countries will mobilise efforts to end all forms of poverty, fight inequalities and tackle climate change, all while ensuring that no one is left behind (Sustainable Development Goals, 2015). Each goal includes specific Targets to be achieved by 2030. While the SDGs are not legally binding, governments are expected to take ownership and establish frameworks for achievement of the goals.

The key idea behind sustainable development is meeting the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987). Sustainable development calls for a concerted effort that combines economic growth, social inclusion and environmental protection. Sustainable development depends heavily on the sustainable management of natural resources and ecosystems.

Agriculture is at the centre of the SDGs, a common thread that holds them all together. Investing in the agricultural sector can help to address a range of prominent issues, from hunger and poverty to climate change and unsustainable production and consumption practices (Farming First, 2015). Existing agricultural systems are vital to sustaining the livelihoods of many and are capable of producing enough food for everyone, but they place immense pressure on the environment and natural resources including soils, water and biodiversity (International Institute for Environment and Development, 2013).

Agriculture has an important role to play in addressing people's future needs – while it is responsible for feeding the world, it is also a significant source of greenhouse gas emissions. Over the past 50 years, emissions from agriculture, forestry and fisheries have nearly doubled, and could rise by a further 30 per cent by 2050 if immediate action is not taken (Food and Agriculture Organization of the United Nations, 2014). The agricultural sector needs to pave the way in adopting a model of sustainable development and management of resources. The SDGs provide a framework for agriculture to make steps towards much needed change.

2.3 TSARA programme

TSARA is exploring ways to support and develop transformation pathways towards delivering on our commitments to the SDGs and their Targets. TSARA is a three-year research programme funded through the Joint Programming Initiative on Agriculture, Food Security and Climate Change (FAACE-JPI). FACCE-JPI aggregates data from 22 countries that are committed to building an integrated European Research Area addressing the interconnected challenges of sustainable agriculture, food security and impacts of climate change.

The TSARA programme includes four main stages in the development of transformation pathways. The first stage involves classifying a typology of different land uses and agricultural practices used in each of the four case study countries (UK, France, the Netherlands and New Zealand). The second stage involves the development of indicators that can help to track progress towards the SDGs and their associated Targets. The third stage incorporates the land use typologies and indicators into a model. The model uses baseline data to forecast outputs and impacts of agriculture over the next few decades. The fourth stage is about reconciling the baselines with the desired future state. In doing so, a number of alternative pathways can be developed to support achieving the SDGs and the desired end state.

Briefly, the TSARA project is coordinated by Rothamsted Research, who focus on using a model developed in earlier research to model new data. Wageningen University provides data and analysis of agricultural systems at the farm level and develops farm typologies and indicators. The Institut du Développement Durable et des Relations Internationales (IDDRI, France) is focused on backcasting and analysing the drivers of different transformation pathways. In New Zealand, AgResearch is looking to develop the model for New Zealand conditions and farming systems.

Through this structure, the project aims to promote a strong collaborative approach and ensure a wide range of stakeholders is involved in the development of pathways for achieving the SDGs.

2.4 Objective of the report

The purpose of this report is to provide an update on the progress made in FY18 towards AgResearch's contribution to the TSARA research. It is a follow-up to the report on the first stage of this research. The objective of this report is to describe how the TSARA model can be used in New Zealand. To do this, indicators need to be developed that can be used to track New Zealand's progress against the relevant SDGs and the TSARA model needs to be adapted for New Zealand agriculture systems.

The report is structured as follows. The next section reports on the stakeholder engagement process that identified indicators for assessing progress towards the SDGs in a New Zealand context. The subsequent section focuses on the Rothamsted model and how it can be adapted to model New Zealand data. A discussion section follows that considers how the SDGs can be adopted in policy and put into practice in New Zealand and how the indicators identified can be included in the modelling work.

3. INDICATORS FOR THE SUSTAINABLE DEVELOPMENT GOALS

3.1 Workshop process

The UN Statistical Commission has developed existing indicators that can be used to track progress towards the SDG Targets. The TSARA programme aims to expand on this set of indicators, with a specific focus on developing indicators that are useful for stakeholders in the government and private sector. This phase of the research involved holding a workshop with relevant government stakeholders to identify possible indicators that could be used in New Zealand to measure progress towards achieving the SDGs.

The SDGs cover 17 different Goals and 169 Targets under those goals. For the purposes of the New Zealand contribution to the TSARA programme, those Goals were narrowed down to the five Goals that are most relevant to agriculture and the environment. Under those five Goals, Targets were chosen that cover a wide range of ecosystems while remaining relevant to New Zealand. They are shown in **Table 1** below.

Table 1. SDG Goals and Targets included in stakeholder workshop process

SDG	Target
Goal 2 – Zero Hunger End hunger, achieve food security and improved nutrition and promote sustainable agriculture.	**Target 2.3** By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.
Goal 6 – Clean Water and Sanitation Ensure availability and sustainable management of water and sanitation for all.	**Target 6.4** By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity. **Target 6.6** By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.
Goal 8 – Decent Work and Economic Growth Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.	**Target 8.4** Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable consumption and production, with developed countries taking the lead.
Goal 14 – Life below Water Conserve and sustainably use the oceans, seas and marine resources for sustainable development.	**Target 14.1** By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution.
Goal 15 – Life on Land Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss.	**Target 15.1** By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements. **Target 15.3** By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land-degradation neutral world.

Each country in the TSARA programme is developing country-specific indicators. The research involves working with policy representatives and other stakeholders, including holding workshops on SDGs and indicators.

On 23 March 2018, New Zealand researchers held a workshop in Wellington to collaboratively develop indicators for the SDGs. Representatives from a range of relevant organisation were invited to help with this process. In attendance were 25 representatives from government organisations including:

- Department of Internal Affairs (DIA)
- Department of Conservation (DoC)
- Greater Wellington Regional Council (GWRC)
- Ministry for the Environment (MfE)
- Ministry for Primary Industries (MPI)
- Statistics New Zealand
- Te Puni Kokiri (TPK).

With a focus on the Targets above, the aim of the workshop process was to generate discussion and ideas for how New Zealand might go about achieving the SDGs. The workshop was designed with a collaborative approach in mind, using mainly participatory activities supplemented with written information where needed. The workshop began by introducing the SDGs and what they mean for New Zealand. The first exercise asked participants to think about each of the Targets and what New Zealand would look like in 2030 if these Goals have been met. This exercise was designed to get participants thinking about possible futures for New Zealand, and what it will take to achieve a sustainable future.

The second half of the workshop focused on indicators. To start off, the researchers gave a short presentation, based on prior research (PwC, 2017), on the qualities that make an indicator fit-for-purpose. Those qualities are that indicators should be:

- widely accepted by major stakeholders – Indicators that are widely accepted are more likely to be practical and spur real change. Without common ground, effort is put into defending the indicator rather than discussing what it tells us. Acceptance ensures that indicators are put to use and discussion is focused on action
- clearly defined and standardised – Indicators should be defined clearly and should use data that is standardised so measurement can be repeated across different time periods and countries and used for meaningful comparisons. Standardisation ensures that indicators are able to be used to observe trends and make comparisons
- affordable measurement and accessible data – Indicators should use data that is readily available or can be collected in a time- and cost-effective way, as this allows more data to be collected and can increase use. It ensures indicators are practical and realistic to measure
- performance-based – Indicators should, where possible, measure actual performance and outcomes linked to the Goals, rather than simply monitoring uptake of practices that are expected to promote desired outcomes. A performance focus ensures that indicators are being used to track meaningful results, not to monitor processes

- easily communicated and understood – Indicators should be easy to communicate to users and should be clear, simply and easy to interpret. This is likely to increase interest from stakeholders and the general public
- valid and meaningful – Indicators should adequately reflect the phenomena they are intended to measure and should be appropriate to the needs of the user. These qualities help to ensure indicators are as relevant as possible.

The next exercise asked participants to suggest indicators that could be used to measure progress towards each of the Targets. After possible indicators were identified, participants came together to assess the indicators based on the qualities above. Two indicators from each Target were discussed and checked against each of the criteria to determine whether they could be fit-for-purpose.

3.2 Results from the workshop

In the first exercise, participants described what New Zealand would look like if the SDG Targets are achieved. The discussions for each Target are summarised below.

Target 2.3 – Productivity and opportunity of small-scale producers

Participants discussed the idea that increased productivity and incomes are a reflection of an increase in general wellbeing and that efforts to improve incomes should focus on increasing the value, rather than the volume, of what is being produced. With specific regard to improved outcomes for specific groups, participants discussed options for Māori-owned land, settlement of Treaty of Waitangi claims, involving iwi in decision-making and achieving gender pay equality. Co-operation within communities, as well as between countries, is key to helping to achieve this Target. In their vision of the future, New Zealand will be an international leader in agricultural co-operation and will help lift agricultural productivity globally, including in the developing world.

Target 6.4 – Increasing water-use efficiency

Participants focused primarily on aspects of storage, ownership and supply of water. These all currently present issues that must be resolved in order to achieve Target 6.4. In particular, participants discussed the supply of water to rural areas, addressing ownership of water for all, including Māori, increasing the use of irrigation systems, developing better storage infrastructure and ensuring water is accessible to all. Better water-use efficiency can be achieved through urban design that takes account of water constraints and by improving access to data and methodologies around water management.

Target 6.6 – Protecting and restoring water-related ecosystems

Participants discussed a range of ideas around how they want waterways to look and the systems and processes needed to achieve the restoration of water-related ecosystems. The outcomes they hope to achieve include swimmable rivers, an increase in freshwater biodiversity, and adequate management of pollution and degradation of waterways. They discussed a number of ways to help realise these aims, including implementing a tourist levy, involving communities in decision-making, developing on-farm solutions to nutrient run-off and better understanding of systems allowing the best practices to become more widespread.

Target 8.4 – Efficient production and consumption of resources

Participants focused on sustainability initiatives and managing wellbeing through the four capitals framework. Some of the ideas discussed include pricing schemes that reflect all costs and scarcity of inputs, considering te ao Māori perspective, better matching land-use with land suitability, considering environmental impact when making decisions, more use of sustainable energy and achieving long-term sustainable employment.

Target 14.1 – Reducing marine pollution

Discussion of this Target focused on three areas – stakeholders, fisheries management and pollution and management. For stakeholders, achieving this Target would mean kai moana is safe to gather and eat and iwi are involved in decision-making along with other local perspectives. Fisheries management in the future will involve increased biodiversity and biosecurity that can be achieved by appropriate fishing limits and management of risks to waterways. Pollution and mitigation will be reduced leading to more swimmable beaches. This can be achieved through better awareness of marine pollution and its effects, better management of nutrient inputs and *E. coli*, better storm water management, fencing and erosion control, less use of plastics and reduced litter generally.

Targets 15.1 and 15.3 – Sustainable use of ecosystems and soil protection

Participants discussed a future where more value is placed on natural capital, waterways are cleaner and more swimmable, erosion is under control and more appropriate land-use is put into practice. Their discussion highlighted planting of trees as a way to work towards this, with the government's policy of planting one billion trees taking into account the importance of the right type of trees in the right places.

In the second exercise, participants identified possible indicators that could be used to measure progress towards each Target. Once each Target had a list of potential indicators, participants selected two indicators for each target to be assessed against the qualities of a useful indicator. The full list of indicators that participants identified can be found in Appendix A, along with whether they meet each of the desired qualities of an indicator. The table below shows the results of the collective assessment of the indicators selected for assessment for each Target from the workshop.

Table 2. Stakeholder assessment of indicators

Target	Indicator	Widely accepted by stakeholders	Clearly defined and standardised	Affordable measurement and accessible data	Performance-based	Easily communicated and understood	Valid and meaningful
2.3	Median income of all groups	✓	✓	Not so much	✓	✓	✓
2.3	Share of GDP across all groups	?	✓	Disaggregation difficult	✓	✓	?
6.4, 6.6	Number of iwi using rivers as a source of food	✓ (maybe not nation-wide)	Could be	✓	✓	✓	✓
6.4, 6.6	Ecosystem health indicators, eg MCI	?	✓	✓	✓ ? (depends)	✓	?
8.4	Presence and use of national natural capital accounts	Maybe in the future	?	Depends	Can be over time	× ?	✓
8.4	Emissions, or other environmental measures, per dollar	Maybe in the future	?	Depends	Can be over time	× ?	✓
14.1	Measuring sediment in waterways	✓	Needs improvement	Increased funding needed	✓	✓	✓
14.1	Number of keystone species	✓	Needs improvement	Increased funding needed	✓	✓	If done right
15.1, 15.3	Number of species on IUCN red list	✓	✓	✓	✓	✓	✓
15.1, 15.3	Productivity loss from floods/ drought	✓	✓	Tricky	Not entirely	✓	✓

The indicators in the table above satisfy most of the qualities used to assess a useful indicator. A more detailed assessment of these indicators follows.

2.3 – Median income of all groups

This indicator relates to Target 2.3 as it provides a suitable measure of the incomes of the groups of people mentioned in the target description. It does not measure, however, the agricultural productivity or access to productive resources or opportunities. The participants agreed that this indicator is likely to be widely accepted by stakeholders. The indicator is clearly defined and standardised as median income is a standard measure, however not all of the groups of people mentioned in the Target are defined clearly. Women and indigenous peoples have clear definitions, but the Target also mentions family farmers, pastoralists and fishers as small-scale producers, with no definition of who belongs to these groups. It may also be difficult to access accurate data to measure this indicator. Statistics New Zealand collects data on median income that can be broken down for women and Māori, but not for family farmers and the other groups. In the context of the Target, this indicator is performance-based, easily communicated and understood and valid and meaningful.

2.3 – Share of GDP across all groups

This indicator is a suitable measure for Target 2.3, although like median income, it focuses on measuring income and production. As with the median income indicator, this indicator is performance-based, easily communicated and understood and valid and meaningful. It also requires more definition for some of the groups included and disaggregation of data for the specific groups is unlikely to be available. The participants identified that this indicator may not be widely accepted by stakeholders.

6.4 and 6.6 – Number of iwi using rivers as a source of food

The participants agreed that this indicator is performance-based, easily communicated and understood and valid and meaningful. This indicator can be used as a way to measure the health and cleanliness of rivers by counting those that produce food that is safe to eat, but on its own it is not a measure of the health of a waterway. The participants believed that data is accessible or affordable to collect, however the data is not available currently. It is likely that individual iwi or marae keep information on whether their local river is safe to gather food from, but not all iwi will do this and there is no central database for this information. It is likely that this data would have to be gathered through a survey of iwi or marae, which is time-consuming and can be costly. The participants identified stakeholder acceptance and clear definition as the areas where this indicator falls short. They noted that the indicator may not be accepted nation-wide as a measure of water-related ecosystem health. They also discussed that it would need further definition and standardising to be useful.

6.4 and 6.6 – Ecosystem health indicators

Ecosystem health indicators are suitable for measuring Target 6.6, as changes in ecosystem health can provide an understanding of how well, or not, water-related ecosystems are being protected and restored. There are a number of possible ecosystem health indicators. The participants gave the macroinvertebrate community index (MCI) as an example, and the assessment of the indicator was based off this index. The participants agreed that MCI is clearly defined and standardised, uses affordable and accessible data and is easily communicated and understood. There was less agreement on the three other qualities. While MCI was proposed as a suggested indicator by some participants, others disagreed with its use and validity. It therefore is unlikely to be widely accepted by stakeholders and may not be valid and meaningful. The participants also stated that it may not be performance-based as it does not necessarily capture the overall health of the river or waterway in which it is measured.

8.4 – Presence and use of national natural capital accounts

There was significant disagreement among participants on the usefulness of this indicator. They agreed that it is valid and meaningful as it is a relevant way to measure the decoupling of economic growth and environmental degradation. Most of the participants agreed that although it does not meet the qualities of stakeholder acceptance, accessible data and being performance-based, with some development it could do so in the future. This indicator requires further definition and standardisation to be useful as an indicator. Most participants did not think this indicator is easily communicated and understood.

8.4 – Emissions, or other environmental measures, per unit of GDP

As with the presence and use of national natural capital accounts, participants believed this indicator needs more work before it can be used effectively. It is a useful way of measuring resource efficiency in production for Target 8.4. It is a valid a meaningful indicator, but may not have accessible data, performance-based measurements, or stakeholder acceptance yet. It also needs to be defined and standardised more clearly, which may help with making it easier to communicate and understand. Emissions per unit of product produced for export is collected at a national level for some export commodities. To be a useful indicator this could be used at a national level to consider the overall emissions intensity of GHG emissions per unit of GDP in the New Zealand economy.

14.1 – Measuring sediment in waterways

Measuring sediment in waterways is a suitable indicator for Target 14.1 as it provides a measure of one form of water pollution that can be tracked to understand whether it is successfully being reduced. The participants generally agreed that this indicator would be accepted by stakeholders, is performance-based, is easily understood and is valid and meaningful for Target 14.1. They discussed that it needs improvement in standardising how sediment is measured in waterways, as currently sediment tends to be measured only in sites where it is a concern. Making data accessible is likely to require increased funding in order to take measurements in more areas.

14.1 – Number of keystone species

This indicator relates to Target 14.1 as changes in the number of keystone species can be linked to the level of water pollution. The participants agreed that this indicator meets around half of the key qualities. It is accepted by stakeholders, performance-based and easily communicated and understood. It also needs improvement in standardising measurement and further funding to enable the collection of the necessary data. It is important that the correct definitions and measurements of keystone species are used to ensure that this indicator is valid and meaningful.

15.1 and 15.3 – Number of species on IUCN red list

This indicator meets all the qualities of a fit-for-purpose indicator. One major effect of ecosystem loss is loss of biodiversity (Tilman, et al., 2001). As a result, the number of species on the IUCN red list can indicate the effectiveness of ecosystem conservation, one of the aspects of Target 15.1. On its own, this indicator does not provide a complete picture of ecosystem health, rather it focuses on one aspect, but in combination with other indicators could be an effective measure. It is a valid indicator for this Target as fewer species at risk of extinction shows that conservation of ecosystems is being achieved. As this data is already being collected by the IUCN, it is easily measured and accessed. It is accepted by stakeholders, well defined and standardised, easily communicated and performance-based. This indicator could be made more specific to New Zealand's performance by limiting it to endemic New Zealand species on the IUCN red list.

15.1 and 15.3 – Productivity loss from floods/ drought

This indicator is related to Target 15.3, as measuring the productivity loss due to floods and drought gives an understanding of the extent to which land is degraded or in need of restoration. The participants agreed that this indicator meets most of the key qualities. It is accepted by stakeholders, could be clearly defined and standardised, is easily understood and is valid and meaningful. It is not entirely performance-based, but can be over time. Data collection for this indicator is likely to be difficult as it may require surveying farmers and producers to gather information on productivity loss due to these events.

3.2.1 Further assessment of indicators

The researchers completed an assessment of all of the indicators participants identified against the qualities of a fit-for-purpose indicator. The ten best indicators from the assessment are presented in Table 3 and described below, with explanations for how they meet the qualities and what is needed for them to be feasibly used. The full list of indicators that participants identified can be found in Appendix A. Many of the indicators will required further development before they meet all of the criteria and can be used meaningfully.

Table 3. Potentially fit-for-purpose indicators

Target	Indicator
2.3	Gender equality pay measure
2.3	Increase in four capitals stock (financial, social, natural, human)
6.4 and 6.6	E.coli measured in fresh water
6.4 and 6.6	Amount of nitrogen, phosphorus and sediment in rivers and fresh water
8.4	Gross National Income (GNI)
14.1	Environmental reporting series, coastal and estuarine water quality
14.1	Environmental reporting series, heavy metal load in sediment
15.1 and 15.3	Environmental reporting series, soil moisture and drought
15.1 and 15.3	Percentage change in land that is suitable for crop production
15.1 and 15.3	Environmental reporting series, land cover

2.3 – Gender equality pay measure

A measure of gender pay equality is a suitable indicator for Target 2.3 as it is one method of measuring the relative incomes of women, who are specifically referred to in the target. Statistics NZ recommends using the median hourly earnings from the New Zealand Income Survey as a measure for calculating the gender pay gap (Statistics NZ, 2018). Using this method, the indicator of gender pay equality meets most of the qualities used to assess a useful indicator. Gender pay equality is clearly defined, easily communicated, performance-based and meaningful for the Target. There is accessible data for this indicator. Stats NZ collects data on incomes, and this data is able to be disaggregated by gender. The quality that it is most likely to not have is wide stakeholder acceptance. This is due to gender pay equality still being seen as a somewhat controversial topic. In saying that, the Target specifically refers to increasing the incomes of women. In the context of the Target, it is likely most stakeholders would agree with this indicator. Although it is available, the data is not collected any more frequently than the census, so this is more suited to measuring long-term trends in gender pay.

2.3 – Increase in the four capitals

The Treasury uses the concept of four capitals in its Living Standards Framework (LSF) to organise indicators of sustainable intergenerational wellbeing (Ng, 2017). The four capitals are natural capital, social capital, human capital and financial capital. Under each of the capitals are a number of indicators that measure the health of the capitals. While the four capitals make use of indicators, an increase in the four capitals is not specific enough to be an indicator in and of itself. As Target 2.3 focuses on productivity and incomes of small-scale producers, the indicators used to measure financial capital may be of use. Some of the indicators the Treasury uses to measure financial wellbeing include household financial wealth, household disposable income and net fixed assets per capita (Ng, 2017). These indicators are accepted by stakeholders, are easily communicated and understood, are performance-based and valid and meaningful. As they are already being used by Treasury, they should have clear definitions, be standardised and have data that is easily measurable.

6.4 and 6.6 – *E. coli* measured in fresh water

Measuring the levels of *E. coli* in fresh water is a useful indicator for Target 6.6 in particular as it is a useful measure of the health of freshwater ecosystems. It is currently used as an indicator of freshwater quality, but primarily where *E. coli* levels are a concern. For it to be useful as an indicator of water quality at a national level, it may require further standardisation. A higher level of funding will be required to increase the frequency of measurement and number of sites measured.

6.4 and 6.6 – Amount of nitrogen, phosphorus and sediment in rivers and fresh water

The amount of nitrogen, phosphorus and sediment in fresh water is another indicator that is already used to measure the health of fresh water in areas where it is of concern. As with *E. coli*, more funding and a standardised way of measuring is needed to be able to collect data in more waterways.

8.4 – Gross National Income (GNI)

GNI is a measure of national production that is different from GDP. GNI is defined as the total domestic and foreign output created by the residents of a country. It consists of GDP as well as incomes earned by residents working overseas, minus incomes earned domestically by non-residents (OECD, 2017). It is likely to meet all the qualities of a useful indicator. It has a clear definition, is generally accepted by stakeholders, is performance-based and is easily understood. It is already in use and reported as a measure of country's productivity, so data is available and accessible. However in the specific context of the Target, it does not measure efficiency of production or decoupling economic growth from environmental degradation. It is valid as an indicator of the wider goal of economic growth.

14.1 – Coastal and estuarine water quality

Indicators of coastal and estuarine water quality are suitable for measuring progress towards Target 14.1 as they can provide a measure of the level of marine pollution in these areas. MfE currently collects a number of indicators for coastal and estuarine water quality. These indicators include the levels of nutrients, turbidity and dissolved oxygen in estuaries and coastal areas in a number of regions throughout New Zealand (Statistics NZ, 2015). These indicators are valid and, together, create a meaningful picture of coastal and estuarine water quality that can be used to track the reduction in marine pollution. These indicators are accepted by stakeholders, well-defined and standardised performance-based and easily communicated. As they are already in use, measurement and collection of data should not be a problem. These indicators are likely to be more useful if measured at more sites and more often; however this is likely to decrease the affordability of collecting data for these indicators.

14.1 – Heavy metal load in sediment

As with coastal and estuarine water quality, this indicator is currently measured by MfE and reported in Statistics NZ's environmental reporting series (Statistics NZ, 2015). High concentrations of heavy metal in waterways is typically a sign of contamination from urban areas. It is currently measured in 10 regions, but may be more useful if measured at more sites and more frequently. It is a valid indicator of marine pollution, is widely accepted by stakeholders, performance-based and easily communicated and understood.

15.1 and 15.3 – Soil moisture and drought – Potential evapotranspiration deficit

This indicator provides a measure of land that is affected by drought, and is suitable for Target 15.3 in particular as it shows how well this land is being restored. This indicator is another that is included in the environmental reporting series (Statistics NZ, 2015). Soil moisture and drought are measured through a drought index called potential evapotranspiration deficit (PED). PED is currently measured during growing season each year at 30 sites throughout New Zealand. It is a useful indicator for Target 15.3 as a decrease in the number of sites undergoing or at risk of drought shows progress being made towards restoring drought-affected land and protecting land from drought. It is well defined and standardised, could be easily communicated and is performance-based. While data is currently being collected, data from additional sites would make the indicator more representative and more useful.

15.1 and 15.3 – Percentage change in land area that is suitable for crop production

The percentage change in land area that is suitable for crop production is a valid and meaningful indicator for measuring the conservation of ecosystems. This indicator can show changes in, for example, the amount of land that has been changed from agricultural production to housing or roading. It would also capture the impact of land degradation, such as erosion or desertification. The indicator is accepted by stakeholders, standardised, performance-based and easily communicated and understood. There are a number of definitions of suitability for crop production, and to put this indicator to use, a single definition will need to be used. Similar data is currently collected by MfE and, when a definition is agreed upon, can be measured more often and throughout New Zealand to provide a more useful indicator.

15.1 and 15.3 – Land cover

Land cover is also part of the environmental reporting series (Statistics NZ, 2015). It measures the extent of vegetation, water bodies, built environments and bare natural surfaces across the country. Changes in land cover can be used to measure the conservation of land under Target 15.1 and desertification under Target 15.3. Data is collected using satellite images of the land, and is provided at a granular level with regional breakdowns. Data is available for the past 20 years, and can be used to understand how land cover has changed over time. This is a performance-based indicator that is accepted by stakeholders, well-defined and standardised, able to be measured, easily communicated and meaningful for the Targets it is intended to measure.

3.3 Progress on indicators

The workshop discussion and results as well as the subsequent assessment of proposed indicators demonstrate progress towards New Zealand indicators for SDGs. Workshop participants include policy-makers and stakeholders. They were able to collectively develop fit-for-purpose indicators for five Goals related to agriculture and the environment. Importantly, many of the indicators are based on data that is currently collected, although some collection may need to be expanded.

4. MODELLING TRADE-OFFS IN AGRICULTURE

4.1 Introduction

This chapter describes the Rothamsted model and how it works, outlines the results of modelling New Zealand cropping data and explores how the model could be adapted to be more useful for New Zealand agricultural systems. Although not a major land user in terms of utilised area, a standard cropping system in the Canterbury plains was chosen due to modelling simplicity and modelling outcome interpretation. It is a first attempt to capture the multiple trade-offs between crop yield and environmental outcomes under different management options using the Rothamsted model, in recognition both that future modelling will emphasise pastoral agriculture and that the presence of grazing ruminants on pastoral landscapes introduces new nutrient dynamics. In addition, the indicators used in this modelling exercise (biophysical and environmental) are not necessarily related to the ones described above. Indicators currently in the Rothamsted model were used to demonstrate the method for analysing trade-offs. Future work is expected to include additional indicators based on the work with stakeholders, and then model the trade-offs that arise with those indicators.

4.2 The Rothamsted model

Field experiments to monitor the wider implications of modern agricultural production and its externalities such as environmental pollution, depletion of natural resources and biodiversity, are very expensive. Expectedly, simulation models have an important role to play in helping us understand the landscape dynamics and bridging the gaps between what is provided by field measurements and what we need to know to capture the wider implications of agricultural systems in a holistic manner. Landscape modelling may also aid in the formulation, testing and validation of a hypothesis, often in spatial and temporal dimensions that are impossible to recreate and validate with field experiments.

A large number of agricultural models simulate the implications of farm management practises on the dynamics of critical processes and system outcomes. They have been developed at various scales: site- or field- (Cichota et al., 2013), farm- (Beukes et al., 2010), catchment- (Gielda-Pinas et al., 2015) or regional-scale (Vibart et al., 2015). Important objective outcomes in such models include crop and fodder growth, animal performance, soil organic matter dynamics, water flows, GHG emissions, nutrient losses, and impacts on competing organisms. A number of models simulate specific management decisions, fluxes (i.e. water from land to fresh water bodies), forecasts (i.e. pasture production forecasts), and other components of landscape farming, but fewer models are able to integrate some of the impacts of farming a landscape, and explore some of the interactions between the many components. Even fewer models can explore spatial and temporal linkages from a farm to a catchment scale. The most thought-provoking aspect of landscape modelling is the attempt to reproduce some of the dynamics these landscapes host, and it is important that models reflect the important mechanisms behind production and environment (Gaucherel & Houet, 2009).

Sustainable agricultural transformation must consider and prioritise a range of Targets (FAO, 2015). Win-win solutions may not be possible for some agricultural Targets, and trade-offs are thus expected. These are likely to occur for example between provisioning services (i.e. agricultural production) and regulating services (i.e. water quality, soil conservation and carbon sequestration) (Schwoob, 2016). The Rothamsted model (herein the landscape model) is an integrated model of crop, water and soil processes that occur in UK agricultural landscapes. The landscape model simulates the biophysical processes of an agroecosystem at the field or farm level, across a landscape. An agricultural landscape is conceptually understood here as a distinct pattern of farming systems and landscape elements in a homogeneous biophysical and administrative capacity (i.e. somewhat homogeneous conditions for farming in terms of climate, soil and administrative capacity) (Hazeu et al., 2010; Andersen, 2017).

The model has been validated using 50 years' worth of data from two long-term experiments conducted in the UK. The temporal and spatially explicit model runs on a daily step, and it simulates the numerous interactions that occur on agricultural fields. The aim of the model is to help us understand some of the critical crop-soil-water interactions and trade-offs between farm management practices that influence farm profitability and environmental footprint. Specifically, it has been used to enhance our understanding of trade-offs between temperate crop yields and environmental impact.

The landscape model integrates different aspects of landscape farming such as soil organic carbon (C) dynamics (Coleman & Jenkinson, 2014) extended for nitrogen (N) and phosphorous (P) dynamics (Coleman et al., 2017), and potential and water- and nitrogen-limited conditions for crop growth (Wolf, 2013), along with management practices aimed at improving crop yields. Briefly, in the model the soil is divided into three layers, a compromise between minimising complexity and capturing heterogeneity of the soil profile (Coleman et al., 2017). Soil mineral N comprises ammonium (NH_4^+) and nitrate (NO_3^-). Nitrogen cycling and dynamics are at the centre of the model. Nitrification [aerobic process where soil NH_4^+ is oxidised to form NO_3^- (prone to leaching) and nitrous oxide (N_2O – a potent GHG)] and denitrification (anaerobic process where soil NO_3^- is reduced to N_2O and N_2) are key soil processes within this cycle.

The crop model is a determinate plant growth model; growth stops once a genetically pre-determined structure is completely formed, completing a life cycle. It uses light use efficiency (LUE; g DM MJ^{-1}) to calculate biomass production (Coleman et al., 2017). Plant biomass is partitioned between above (stems and leaves) and below ground (roots and storage organs) depending on developmental stage (Wolf, 2013), and plant uptake of N is determined by crop demand and soil supply. The grass model differs from the crop model; grass is a perennial crop, but with indeterminate growth, that prevents plants from flowering.

In the landscape model, trade-offs between multiple objectives (biophysical and environmental) are explored using an optimisation algorithm to determine best possible compromise (ie frontier) using Pareto front analysis (Coello Coello et al., 2007) of model outputs. The optimised Pareto fronts illustrate the trade-offs between variables such as crop yield and nitrous oxide emissions, for example (Figure 2).

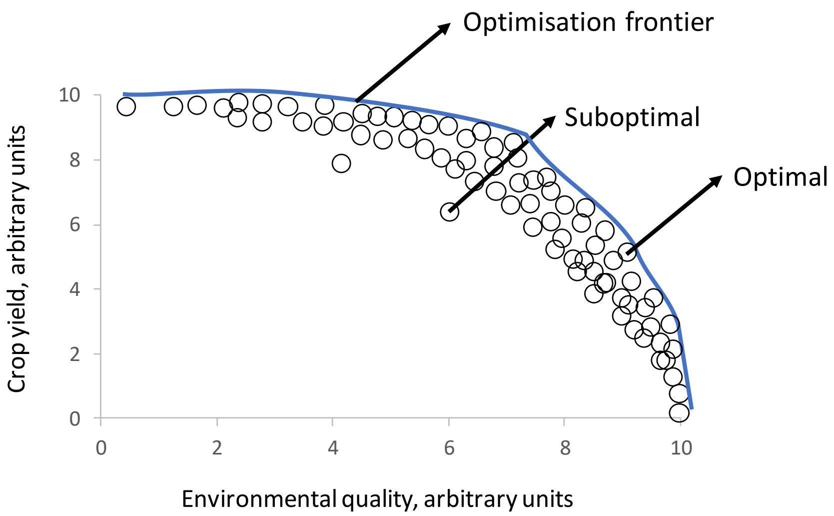

Figure 2. A conceptual illustration of an environmental vs. biophysical production (i.e. crop yield) possibility frontier (adapted from Coleman et al., 2017). The circles closer to the optimisation frontier (blue line) represent independent outcomes of management that optimises both yield and environmental quality simultaneously (i.e. scoring better on both objectives). Beyond these points,

outcomes are currently unattainable. Suboptimal circles = either production or environmental quality could be improved without an impact on the other.

The model has been used to predict the multiple outcomes of a wheat crop grown under landscape conditions that are typical of arable England (Coleman et al., 2017). The model was evaluated against crop growth and nutrient uptake data of cereals and grasses, and has been successful (i.e. showing a good predictive ability) in its simulations of wheat yield, and grain N and P concentration (Coleman et al., 2017). More recently, a simplified version of the landscape model was used to estimate C, N and P pools and pool changes and nutrient fluxes of arable and grassland systems in the UK over the last two centuries (Muhammed et al., 2018).

4.3 Cropping systems in the Canterbury Plains of New Zealand

New Zealand has one of the world's highest rates of agricultural land intensification over recent decades, but domestic agricultural practices are yet to reach the intensity of other areas such as the EU (OECD, 2017). Grain crops are not a major land user in New Zealand when compared with the major pastoral sectors (sheep and beef, and dairy), but the sector was convenient for assessing and demonstrating the modelling method. The total area harvested for herbage and vegetable seeds in the 2016-17 season reached its highest point (42,000 ha) since 2007. In contrast, the total area in wheat and barley dropped to 83,000 hectares, the lowest since 2008 (Statistics NZ, 2018).

Canterbury is the largest region in New Zealand by Regional Council boundaries, and it is of significance to New Zealand's agricultural production. The region comprises a diverse mix of intensive dairy, sheep and beef, and cropping operations on the plains, to extensive sheep and beef farms on high country (Dynes et al., 2010). The region comprises up to 85% and 63% of the total area in wheat and barley, respectively, and half of New Zealand's area in grain seed and fodder crops is in Canterbury (Statistics NZ, 2018). In the region, the area in wheat dropped to 34,000 ha in 2017, from a high of 47,800 ha in wheat in 2012. In contrast, dairy cattle numbers in Canterbury continue to rise (the region currently carries 20% of the national herd), compared with a relatively steady trend in New Zealand's dairy herd numbers (Statistics NZ, 2018).

In 2013-14, irrigation was the largest consented user of consumptive water (ie water not immediately returned to a water body) by volume (51%), followed by households and industry, and Canterbury accounted for almost two thirds (478,000 ha) of the total consented water volume for irrigation (Ministry for the Environment and Statistics NZ, 2017). Almost 95% of irrigation in Canterbury is under a spray system (Statistics NZ, 2018). Irrigation provides greater and more stable crop yields and crop quality.

4.4 Using the landscape model to simulate a cropping system in the Canterbury Plains

4.4.1 Model inputs

The landscape model requires weather, soil, and crop and management data (Table 4). For example, weather data includes radiation (kj m^{-2}), minimum and maximum temperature (°C), and rainfall (mm), amongst other variables, on a daily basis.

Table 4. Data required to parameterise the landscape model.

Weather (daily)	Radiation (kj m^{-2}), minimum and maximum temperature (°C), vapour pressure (kPa), wind (m s^{-1}); daily average), rain (mm), sunshine hours (h).
Soil properties for each layer (initial)	Depth of soil layers (mm), clay (%), silt (%), soil bulk density (BD, g cm^{-3}), soil pH, soil organic carbon (SOC, %), available and unavailable P (kg P ha^{-1}), mean and maximum slope (proportion).
Crop and management	Crop name, sowing date, N fertilizer type, N fertiliser application date and amount applied (kg N ha^{-1}), P fertiliser type, P fertiliser application date and amount applied (kg P ha^{-1}), organic matter addition type, organic matter application date and amount applied (t C ha^{-1}).

A simple cropping system in the Canterbury plains was simulated using the landscape model (Figure 3). We selected the Standard arable rotation (grain, seed and legume vegetables) representative of the region from Hume et al. (2015). To gain a representation of current management practices, arable and horticultural growers across Canterbury were surveyed and detailed management information was provided for crop rotations (Hume et al., 2015). These crop rotations were used to model these farms to inform the Matrix of Good Management (MGM) project (Robson et al., 2015) to gain a representation of current management practices in Canterbury.

The Standard arable rotation comprised grain, seed and legume vegetable crop types, including grain (barley and wheat), seed production (clover, ryegrass seed, carrot) and legume vegetables (green beans and peas). A five-year rotation was represented across four crop blocks in Overseer®, with no grazing taking place on farm. However, outputs from Overseer® were not used to parameterise the landscape model. Centre pivot irrigation was set with good management practice (GMP), based on a soil water budget and 50% profile-available water as a trigger point to start irrigating (see Hume et al., 2015 for more info regarding irrigation GMP). Crop yields were adjusted to represent what might be expected in this particular climate and soil. Fertiliser applications also followed GMP (Hume et al., 2015).

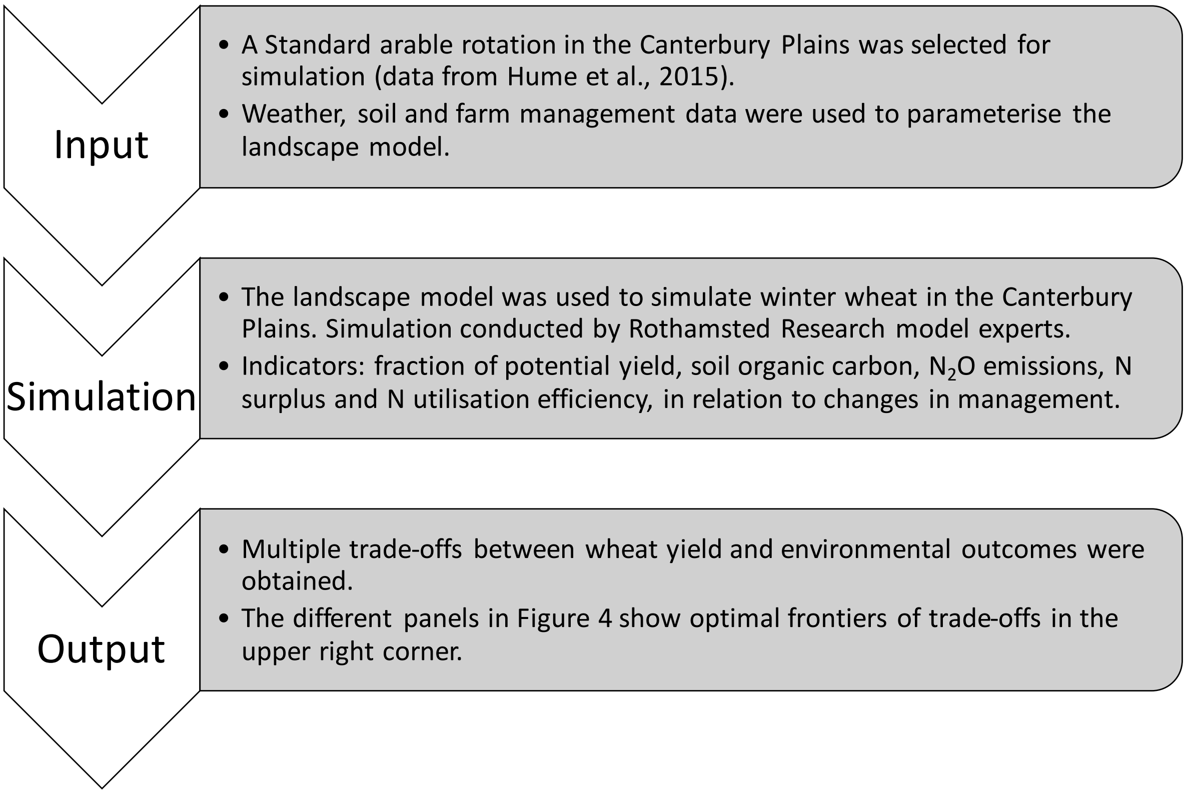

Figure 3. Stepwise process followed during the modelling exercise.

In order to explore the multiple trade-offs between wheat yield and environmental outcomes using the landscape model, we used data provided by Plant and Food Research (PFR) (Ellen Hume, PFR; Val Snow, AgResearch; personal communication). These datasets included weather, soil properties, and farm management data used to parameterise the model (Table 4). Long-term weather data typical of Canterbury Plains (climate cluster 03; daily time step from 01-01-1972 to 31-10-2013) and soil properties data from a well-drained, shallow loam with a potential rooting depth of 60 to 90 cm and low topsoil P retention, were used to parameterise the landscape model (***Table 5***). The model runs for 10 years.

Table 5. Key agronomic characteristics (crop and soil) and control variables (N, P and manure applications) of winter wheat production in the Canterbury Plains used to parameterise the landscape model.

Crop	Winter wheat (*Triticum aestivum*).
Soil characteristics	13% clay, 40% silt, 1% SOC, 1.2 g cm^{-3} BD, 30% stones.
Crop sowing date	10^{th} April; six months out of sync with UK/Europe.
N and P fertiliser and manure applied	Up to nine N applications; appl. 1 to 8 (0 - 100 kg N ha^{-1}), appl. 9 (0 - 120 kg N ha^{-1}). A single P application (0 - 150 kg P ha^{-1}).

In the Canterbury Plains, the greatest grain yields have been obtained by sowing wheat in late March (Craigie et al., 2015).

4.4.2 Preliminary model outcomes

Each panel in Figure illustrates the best trade-off that can be achieved between the two variables shown, but the trade-offs are calculated for all variables together. So all the points shown are on the frontier of all variables (indicators) investigated (i.e. fraction of potential yield, changes in SOC (δ SOC), SOC, GHG (N_2O) emissions, N surplus, and N utilisation efficiency NUE) in relation to changes in management. The different management options tested (i.e. control variables in Table 5) are mostly dates and amounts of N and P application, and to a lesser extent, sowing dates and application of different amounts of farmyard manure at different rates. Specifically, the control variables selected for this modelling exercise were N fertiliser (up to nine applications, applied at 2-week intervals, each application limited to 0-100 kg N ha^{-1}) and P fertiliser (applied a week before sowing, limited to 0-150 kg P ha^{-1}).

For each set of control variables, the set of six indicators as listed above, were calculated. Indicator values were calculated based on mean values of 10 years (2000-2010), except for SOC indicators, which were based on SOC at the end of the simulation, and δ SOC as the difference between SOC at start and end of the simulation. In other words, the starting SOC value was considered 1% C, and the SOC value at the end of the 10-year run was reported as an outcome (e.g. if SOC = 1.5%, then SOC reported is 1.5% and δ SOC = 1.5 – 1.0 = 0.5; SOC and δ SOC are directly related (right panel in Figure).

Annual N_2O emissions (GHG in Figure 2) are expressed as kg CO_2e ha^{-1} using a conversion factor of 296 (296 kg CO_2e per kg N_2O emitted).

Nitrogen surplus and NUE are calculated as:

N surplus (kg N ha^{-1} $year^{-1}$) = N in fertiliser – (N in grain at harvest + N in straw at harvest)

NUE (unitless) = (N in grain at harvest + N in straw at harvest) / (fertiliser N + atmosphere N), expressed as absolute of 0.9 (i.e. how close values are of 0.9)

Nitrogen in farmyard manure was not included in the calculation of N surplus and NUE (Kevin Coleman, personal communication). In each panel, emphasis is on management options that meet certain criteria: i) high-yielding, efficient, non-polluting management practices, and ii) minimal use of farmyard manure.

Fraction of potential yield and δ SOC (unitless) broadly range from 0 to 1 and from -0.5 to 1.0, respectively (Figure 2). It is important to note that in order to present frontiers uniformly, the different panels show their optimal frontiers of trade-offs in the upper right corner. For example, to accommodate frontiers in the upper right corner of panels, GHG (N_2O) values in the y-axis were swapped, and the values presented need to be interpreted as absolute values.

Trade-off curves were obtained by an optimisation procedure during multiple iterations on multiple objectives using a non-dominated sorting algorithm. From top to bottom panel, results show that changes in SOC and SOC (%) tended to increase with increases in potential yield almost linearly up to about 0.5 of potential yield before flattening (red points to a slightly lesser extent). As yield increased (most probably due to changes in fertiliser application), the lowest possible N_2O (kg CO_2e ha^{-1}) emissions to be achieved also increased, but the shape was far from linear. Nitrogen surplus (kg N ha^{-1}) tended to decrease (red points to a lesser extent) with increases in potential yield (fraction of potential yield). Nitrogen utilisation efficiency (NUE; distance to an absolute target value of 0.9) tended to zero following a logistic pattern; increasingly more N removed in grain and straw at harvest than that entering from fertiliser and atmosphere.

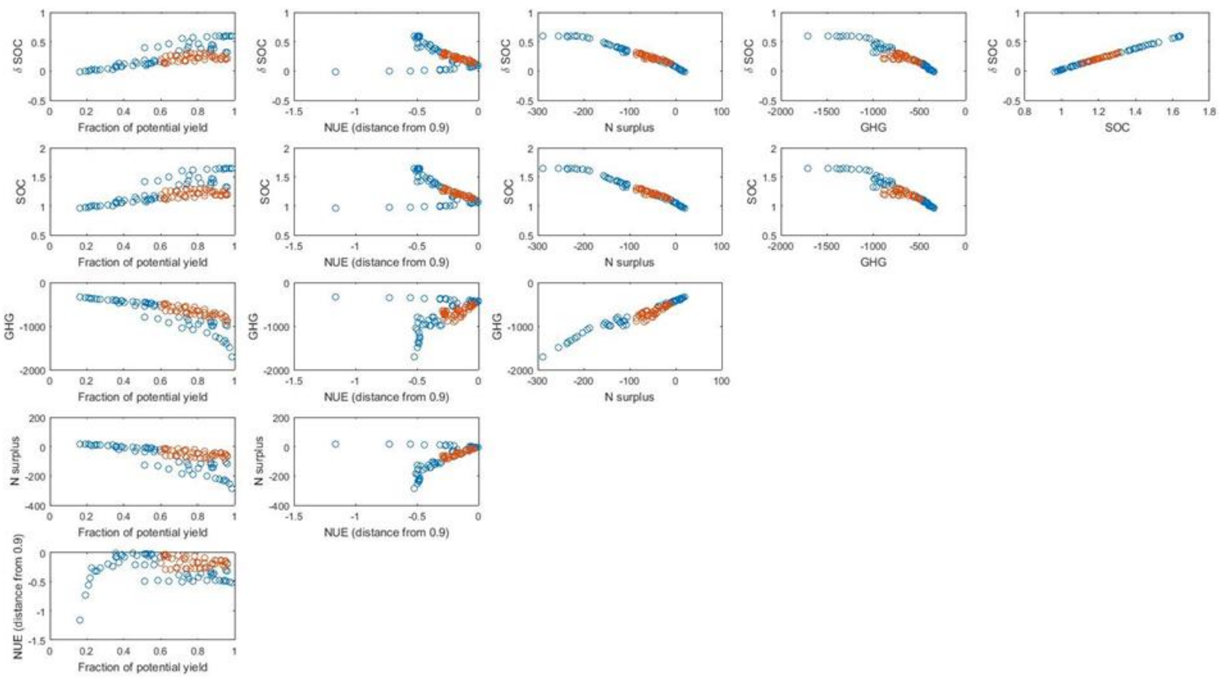

Figure 4. Different panels showing pairwise trade-offs between two variables (trade-offs are calculated for all variables together behind the scenes). All data points shown are on the frontier of all variables investigated [fraction of potential yield, changes in SOC (δ SOC), SOC, GHG (N_2O) emissions, N surplus, and N utilisation efficiency (NUE)]. Note: For any given panel, red points satisfy the following criteria: i) between 0.6 and 1.0 of potential yield, ii) annual N surplus <100 kg N ha^{-1}, iii) NUE between 0.5 and 0.9.

4.5 Discussion

Incommensurable trade-offs are those involving objectives with no common standard of measurement. Farmers are increasingly faced with complex decisions that require considering multiple trade-offs between such objectives, e.g. production, profitability and environmental footprint. Here we consider production and environmental footprint objectives, without addressing farm profitability.

Non-dominated solutions are those where none of the objective variables can be improved without compromising some of the other objective variables. The combinations of these variables provided a series of pairwise comparisons to identify the management options that prompt non-dominated sets of objectives. Allowing the optimisation algorithm to vary the amounts of N and P applied, and to a lesser extent, sowing dates and application of different rates of farmyard manure, led to the identification of trade-offs between variables (fraction of potential yield, δ SOC, SOC, N_2O, N surplus, and NUE) (Figure). On these frontiers (or best trade-offs achieved), no objective can be improved upon without being disadvantageous to at least one of the other objectives.

As an example of these trade-offs, increased wheat yield was associated with an increase in SOC concentration, and increased SOC concentrations were associated with increased N_2O emissions (Figure 4). There is a significant interest in increasing SOC concentration in agricultural soils worldwide. However, in agreement with our findings, increased SOC may increase the environmental footprint of some agricultural systems. Increased SOC concentration alters N cycling and certain soil physical properties, such as soil water holding capacity. The Agricultural Production Systems sIMulator (APSIM) model (Holzworth et al., 2014) was used to represent the effect of increased SOC concentration on N cycling and soil physical properties from wheat production at seven locations around the world, including the Canterbury Plains (Palmer et al., 2017). Under increased SOC, N cycling had a greater effect on the filtering of N and N_2O regulation than on soil physical properties, and the effect of increasing SOC on N cycling also led to significantly higher N_2O emissions (Palmer et al., 2017).

In Coleman et al. (2017), as yield approaches its maximum, both N_2O emissions and nitrate leaching increase substantially with increasing amounts of fertilizer for an increasingly marginal improvement in yield. Nitrate leaching and N_2O emissions are synergistic throughout most of the range described, however a trade-off appears as the emissions reach their minimum value, as this also results in an increase in leaching. This illustrates how an optimisation approach (e.g. minimising N_2O) could have unintended consequences for another process (nitrate leaching), if both objectives were to be considered in isolation.

Although nitrate leaching is not reported, similar preliminary findings were seen in our simulation; the non-linear response of N_2O emissions to increased crop yield also shows that N_2O emissions increase considerably in response to increased amounts of fertiliser beyond a certain ‘threshold’ (0.7 to 0.8 of potential yield). Beyond this point, increasingly marginal improvements in crop yield are obtained (Figure). Following this approach, the optimisation algorithm does not recognise a single fertilization strategy, rather it highlights nonlinearities that allow us to identify where a small reduction in one objective could result in a large benefit to another objective.

Although models and model outcomes should be used with caution, this model allows us to consider multiple interactions under a range of management options; if used properly, key relationships can be identified, and unintended consequences of certain actions can be highlighted. It is important to note that the landscape model or model framework (it includes an assortment of models addressing crop growth and of soil, water and nutrient flow dynamics) has not been validated for New Zealand conditions. Also unlike in the UK, where cereal (1.7m ha) and arable (4.3m ha) comprise 12 and 30% of total utilised agricultural area, the area under crop farming (285,000 ha) is only 2% of New Zealand's total area under farming (Beef and Lamb New Zealand, 2017).

4.6 Next steps – adapting the dairy model to New Zealand conditions

The dairy component of the landscape model (herein the dairy model) is based on the model currently used for reporting GHG emissions from agriculture (UK National Inventory model). The dairy model currently assumes that farmers optimise milk yield by adjusting concentrate intake on a daily basis to achieve a certain amount of energy required by the cows whereas non-lactating cows, replacement heifers and young livestock consume a fixed ration. The model includes several types of forages and supplements such as grazing options (grass grazing and improved grass/clover grazing), conserved forages (grass silage, maize silage, whole-crop silage, barley straw), each with a given energy and dry matter (DM) concentration. The model is energy-based – cows have an energy requirement to produce their target milk yield, and can only consume a certain amount of DM from the above menu, which often falls short of providing the full energy supply required. Hence, the need for concentrate supplementation, which is calculated daily. Dairy breed size is either small, medium, or large.

Given that in the UK dairy sector often the goal is to produce milk at a similar rate throughout the year (i.e. no seasonality in breeding), herd numbers are in steady state (i.e. opening and closing numbers are equal). The herd is assumed to be split between calves, heifers, followers and dairy cows in proportions of 0.25, 0.05, 0.2, and 0.5, respectively. Both the lack of milk production seasonality and a fixed herd split will need to change if we are to capture typical New Zealand dairy systems.

Herd management options include housing, partly housing, and out of the shed throughout the day. When on the field, cows deposit urine and faeces onto the soil and the N enters soil dynamics. All cattle categories emit methane. When cows are in the shed, the manure is managed in a number of ways which need to be specified from a menu of options. The dairy model is also linked to the optimisation algorithm, and the model operates with the following control variables, inputs and outputs.

Control variables:

- **Stocking rate per ha** – This value is multiplied by a vector (0.25, 0.05, 0.2, 0.5) assigning the stock to calves, heifers, followers and dairy cows. The range is set between 0 and 5 cattle per ha.

Inputs:

- **Out date** – The day the cows are turned out. Currently fixed at day 92. When out, cows graze grass supplemented with concentrate. When in the shed, cows consume silage of a defined type.
- **In date** – Similar concept as above, currently fixed at day 274.

Outputs:

- **Milk yield** – Measured in kg, this is a fixed value per cow, so total yield = yield per cow × number of dairy cows.

Integral to the landscape model is a function that calculates daily emissions of N_2O, CH_4 and NH_3 from dairy cows and/or soils, as well as urinary and faecal deposits to grass, and farmyard manure and slurry accumulation. This work is ongoing and we are yet to provide data of a representative, mid-intensity dairy farm system to be simulated with the dairy model.

Most dairy systems in the UK are different from what we have in New Zealand. Dairy systems in New Zealand are specialized (in terms of preferential land use – lactating vs. non-lactating herds) and seasonal (most herds are spring-calving herds). Most cows are out of the barn all year, on rotational grazing systems. A typical mid-intensity New Zealand dairy farm has a milking platform that holds lactating cows only (for about 300 days per year), and a support block or runoff that holds dry cows, replacement heifers and calves. This support block often provides maize silage and pasture silage (North Island), pasture silage (South Island), and some winter fodder cropping, which may also occur on the milking platform, but to a lesser extent. Summers in the North Island often require a summer fodder crop too, and this would be on the milking platform given that this gap in pasture (yield and quality) is still happening during mid- to late-lactation. In terms of irrigation, irrigated systems in Canterbury, fewer irrigated dairy farms scattered throughout New Zealand (especially those located towards the east coast), but most dairy farms in other regions are on dryland.

Starting with calving dates, these vary from the northern-most region (Northland; planned start of calving: 15 July, median calving date: 01 August) to the southern-most region (Southland; planned start of calving: 10 August, median calving date: 20 August). The planned start of calving date is 282 days from the date that mating starts in the herd (New Zealand Dairy Statistics, 2017). The median calving date is used as an indicator of actual calving spread. Calving interval for Friesian/Jersey crosses in the 2016-17 season was 370 days, and lactation lengths of cows that were herd-tested in the 2016/17 season were 202, 232 and 229 days for Northland, Southland and as a national average, respectively (New Zealand Dairy Statistics, 2017). If we assume a replacement rate of the national herd of about 22% (a mean of 4.5 lactations per cow), the proportion of calves, heifers, followers and dairy cows (0.25, 0.05, 0.2, and 0.5) may have to shift to one of 0.0, 0.15, 0.25, and 0.6 for calving and early lactation. These proportions will have to be altered at least seasonally. These are some of the characteristics of seasonal dairying in New Zealand, and will have to be captured by the dairy model in order to simulate local dairy conditions.

4.7 Conclusion

So far, the landscape model has provided sensible outcomes from simulating a simple cropping system in the Canterbury Plains. For example, linear (δ SOC and SOC) and non-linear (N_2O emissions) responses to increased wheat crop yields seem reasonable, especially in light of an optimisation algorithm that identifies clear trade-offs between objectives. The model allowed considering multiple interactions under a range of management options, and thereafter, unintended consequences of certain actions were highlighted.

The presence of grazing ruminants on pastoral landscapes introduces new nutrient dynamics. Beyond site-specific thresholds of grassland intensification, the coupling of C and N cycles in crops and grasslands by elemental stoichiometry becomes decoupled by grazing herbivores by concentrating reactive forms of C and N (Parsons et al., 2013). This decoupling process beyond thresholds often leads to impaired environmental sustainability. Systems that include animals introduce i) new dynamics of N, where for example plant N is converted to urea and subsequently to ammonia by hydrolysis (Harper et al., 1987), and ii) new dynamics of C, where enteric methane emissions are introduced, and intake demand and removal of nutrients in animal product play a role in soil C dynamics (Parsons et al., 2013).

In a broader sense, decoupling productivity and environmental pollution growth is a key objective for modern agriculture, and the use of a model or model framework such as the landscape model will contribute to this objective. Adapting the model to New Zealand dairy conditions will allow for a much broader representation given the significance of dairy as a major land user and its contribution to the country’s economy.

5. DISCUSSION

5.1 The Sustainable Development Goals and TSARA

The SDGs are gaining momentum in New Zealand. With the change in government in 2017 and more widespread understanding of the SDGs, new focus is being put on finding ways to achieve the Goals. The focus is on how New Zealand can start taking practical actions towards the SDGs, in particular measuring and reporting against them. Responsibility for achieving the Goals and monitoring progress towards them sits with the government, but many businesses are increasingly acknowledging the role of the SDGs and taking practical steps to support them. Within the business world, the SDGs represent not just targets, but opportunities for businesses to evolve new sustainable ways of working. Some businesses are already beginning to use the Goals as a guide for their own actions towards sustainability initiatives and reporting.

The government is putting a greater emphasis on the SDGs in setting policy. The SDGs are explicitly referenced in the confidence and supply agreement between the Labour Party and Green Party, negotiated during the formation of the government (New Zealand Labour Party & Green Party of Aotearoa New Zealand, 2017). Several government agencies are working with Statistics NZ to prepare a comprehensive set of measures that will give the government a clear picture of the existing situation in New Zealand and what it will take to achieve the SDGs.

To operationalise the SDGs and make them useful in driving policy, the government needs to understand the trade-offs involved. Different Goals and Targets may conflict with each other and some Goals will require trade-offs to be made between them. It is possible that making progress towards one Goal may result in negative progress being made towards another. For example, Target 2.3 is about increasing the incomes of small-scale producers. One of the ways this can be achieved is through increasing production, however this must be done in such a way that is sustainable and efficient in order to meet Target 8.4. It is important that progress towards one Goal does not work to the detriment of progress towards other Goals.

The government is interested in all of the SDGs. However due to the trade-offs mentioned above, it is necessary to prioritise some of the Goals over others. Of particular importance, both for this project and for New Zealand, are the Goals that are relevant to agriculture. Agriculture is a large part of New Zealand's economy, but can produce environmental effects that need to be mitigated and managed for agriculture to be sustainable into the future. This research is interested in agriculture-related SDGs and focused on the Goals and Targets that most closely align with sustainable agriculture. Those Goals are:

- **Goal 2** – Zero hunger
- **Goal 6** – Clean water and sanitation
- **Goal 8** – Decent work and economic growth

- **Goal 14** – Life below water
- **Goal 15** – Life on land.

New Zealand's participation in the TSARA project is managed through AgResearch and the Our Land and Water National Science Challenge. For these organisations, the SDGs provide a framework for organising the discussion about sustainability. This discussion must include researchers, industry and government. TSARA is thus a mechanism to support and focus that conversation. Encouraging the participation of stakeholders, for example through workshop processes, is one way to support the conversation. Developing fit-for-purpose indicators and modelling them serves to move the conversation forward. For these reasons, TSARA could and should be a useful programme across research, industry and government.

5.2 The TSARA model

The focus of the TSARA programme is in developing Rothamsted Research's landscape model so it can be used to develop pathways to achieving the SDGs. The structure of the TSARA model was described in more depth in our 2017 report (Vibart, et al., 2017). Briefly, the landscape model considers farm types by applying a typology of farms to the area farmed. Overlaying this typology is a classification of climatic and geographic conditions (agri-environmental zones, AEZs). The combination allows the model to quantify trade-offs between production volume and environmental effects for different variables for different farm types in different environmental conditions.

The TSARA model is a tool that can assist with identifying and describing the trade-offs involved with the SDGs. While the model is primarily focused on 'Goal 2 – Zero hunger' it can be used and applied more broadly. Goals 6, 14 and 15 address the pollution caused by agriculture and its impact on the landscape. Goal 8 relates to increasing the sustainability and efficiency of means of production in a general sense, which can also be applied to agricultural production. The model can be useful for providing information on future states and policies across each of these Goals.

One of the major strengths of the model is how it joins multiple scales. The SDGs operate at the international level. They are global Goals that impose obligations on governments at a national level. Success in achieving the SDGs is measured Goal by Goal by each country as a whole. Action towards achieving them, however, occurs at the individual farm or business level. Each farm or business must play their part and take responsibility for their own actions in order for progress to be made. It is at this farm level that the TSARA model operates.

However the SDGs go from the national scale directly to the community or farm level. The intermediate scale – the catchment or region – is skipped. The TSARA model makes an attempt to cover the intermediate scale with AEZs.

AEZs are sections of land that are defined by sharing similar climates, soil types and slope. In this way, all the land within a certain AEZ is suited to the same land use. While AEZs help with capturing information at an intermediate level, they are an imperfect proxy for the regional scale. They often relate to combinations of regions, and are based on land suitability and type rather than administrative boundaries. Nonetheless, by joining the farm-level and the regional level, the model can provide a more useful picture of how different local choices affect regional level outcomes.

5.3 Extending the model to cover New Zealand

The TSARA model, as it is currently being used, is a tool that helps us understand the interactions between crops, soil and water and the trade-offs arising out of different farm management practices. It was developed based on data from the UK and is designed primarily for modelling cropping systems. In order to be useful for New Zealand, there are some ways in which the model must be adapted.

The first way in which the model can be adapted is in providing New Zealand data as inputs into the existing cropping model. The modelling chapter of this report shows that this can be done. The chapter outlined the New Zealand data that was incorporated into the cropping model. Using New Zealand weather, soil and crop and management data, the model could simulate outcomes for a simple cropping system in the Canterbury Plains.

We have demonstrated that it is possible to model the cropping system in New Zealand and get meaningful results. However cropping makes up a very small amount of New Zealand's agricultural production since New Zealand is highly pastoral. Sheep, beef and dairy farming make up the majority of New Zealand's agricultural land use and production (Statistics NZ, 2018). The model would be much more useful for New Zealand if it were adapted to better reflect a wider diversity of agricultural systems.

Rothamsted has incorporated into the landscape model a dairy farming component based on the UK's National Inventory Model for calculating greenhouse gas emissions. That model is based on UK dairy farming systems and practices. For it to be applied in New Zealand there are key differences in how the New Zealand dairy sector operates that the model would need to account for. Adapting the model for seasonal milk production and a fixed herd split are two of the main changes required to enable it to be used for New Zealand dairy farming.

In addition, adapting the existing model for a wider range of farming types will ensure that it can be used meaningfully outside of the common EU farming systems. Doing so will ensure a wider applicability beyond just New Zealand, and will make the model more useful.

5.4 Potential use of the model in New Zealand

All 193 UN member countries have committed to work towards the SDGs. The New Zealand government has affirmed the importance of the SDGs, and the importance it places on the Goals in setting government policy.

For the SDGs to be useful in practice, there must be a way of measuring progress towards their achievement. The SDGs start with high level, aspirational Goals at the top, and are made more specific with Targets. Each Target describes a desired outcome and timeframe for achieving that outcome. But in order to understand how close we are to reaching the Target, we need to use indicators. Indicators allow progress towards the Targets to be tracked and measured in a way that can meaningfully influence decision-making and outcomes.

The UN Statistical Commission has recommended indicators for measuring progress towards some of the SDG Targets. Not all of the Targets have indicators, however, and not all of them are applicable for New Zealand. The government is interested in the conversation around indicators and understands the necessity of having relevant and fit-for-purpose indicators to track towards our Goals. Statistics NZ is looking at indicators with a first-principles approach. It is interested in not just the indicators that we currently have but also the indicators we need. It is open to the possibility of creating new datasets and new indicators.

Through our contribution to the TSARA research programme, we have made good progress on identifying and selecting indicators for measuring progress against the Goals and Targets. Through the workshop process we have described the public sector's vision of the future where New Zealand agriculture has achieved the Goals. Government stakeholders have developed indicators with us on how progress towards those scenarios can be measured and assessed those indicators for how fit-for-purpose they are. The TSARA programme is taking this further with a model which could be used in New Zealand to identify and quantify trade-offs between the economic and environmental aspects of agriculture, two Goals that New Zealand government, researchers and industry groups are particularly interested in achieving.

The progress we have made so far could be very useful for policymakers, researchers and industry groups in developing frameworks and measurement systems for tracking New Zealand's progress toward the SDGs.

6. CONCLUSION

The TSARA research supports the aim of the Our Land and Water National Science Challenge to liaise with researchers, industry and government. The new knowledge being produced in TSARA is giving researchers a clearer picture of priorities and measurement issues to investigate further. It is also giving the agricultural sector a better idea of the potential performance measures and the types of changes that could occur. Finally, it is providing government with practical assessments of potential indicators, lists of these indicators and initial views on the pathways toward achieving the SDGs.

This work is still in progress. We expect that the next year will involve significant collaboration with the TSARA modellers in Europe. We also believe that there is an important opportunity for collaboration here in New Zealand. The Treasury and Statistics NZ are undertaking work on well-being and the SDGs. Our research team has built considerable understanding of the SDGs in relation to agriculture. This understanding is based on collaboration with a wide range of stakeholders and careful review of the literature on indicators. We hope to contribute our understanding and expertise to the national conversation about measuring progress towards the SDGs.

7. REFERENCES

Andersen, E. (2017). The farming system component of European agricultural landscapes. *European Journal of Agronomy, 82*, 282-291.

Beef and Lamb New Zealand. (2017). *Compendium of New Zealand Farm Facts. 41st Edition. Publication No P17007.* Wellington: Beef + Lamb New Zealand Economic Service.

Beukes, P. C., Gregorini, P., Romera, A. J., Levy, G., & Waghorn, G. C. (2010). Improving production efficiency as a strategy to mitigate greenhouse gas emissions on pastoral dairy farms in New Zealand. *Agriculture, Ecosystems and Environment, 136*, 358-365.

Cichota, R., Snow, V. O., & Vogeler, I. (2013). Modelling nitrogen leaching from overlapping urine patches. *Environmental Modelling & Software, 41*, 15-26.

Coello Coello, C. A., Lamont, G. B., & Van Veldhuizen, D. A. (2007). *Evolutionary Algorithms for SOlving Multi-objective Problems. Second Edition.* Boston: Springer.

Coleman, K., & Jenkinson, D. S. (2014). *RothC – A model for the turnover of carbon in soil. Model description and users guide (updated June 2014).* Harpenden: Rothamsted Research.

Coleman, K., Muhammed, S. E., Milne, A. E., Todman, L. C., Dailey, A. G., Glendining, M. J., & Whitmore, A. P. (2017). The landscape model: A model for exploring trade-offs between agricultural production and the environment. *The Scoence of the total environment, 609*\, 1483-1499.

Craigie, R. A., Brown, H. E., & George, M. (2015). Grain yield of winter feed wheat in response to sowing date and sowing rate. *Agronomy New Zealand, 45*, 1-8.

Department of Conservation. (2014). *Briefing to the Incoming Minister.* Wellington: Department of Conservation.

Dynes, R. A., Burggraaf, V. T., Goultier, C. G., & Dalley, D. E. (2010). Canterbury farming: production, processing and farming systems. *Proceedings of the New Zealand Grassland Association, 72*, 1-8.

Energy Efficiency and Conservation Authority. (2016). *Programme Review Conclusions and Recommendations.* Wellington: EECA. Retrieved from https://www.eeca.govt.nz/resources-and-tools/research-publications-and-resources/corporate-and-strategic-publications/

Energy Efficiency and Conservation Authority. (2017, May 11). *Wood energy*. Retrieved from EECA Business: https://www.eecabusiness.govt.nz/technologies/renewable-energy/wood-energy/

FAO. (2015). *FAO and the 17 Sustainable Development Goals.* Rome: FAO.

Farming First. (2015). *The Story of Agriculture and the Sustainable Development Goals*.

Food and Agriculture Organization of the United Nations. (2014). *Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks.*

Gaucherel, C., & Houet, T. (2009). Preface to the selected papers on spatially explicit landscape modelling: Current practices and challenges. *Ecological Modelling, 220*, 3477-3480.

Gielda-Pinas, K., Ligmann-Zielinska, A., & Zwolinski, Z. (2015). Land use and land cover changes simulated with agent-based modelling for water conservation at catchment scale. *Limnological Review, 15*, 95-105.

Glendining, M. J., Dailey, A. G., Williams, A. G., Evert, F. K., Goulding, K. W., & Whitmore, A. P. (2009). Is it possible to increase the sustainability of arable and ruminant agriculture by reducing inputs? *Agricultural Systems*, 117-125.

Griggs, D., Stafford-Smith, M., Gaffney, O., Rockstrom, J., Ohman, M., Shyamsundar, P., . . . Noble, I. (2013). Policy: Sustainable development goals for people and planet. *Nature, 495*, 305-307.

Harmsworth, G. S. (2016). Indigenous Māori values and perspectives to inform freshwater management. *Ecology and Society*.

Harper, L. A., Sharpe, R. R., Langdale, G. W., & Giddnes, J. E. (1987). Nitrogen cycling in a wheat crop: soil, plant and aerial nitrogen transport. *Agronomy Journal, 79*, 965-973.

Hazeu, G., Elbersen, B., Andersen, E., Baruth, B., van Diepen, K., & Metzger, M. (2010). A biophysical typology in agri-environmental modelling. In F. M. Brouwer, & M. van Ittersum, *Environmental and Agricultural Modelling: Integrated Approaches for Policy Impact Assessment* (pp. 159-187). Wageningen: Springer.

Hume, E., Brown, H., Sinton, S., & Meenken, E. (2015). *Arable and horticultural crop modelling for the Matrix of Good Management - a technical summary. A Plant & Food Research report prepared for: Environment Canterbury.*

International Institute for Environment and Development. (2013). *Agriculture and food systems for a sustainable future: an integrated approach.*

Livestock Improvement Corporation Limited and Dairy NZ Limited. (2017). *New Zealand Dairy Statistics 2017.* Retrieved from www.dairynz.co.nz/dairystatistics

Ministry for the Environment. (2017). *New Zealand's Greenhouse Gas Inventory 1990–2015.* Wellington: Ministry for the Environment. Retrieved from http://www.mfe.govt.nz/node/23304/

Ministry for the Environment and Statistics NZ. (2017). *New Zealand's Environmental Reporting Series: Our fresh water 2017.* Retrieved from www.mfe.govt.nz and www.stats.govt.nz

Muhammed, S. E., Coleman, K., Wu, L., Bell, V. A., Davies, J. A., Quinton, J. N., . . . Whitmore, A. P. (2018). Impact of two centuries of intensive agriculture on soil carbon, nitrogen and phosphorus cycling in the UK. *The Science of the total environment, 634*, 1486-1504.

New Zealand Labour Party & Green Party of Aotearoa New Zealand. (2017, October 24). *Confidence and Supply Agreement for the 52nd Parliament.* Retrieved from New Zealand Green Party: https://www.greens.org.nz/sites/default/files/NZLP%20%26%20GP%20C%26S%20Agreement%20FINAL.PDF

Ng, T. (2017). *Living Standards Framework.* Retrieved from The Treasury: https://treasury.govt.nz/publications/presentation/living-standards-framework

NZFA&T. (2017). *New Zealand Foreign Affairs & Trade - Sustainable Development Goals*. Retrieved from http://www.mfat.govt.nz/en/peace-rights-and-security/work-with-the-un-and-other-partners/new-zealand-and-the-sustainable-development-goals-sdgs/

OECD. (2017). *Gross national income*. Retrieved from OECD Data: https://data.oecd.org/natincome/gross-national-income.htm

OECD. (2017). *OECD Environmental Performance Reviews: New Zealand.* Paris: OECD Publishing.

Palmer, J., Thorburn, P.J., Biggs, J.S., Dominati, E.J., Probert, M.E., Meier, E.A., Huth, N.I., Dodd, M., Snow, V., Larsen, J.R., Parton, W.J., 2017. Nitrogen cycling from increased soil organic carbon contributes both positively and negatively to ecosystem services in wheat agro-ecosystems. Frontiers in Plant Science 8, 1-13.

Parliamentary Commissioner for the Environment. (2015). *Managing water quality: Examining the 2014 National Policy Statement.* Wellington: Parliamentary Commissioner for the Environment.

Parsons, A. J., Thornley, J. H., Newton, P. C., Rasmussen, S., & Rowarth, J. S. (2013). Soil carbon dynamics: The effects of nitrogen input, intake demand and off-take by animals. *The Science of the total environment, 465*, 205-215.

PwC. (2013). *Growing the productive base of Maori Freehold Land.* Wellington: Ministry for Primary Industries.

PwC. (2017). *Signs to look for: Criteria for developing and selecting fit for purpose indicators.*

Robson, M. C., Brown, H. E., Hume, E., Lilburne, L., Pinxterhuis, I. J., Snow, V. O., & Williams, R. H. (2015). *Overview Report – Canterbury Matrix of Good Management Project.* Christchurch: Environment Canterbury.

Schwoob, M.-H. (2016). *Agricultural Transformation Pathways Initiative – 2016 Report, IDDRI & Rothamsted Research.*

Statistics NZ. (2015). *Coastal and estuarine water quality*. Retrieved from New Zealand's Environmental Reporting Series - Environmental Indicators: http://archive.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Marine/coastal-estuarine-water-quality.aspx

Statistics NZ. (2015). *Heavy metal load in sediment*. Retrieved from New Zealand's Environmental Reporting Series - Environmental Indicators: http://archive.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Marine/heavy-metal-load-sediment.aspx

Statistics NZ. (2015). *Land cover*. Retrieved from New Zealand's Environmental Reporting Series - Environmental Indicators: http://archive.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Land/land-cover.aspx

Statistics NZ. (2015). *Soil moisture and drought*. Retrieved from New Zealand's Environmental Reporting Series - Environmental Indicators: http://archive.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Atmosphere-and-climate/soil-moisture-drought.aspx

Statistics NZ. (2018, April 19). *Agricultural and horticultural land use*. Retrieved June 21, 2018, from Environmental Reporting Series - Environmental indicators: http://archive.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Land/land-use.aspx

Statistics NZ. (2018). *Agricultural production statistics: June 2017 (final).* Retrieved from Statistics NZ: https://www.stats.govt.nz/information-releases/agricultural-production-statistics-june-2017-final

Statistics NZ. (2018). *Measuring the gender pay gap*. Retrieved from Statistics NZ: http://archive.stats.govt.nz/browse_for_stats/income-and-work/Income/gender-pay-gap.aspx

Sustainable Development Goals. (2015). Retrieved from United Nations: http://www.un.org/sustainabledevelopment/sustainable-development-goals/

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., . . . Swackhamer, D. (2001). Forecasting Agriculturally Driven Global Environmental Change. *Science, 292*, 281-284.

UN Inter Agency and Expert Group on Sustainable Development Goal Indicators. (2016). *Report of the Inter-Agency and Expert Group on Sustainable Goal Indicators Annex IV: Final list of proposed Sustainable Development Goal Indicators.* New York: United Nations. Retrieved from https://sustainabledevelopment.un.org/content/documents/11803Official-List-of-Proposed-SDG-Indicators.pdf

United Nations, Department of Economics and Social Affairs. (2015). *Millennium Development Goals: 2015 Progress Chart.* New York: United Nations. Retrieved from http://www.un.org/millenniumgoals/2015_MDG_Report/pdf/MDG%202015%20PC%20final.pdf

University of California at Berkeley. (2010). *The Robbins Collection - School of Law*. Retrieved from The Common Law and Civil Law Traditions: https://www.law.berkeley.edu/library/robbins/CommonLawCivilLawTraditions.html

van Ittersum, M. K., Ewert, F., Heckelei, T., Wery, J., Alkan Olsson, J., Andersen, E., . . . Wolf, J. (2008). Integrated assessment of agricultural systems - A component-based framework for the European Union (SEAMLESS). *Agricultural Systems*, 150-165.

Vibart, R., Smith, M. J., Kaye-Blake, W., Brown, M., Stirrat, K. A., & Mackay, A. (2017). *Towards Sustainable and Resilient Agriculture (TSARA): A New Zealand Perspective.* Palmerston North: AgResearch.

Vibart, R., Vogeler, I., Dennis, S., Kaye-Blake, W., Monaghan, R., Burggraaf, V., . . . Mackay, A. (2015). A regional assessment of the cost and effectiveness of mitigation measures for reducing nutrient losses to water and greenhouse gas emissions to air from pastoral farms. *Journal of Environmental Management, 156*, 276-289.

Wolf, J. (2013). *LINTUL-4 generic simulation model for crop growth under potential, water limited and N-limited conditions and under climatic change.* Wageningen University: Plant Production systems group.

World Commission on Environment and Development. (1987). *Our Common Future: Report of the World Commission on Environment and Development.*

8. APPENDIX A – FULL LIST OF WORKSHOP INDICATORS

The table below shows the full list of indicators identified for each Target by stakeholders at the workshop.

Target	Indicators
2.3	• (Increased) target GDP capital stock (Natural, Financial, Social and Human capital) • Increased incomes for affected groups • Number of whānau able to access healthy food sources • Number of outstanding treaty claims • Number of sustainable employers redistributing wealth into communities • Median income of all groupings mentioned • Share of GDP across all groups • Led or maintained social welfare -> research -> hard but important and doable • Gender equality pay measure • Measures of equality • Uptake and awareness of financial services • Income distribution across all groupings • Average income of female owned businesses • Reduced rate of suicide (focus on rural sector) • Measure wellbeing producers of hapū, iwi, whānau (not just income, multiple capitals) • Uptake of accreditation eg, organic other value add • Average income of Māori business owners
6.4 and 6.6	• Timely, accessible, repeatable data on water use and availability • Data to meet all criteria • Stakeholder acceptance of systems of ownership • Transparent system of water allocation and charges accepted by communities • Count or per cent of neutral water users • *E. coli* measured in fresh water • Number of swimmable freshwater bodies (define 'swimmable') • Amount of N, P, sediment in rivers fresh water • Amount of freshwater native species and habitats restored • Groundwater contamination measured • Community perception of water scarcity • Ecosystem health indicators, eg MCI • Number of iwi using rivers as source of food • Social and perception-based measures of water quality
8.4	• Volume to landfill alternatives • GNI not GDP -> link these emissions per unit -> greenhouse gas emissions and sinks and intensity • Environmentally adjusted productivity • Presence and use of national natural capital accounts • Consistent measurement and components – repeatable, robust data • Better data and better data share to effectively model and measure the environmental impacts • Shared investment – contribution efforts • Emissions per $ • Other environmental measures per $ • Funding for system development • Communication of value to stakeholders

	• Extent of environmental taxes • Extent that you don't need environmental taxes • Proportion of land well-matched to its best use, whether it's production or wetland etc best use includes all ecosystems services and national capital etc • Indicators need to be strength based and collective not individual
14.1	• Existing environmental reporting series (MfE and Stats NZ) – coastal and estuarine water quality • Environmental reporting series – heavy metal load in sediment • Landfill volumes • Health of vulnerable marine ecosystems (eg coral reefs) • Nutrients in waterways • Nutrient discharges • (Level) health of fish stocks and associated species • Engagement and shared decision-making across communities and including partners (Māori) • Measure of pressures on marine, eg land use • Transparent measuring • How much waste is collected in coastal clean ups per metre • Number of keystone species • Recycling volumes and alternative uses of waste products • Measuring sediment in waterways • Measuring pathogens in waterways • Value from recycled products • Pollutant discharges • Measuring (less) amount of plastic in our marine environment (trend series)
15.1 and 15.3	• Existing environmental reporting series land cover • Agricultural and horticultural land use • Environmental reporting soil moisture and drought • Indicators to international agreements eg, Paris, CBD, Ramsar • Irrigated land • Number of species on IUCN red list and species • Productivity loss from floods/drought • Quality of freshwater • Indicators should align to those internationally for the same agreement • Waterways cleaned up (from below bottom line) • Holistic measure of water quality (ie where it is good and bad – not just bad) • Contaminated land cleaned up • Indicators of freshwater ecosystem health are improving eg, MCI • Count or per cent of 'neutral water users' • Biodiversity is no longer declining at national/ecosystem level • Biodiversity indices • Percentage change in land that is suitable for crop production • Land use intensity • Proportion of land at risk of desertification