Exploring a strategy for managing on-farm surplus nutrients: Aiming for mutual benefits to dairy farmers and the environment.

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Declaration

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Louise V. Deane 23 November 2022

Supervisor's Certification

I certify that this Master of Applied Innovation thesis is the result of practice based research carried out by the learner under my academic facilitation and supported by the supervision of Dr Celine Kerney.

The work complies with the expected length (typically around 25k – 35k words of core content) given the numerous necessary pivots resulting from the Covid pandemic and the nature of Pragmatic Action Research.

Jan Hendrik Roodt (PhD EngSci) 28 November 2022

Abstract

In this thesis, the problem of surplus nutrients from dairy farming and food waste was investigated and the potential of an enterprise based around using black soldier fly larvae (BSFL) to process dairy manure and food waste was considered as a means of mitigating part of this problem whilst promoting additional environmental improvements and benefiting other stakeholders, particularly dairy farmers. A transdisciplinary approach with a pragmatic action research methodology was employed due to the wicked nature of this problem. This approach provided the flexibility to follow up insights and explore the problem and potential innovation in depth and width.

Throughout the research, the reasons why current processes for reducing nutrient loss from dairy farms are not working as intended were discovered, and an insight was confirmed that dairy farmers do not appreciate being told what to do by people who do not understand their context. Additionally, it was found that although farming BSFL has great environmental and economic potential, the technology for this is not yet consistent in a temperate climate. It is concluded that BSFL-based waste treatment on dairy farms has the potential to reduce nutrient loss and provide income. However, there is work to be done to overcome the barriers to farming BSFL in New Zealand, and including dairy farmers in the design of the technology and the enterprise will help to gain buy-in for the idea.

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I wish to acknowledge the participants who had conversations, filled out surveys and allowed me to interview them; without their honesty there would be no insights to guide the next steps.

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Acronyms

801: The paper I wrote about transdisciplinarity

804: The research paper I completed for the Postgraduate Certificate of Innovation

AAFCO: The Association of American Feed Control Officials

BMC: Business Model Canvas

BSF: Black soldier flies

BSFL: Black soldier fly larvae

CH_4: Methane

DAF: Waste milk residue from cleaning the pipes in dairy factories

DM: Dairy manure

EPA: Environmental Protection Agency

GHG: Greenhouse gas

GMO: Genetically modified organism

IPCC: International Panel on Climate Change

IPIFF: International Platform of Insects for Food and Feed

MFE: Ministry for the Environment

MPI: Ministry for Primary Industry

Mt CO_2-e: Megatonnes of carbon dioxide equivalent greenhouse gasses

N: Nitrogen

NH_4: Ammonia

NO_2: Nitrous oxide, a greenhouse gas.

NO_x: NO_2 or NO_3 Nitrous oxide, a greenhouse gas.

NZ: New Zealand

SCR: Soy curd residue

T^3: Transition Towns Thames

TDR: Transdisciplinary research

TFWRG: Thames food waste resource group

UN-GA: United Nations General Assembly

UNC: University of North Carolina

UNSDG : United Nations Sustainable Development Goal

VPC: Value Proposition Canvas

WRC: Waikato Regional Council

Glossary

Architype: A typical example of something.

Axiom: A formal statement or principle in mathematics, science, etc., from which other statements can be obtained.

Biowaste: Biological waste

Circular economy: A model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products for as long as possible.

Discursive: Digressing from subject to subject.

Epistemology: The part of philosophy that is about the study of how we know things.

Exogenous: Found or coming from outside something.

Externalities: Damage caused by a company's activities for which it does not pay, or something positive created by it for which it does not receive payment.

Instar: An instar is a developmental stage of arthropods, such as insects, between each moult (ecdysis), until sexual maturity is reached.

Integral analysis: Tools to help us be conscious of our own and others' perspectives and how they have come about, with the aim of combining and synthesising the various viewpoints.

Isomorphs: Points that are the same or similar in structure or shape.

Iterative: Doing something again and again, usually to improve it.

Modus operandi: Way of working.

Ontology: The part of philosophy that studies what it means to exist.

Paradigm: A model of something, or a very clear and typical example of something.

Pelagic: Relating to or living in areas of the sea away from the land.

Pragmatism: The quality of dealing with a problem in a sensible way that suits the conditions that really exist, rather than following fixed theories, ideas, or rules.

Qualitative research: A type of research that aims to find out people's opinions and feelings rather than information that can easily be shown in numbers.

Quantitative: Relating to numbers or amounts.

Recursive: Involving doing or saying the same thing several times in order to produce a particular result or effect.
Reflexivity: questioning one's own taken for granted assumptions.
Regenerative agriculture: A conservation and rehabilitation approach to food and farming systems.
Silvopasture: The practice of integrating trees, forage, and the grazing of domesticated animals in a mutually beneficial way.
Synthesis: The combination of components or elements to form a connected whole.
Transdisciplinarity: The inclusion of non-academic stakeholders in the process of knowledge production.
Wicked problem: Problem with many interdependent factors making it seem impossible to solve.

Chapter 1 Introduction

This thesis is the final paper of three completed for the Post Graduate Certificate of Innovation and the Master of Applied Innovation through the Design Factory at Wintec. In the first paper, 801, I investigated transdisciplinary research, relating it to my own life experience and considering how it might be used to research the issues below. In 804 I started the investigation of my chosen idea, how it could be turned into an enterprise that would contribute towards solving the issues, and the methodology and methods that might be suitable to get primary data. Full copies of my 801 and 804 papers are available in my portfolio on Mahara. In this master's thesis, the literature review examines specific secondary data directly related to this research, and I use multiple and mixed methods to collect and analyse the data that feeds into my proposed resolution scenarios and recommendations. These papers support an action-based project that will continue after this thesis is completed.

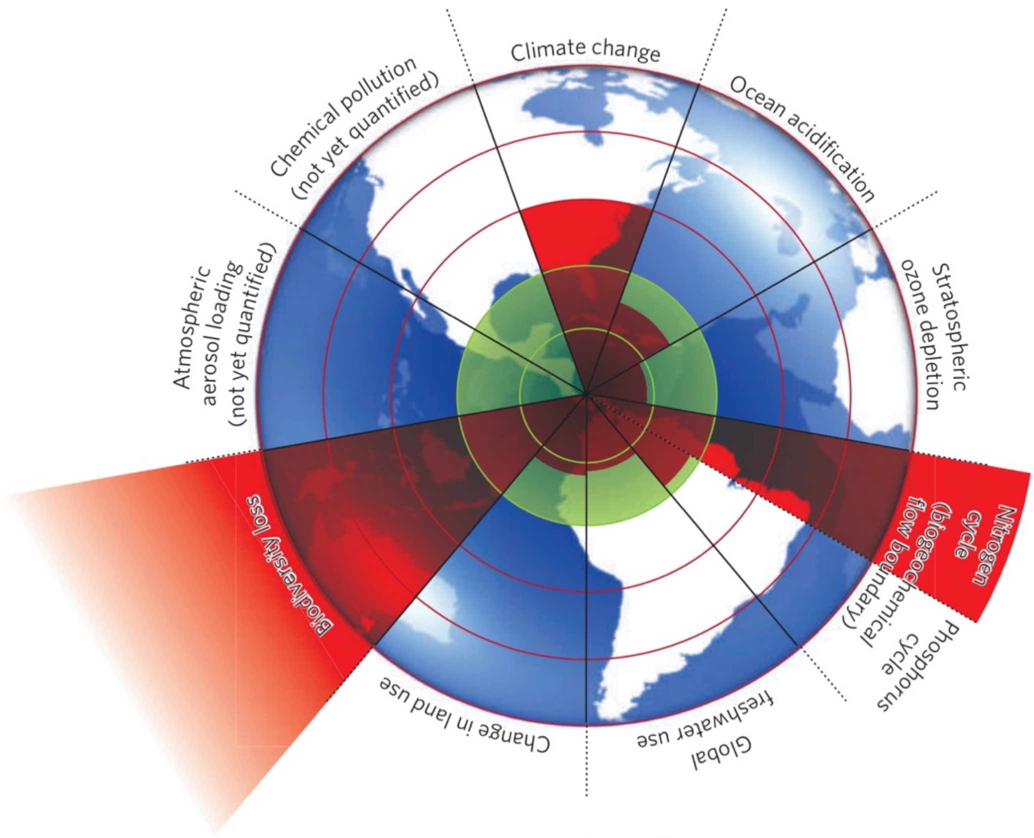
In this chapter I introduce the issue of surplus nutrients in the New Zealand and global context and state my position as researcher. I outline the research journey leading to the research question and idea and introduce the stakeholders who have contributed. I finish with the limitations encountered.

1.1 The context of this study

Globally, economic demands have been used to justify overriding the needs of the environment in which that economy operates, a modus operandi that has led to severe degradation of ecosystems. Rockström (2009) illustrates how planetary boundaries are being stretched and overstepped due to human action.

Figure 1

Nine planetary systems are in relation to a safe operating space for humanity.



Note. From "Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded". From A safe operating space for humanity by Rockström, J., 2009, *Nature, 461*(7263), 472-475. https://doi.org/10.1038/461472a Copyright © 2009, Springer Nature. Reprinted with permission.

We can see from Figure 1 that natural nutrient cycles have been severely impacted by human actions. Nutrients, while essential for all living things to live and grow, become environmental pollutants if in the wrong form and/or place.

The main issue this research aims to address, is that of surplus nutrients from dairy farms including those from dairy cow manure (DM) and chemical fertilisers. In situations where the dairy farm lacks the capacity or capability to absorb the nutrients back into the farm or adequately dispose of them in other ways, these nutrients can cause serious environmental problems. Problems include: terrestrial, freshwater and marine eutrophication (Chobtang et al., 2016) and overgrowth of pathogens such as the bacteria *E.*

coli, Campylobacter and *Salmonella* spp., the protozoans *Cryptosporidium parvum* and *Giardia lambia,* and rotaviruses that are harmful to humans and other life (Gerba & Smith Jr, 2005, p. 1). In New Zealand, these issues have been highly publicised, gaining substantial public interest. A December 2018 poll conducted for Fish and Game by Colmar Brunton recorded that 82% of participants said they were extremely or very concerned about pollution of rivers and lakes (Cosgrove, 2019). Decaying DM also releases a range of greenhouse gasses (Chobtang et al., 2016).

This thesis details the process followed to see if an enterprise could be created to address the issue of surplus nutrients in the environment along with other significant environmental problems such as: greenhouse gas emissions; food waste going into landfill; the need for alternatives to unsustainable high protein animal feeds especially for fish in aquaculture and the need for natural fertilisers to replace chemical fertilisers.

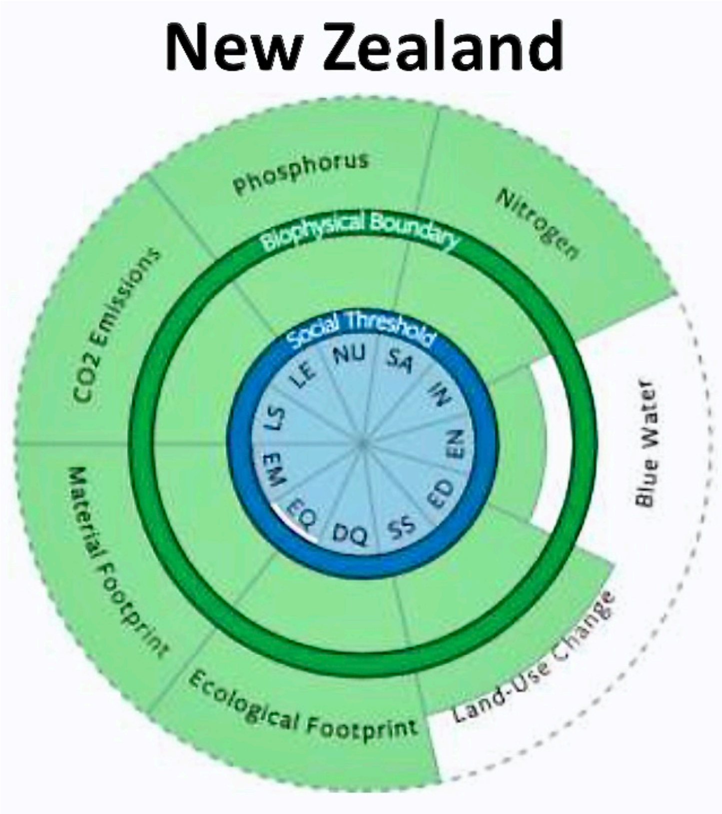
Whilst working on these environmental issues, the impact on human stakeholders will need to be considered. Change can be challenging for people and if mismanaged can lead to considerable harm. Throughout this research process I have kept in mind how to bring about a just, informed and empowered transition to new farming practices.

1.1.1 New Zealand's place in the picture of global dairy farming: benefits and issues

Dairy farming is a significant industry in New Zealand. In 2017-18 it accounted for 28% of the total value earned from merchandise exports in New Zealand and employed 46,000 people (LIC and DairyNZ, 2018). The carbon emissions, or equivalent greenhouse gases per kilogram of fat and protein corrected milk from New Zealand pasture-based farming systems are less by up to a factor of two than those in many other countries (Chobtang et al., 2016) so on a global level it makes sense to continue to produce milk in New Zealand rather than in other countries where milk production has greater climate change effects. This, unfortunately, does not offset the serious local environmental impacts of dairy farming or consider whether an overall drop in global dairying might be necessary. The complex nature of this issue means that it may not be sufficient to rely on one or two statistics to measure the success of current or potential future waste systems, rather there is a need for a transdisciplinary enquiry, with a wide focus to attempt to address the ongoing issues of nutrient pollution of New Zealand waterways. Figure 2 illustrates that nutrient overshoot is a serious issue in New Zealand that needs to be addressed.

Figure 2

New Zealand's position with regard to planetary boundaries



Note. The above diagram shows both nitrogen and phosphorus to be well beyond the biophysical boundary for New Zealand. From "Doughnut economics: Seven ways to think like a 21st centuary economist," K. Raworth, n.d. https://www.mbie.govt.nz/dmsdocument/5722-doughnut-economics-kate-raworth. Diagram originally from "A good life for all within planetary boundaries," by D. O'Neill, A. Fanning, W. Lamb and J. Steinberger, 2018, *Nature Sustainability* 1, no. 2: 88-95. https://www.nature.com/articles/s41893-018-0021-4.

In their economic evaluation of the costs of mitigating or remedying the environmental impacts from dairy farming, Foote et al. (2015) concluded, "it is likely that the environmental externalities from dairy farming may exceed the value of dairy's export revenue and the contribution to GDP (total of NZ$16.6 billion)"(p. 1). Senge (1990) offers this insight into the reasons for our not taking externalities into account. "We learn best from experience, but we never directly experience the consequences of many of our most important decisions" (p. 21).

The literature review contains a more detailed exploration of the context of the environmental problems of dairy farming, with specific details of the issues of dairy manure (DM) and effluent and those of fertiliser use (See Ch. 2.2.2). I also look at what farmers are already doing to mitigate these issues.

1.1.2 Impacts on dairy farmers

Taking care of DM involves substantial costs for dairy farmers in time, labour and money. The National Policy Statement for Freshwater Management (Ministry for the Environment, 2017) requires all regional councils to set quality limits for all ground and surface water bodies in their region, in consultation with the community, including tangata whenua by 31 December 2025. This includes considering "the connections between freshwater bodies and coastal water" (p. 12). Many dairy farmers are operating with high levels of debt so the additional costs of upgrading effluent treatment and storage infrastructure, that will be needed to meet the new regulations, is a source of pain for them.

1.1.3 Why the issue of surplus nutrients is a 'wicked problem'

Kolko (2012) defines a wicked problem as…

> a social or cultural problem that is difficult or impossible to solve for as many as four reasons: incomplete or contradictory knowledge; the number of people and opinions involved; the large economic burden; and the interconnected nature of these problems with other problems (p. 10).

The problems associated with surplus nutrients from dairy farming are wicked because there are different points of view about the causes and effects of the pollution and about how much the environment should be considered when looking at economic activity. The economic burden of this issue was investigated by Foote et al. (2015), who estimate that the cost of dealing with these issues might be greater than the economic benefits of dairy farming.

Further complexity comes from the number of interrelationships, such as those between soil types, microbes within the soil, plant variety, rainfall, and temperature, that affect the capacity of the farm to use nutrients. As a result, each farm must be considered within its own context. There are a number and variety of stakeholders affected by the pollution and the problems of dealing with it, including non-human life such as fish. This complexity leads to challenges regarding where best to intervene to have the desired impact. The media has added to the challenge of tackling this issue. Since the start of this research, I have heard many commentators reporting in a divisive way that encourages different groups of people to blame each other rather than work together to improve the situation; consequently, the topic of water pollution has become a very sensitive issue for dairy farmers, making it a difficult subject to approach. This was illustrated at my first public meeting which approached the idea of fish farming as a complementary alternative to dairy farming in flood prone areas of the Hauraki plains. This idea used the surplus nutrients in the rivers to grow algae as the base of the food chain to feed the fish. My presentation mentioned the problem of surplus nutrients from dairy farming and this statement caused a protest from a couple of the participants that almost derailed the meeting. All the dairy farmers I have interviewed have expressed suspicion of the motivations of anyone coming to ask them questions.

1.2 A transdisciplinary approach for a wicked problem

> Transdisciplinarity is a social justice-oriented approach to research in which the resources and expertise from multiple disciplines are integrated in order to holistically address a real-world issue or problem…. Transdisciplinarity views knowledge-building and dissemination as a holistic process and requires innovation and flexibility (Leavy, 2016, p. 35).

I have chosen to use transdisciplinary research (TDR) methods in investigating this issue because of its 'wicked' nature. In my 801 document I investigated the history and principles of TDR and whether it was compatible with my own life experiences. From this investigation I came to believe that the big picture, holistic approach that TDR offers would be far more likely to get to the root of the problem than a siloed, disciplinary approach.

Transdisciplinarity is a methodology that allows for multiple perspectives, at different levels, to be considered, on both the problem and potential solutions (Nicolescu, 2010). In this thesis, knowledge has been sought from a wide range of stakeholders and experts including dairy farmers; the Thames Food Waste Resource group; AgResearch; black soldier fly larvae farmers; scientists; worm farmers and experts in systems dynamics and modelling (See Ch. 3.3). Rieple and Snijders (2018) suggests that using an approach that respects the different realities of stakeholders will be necessary to get buy in. My experience of interviewing stakeholders for this thesis reinforces this and as the development of the solution progresses, I think it will become even more essential. An integral value that arises from the use of a transdisciplinary approach is that of developing solutions that are for the common good (Nicolescu, 2010) therefore, this will be a key gauge to check along the way.

1.3 My background and personal motivation

Transdisciplinary methods acknowledge that the interpretation of knowledge renders it subjective, or more explicitly, subject to the bias of the interpreter (Brown, 2010; Popa et al., 2015). With this in mind, it is essential to be aware of my biases. Therefore, I will introduce myself, my context, and the background to this research project.

I am a white, middle-aged woman, dyslexic and originally from the United Kingdom. Since childhood I have become increasingly interested in the natural environment and after completing a degree in Outdoor and Science Education have taught Science at high school and Ecology to primary school pupils. I live on, and with the help of my husband and many Willing Workers on Organic Farms, have developed from scratch a small permaculture farm, and designed and built our straw bale home, a passive solar straw bale farm shed/studio. I have also have designed, and assisted with building, a passive solar eco home as a rental property.

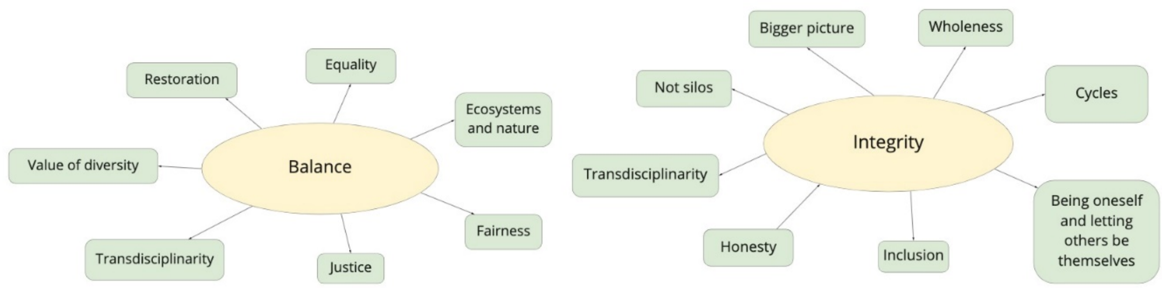
Throughout my adult life I have been a community and environmental volunteer and occasional activist. In these experiences, I have observed a barrier between the environmental movement and industries such as farming, which seems to come from an inability to understand and accept each other's context and point of view. I strongly believe we need all forms, sources, and perspectives of knowledge to solve the complex problems of our era. This issue of nutrient pollution, and avoiding nutrient loss, is important to me because I believe in our connection to the natural world. This connection is both spiritual and literal. As an 'Earth Education' instructor to primary school children we taught how the materials of earth are continually reused so that we contain the matter (molecules) that may have been part of a rock or a dinosaur and how these materials, once polluted can go on to poison other living things (Van Matre & Farber, 2005).

1.3.1 My values:

I aim to integrate my values into this study and have thus sought to define them. I first worked out my personal values whilst looking at organisational values for the Seagull Centre Trust in 2015. Brown (2018) recommends working out one's values because it is hard to live up to them if you cannot name them. She also suggests that it is useful to know our own and other's values for the insights it gives into behaviour. She advises narrowing the list down to two that incorporate the others.

Figure 3

My values and what they represent to me.



As a dyslexic person I am a big picture thinker and tend to see systems rather than isolated details and I am consequently drawn to the transdisciplinary approach. This big picture view means that I'm open to my BSFL enterprise innovation varying from my initial detailed aims of working with dairy farmers on processing DM, to considering using BSFL for processing other bio-waste streams in different contexts, and alternative uses for the products in addition to animal feed.

My experiences of learning differently to most people have led me to aim for an accessible writing style for my own understanding and so that the findings can be shared with those who have participated. McNiff and Whitehead (2006) suggest that excessive use of disciplinary jargon creates professional elitism which limits the relevance of the research to people's real lives.

Dyslexic people often gain knowledge through intuition which leads to insights (Davis, 1994), where the source of the knowledge is not always overt. The processing of multiple different sources and forms of knowledge often takes place subconsciously, making it difficult to pinpoint the origin, and therefore to validate it (personal experience). In the interest of academic rigour, I use various ways to corroborate insights including: diagramming; talking ideas through with other people; reflective writing as proposed by Richardson (2000) where she suggests using “the writing process as a method of enquiry - a method of discovery and analysis” (p. 923); using multiple methods to triangulate results (Leavy, 2016) and iteratively rechecking to ensure conclusions are sound in light of new data.

1.4 The journey to the start of the master’s thesis

This investigation came about because of a gradual dawning of awareness about some problems in the farms on the Hauraki Plains, the majority of which are dairy farms (Positively Promoting the Plains, 2017). Some of the farms are frequently flooded and water quality in rivers and the Firth of Thames has been declining with high nutrient and pathogen levels. I had an aha! moment when I saw a TED talk by Barber (2010) called “How I fell in love with a fish” which presented an ecosystem based fish farm that used the nutrients in the Guadilquivir river in Spain to grow algae as the trophic base of a food web that feeds the fish. By using surplus nutrients, the farm effectively cleaned the river water. This led to many conversations, a public meeting in Thames and further meetings at the Hauraki District Council to introduce and gauge interest in the idea, starting a Postgraduate Certificate of Innovation at Wintec, presentations to Hauraki District Council and T3 and a trip to Spain to visit this inspiring fish farm. There has been interest in this idea, with one company currently looking into taking it further. However, the risks of a project that needs a minimum of 200 hectares have meant that it did not take place at the time.

In order to progress to the Master of Applied Innovation I needed to rethink ways to tackle these issues whilst testing some of the ideas that might provide evidence to support ecosystem-based fish farming in the future. Any initial solutions needed to be on a small enough scale to reduce start-up costs thereby reducing risk. I looked at other ways of using surplus nutrients and decided to focus on a source of much of the surplus nutrients in the Hauraki district; dairy farms (Green & Zeldis, 2015). The most practical point to intercept nutrients is the milking sheds and hard stands where the manure is already being collected. Direct collection of manure from pastures is not feasible for this enterprise.

The percentage of DM that is collected from milking sheds and hard stands is not high in relation to the DM excreted onto pasture; it was around 5% in 2016. However, I suspect that proportion is increasing as farmers are being encouraged to use hard stands, in times of wetter or cooler weather, in order to not overload the farm's capacity to absorb the nutrients. The collected proportion may seem small however, it can be significant in balancing the nutrient inputs and outputs on the farm.

As part of the process of preparing for 804, I researched a variety of ways to use the surplus nutrients from DM and dairy effluent, i.e., the DM and urine in water collected when milking sheds and hard stand areas are washed down; see Table 1.

Table 1

Other ideas for using surplus nutrients from dairy farming.

Idea	Positives	Negatives
Ecosystem based fish farming using nutrients in the river water to grow algae to feed fish	• A good use for land at increased risk of flooding from sea level rise. • A regenerative way to farm fish. • Benefits for bird populations. • Cleans the water.	• Requires a big area of land. • Land is currently expensive. • Initial set up costs high.
Using the effluent to grow algae in a contained environment rather than an ecosystem environment.	• Similar to my original idea. • Reduces the pathogen levels in the effluent. • Reduces the nutrient levels.	• Already being done. • Expensive infrastructure. • More suitable for farms where all the effluent is collected.
Using the effluent as a nutrient source for vertical vegetable farming	• There are successful trials showing it works. • Reduces nutrient levels. • Reduces pathogen levels.	• Legal questions around food health and safety as food for humans. • Public perception.
Using the DM to grow other insects	• The insects can be used to feed fish and other animals. • Insects have efficient food to protein ratio conversion rations.	• Many insect species can cause problems if they escape such as: carrying disease; pestering people or livestock; harming natural ecosystems that have not co-evolved with them.

Using the DM to grow black soldier fly	• As above, plus • BSF do not pester. • BSF are already naturalized in NZ. • BSFL process waste very quickly	• Need heat to grow in winter in NZ. • DM is not a complete food for BSFL.

During the certificate stage (804) of this study, I investigated different tools for establishing a business such as creating business models including the UN Sustainable Development Goals; researched the literature around farming BSFL, and considered the infrastructure that might be needed to make it work in New Zealand's climate. I also studied the methods that I could use to make this an academically rigorous transdisciplinary study.

1.5 Research question

> How might we work with dairy farmers to manage the impacts of surplus nutrients on the environment in such a way as to benefit the dairy farmers and the environment?

Note. "We" refers to all those of us who contribute their input and knowledge to the innovation.

This question could be answered in many possible ways. To narrow the range of possibilities, I've include the following goals:

1. To answer the question in such a way as to convert biological waste products into resources that can be used to feed animals and/or plants, i.e., to create a circular economy[1].
2. To maximise the environmental benefits from the solution.
3. To build a viable enterprise around the research question.

[1] "Circular economy: an alternative to a traditional linear economy (make, use, dispose) in which we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life" European Parliament. (2018). *Circular economy: definition, importance and benefits*. https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits.

1.5.1 The value in answering this question

If this research question is answered, and the results acted upon, it could offer dairy farmers a way to limit the amount, and consequently the above-mentioned impacts of surplus nutrients by providing a means of using these nutrients in a way that grows products that can be sold to provide income. There would be the additional benefit of putting an exemplar of wider circular economy into a significant New Zealand farming sector.

1.6 The idea for this enterprise

The longer-term idea for this enterprise was proposed in my 804 paper. It was based on the literature researched at that time and adapted for this paper (908). The purpose of 908 is to take the theoretical idea and methods from 804 and implement them in the real world. Experience gained through the research for 908 has clarified that the duration of the master's is insufficient to establish the enterprise as there is more research and work needed before an enterprise would be viable. Some of this extra work has been done during this thesis and in the conclusion, I suggest the next steps needed to overcome the barriers to implementing this idea.

The idea is to design, or put together from existing equipment, a suite of technology for growing black soldier fly larvae (BSFL) in a temperate climate such as New Zealand. It could be incorporated into an existing dairy farm waste system or replace part of it. This could be sold or leased to dairy farmers so they can use surplus DM collected from milking sheds or other hard stands and mix it with food waste, as a substrate to grow BSFL. The enterprise would then partner with the farmers to sell the BSFL to companies that need high protein animal feed. The frass, which is a combination of the insect's manure and cast-off exoskeletons, would then be sold to fertilizer companies and/or returned to the farm to fertilize paddocks or crops. The aim being for the farmer to be able to generate sufficient income, at a minimum, to offset the costs of waste treatment and the labour needed to grow the BSFL. Additionally, for the enterprise to be able to pay a living wage to those who work for it and ideally generate surplus income to be used to investigate other regenerative farming business ideas.

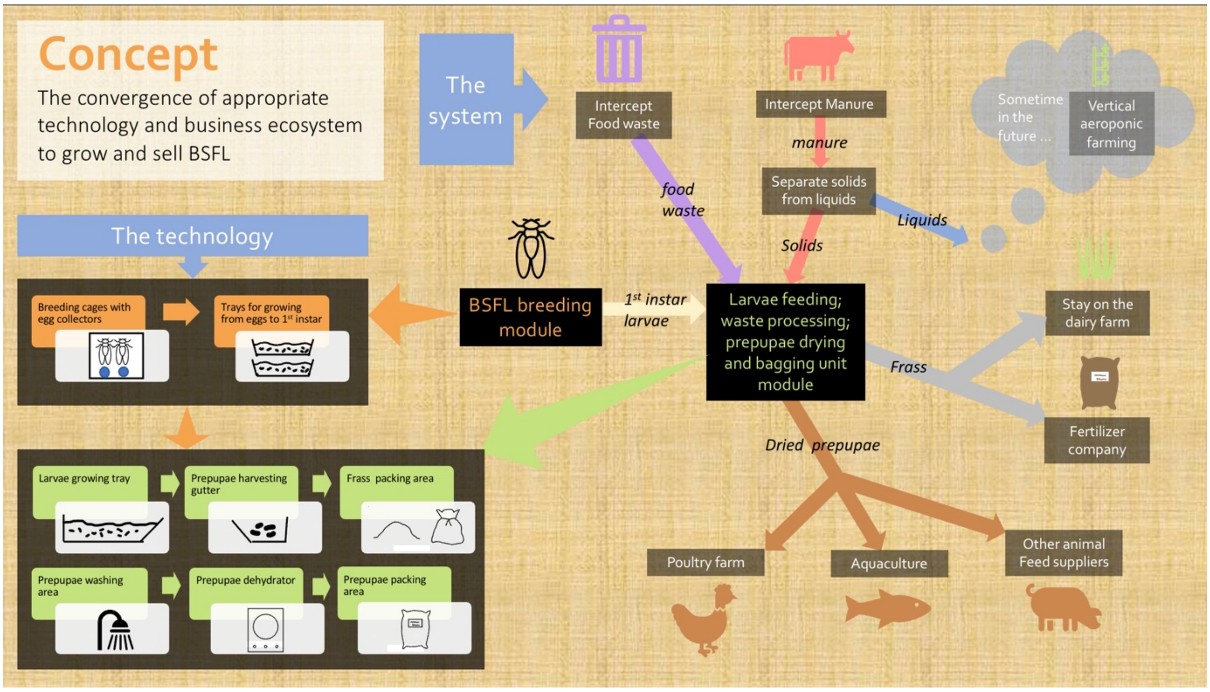
The specific structure of the business will be worked out in partnership with the stakeholders after this thesis is completed. The business will need to develop the technology at an appropriate level and scale to work with the ways New Zealand dairy farms operate.

The shorter-term goals would be to:

- create a home scale BSFL tub which would be both a minimum viable product for the enterprise, and a means to demonstrate at a small scale, the idea of using BSFL to process biological waste.
- collaborate with the few New Zealand based insect farming businesses and other interested parties to work on eliminating or minimizing the barriers that are currently inhibiting the growth of these businesses.

Figure 4

Technology that will be needed in the business and how it might fit into the business ecosystem



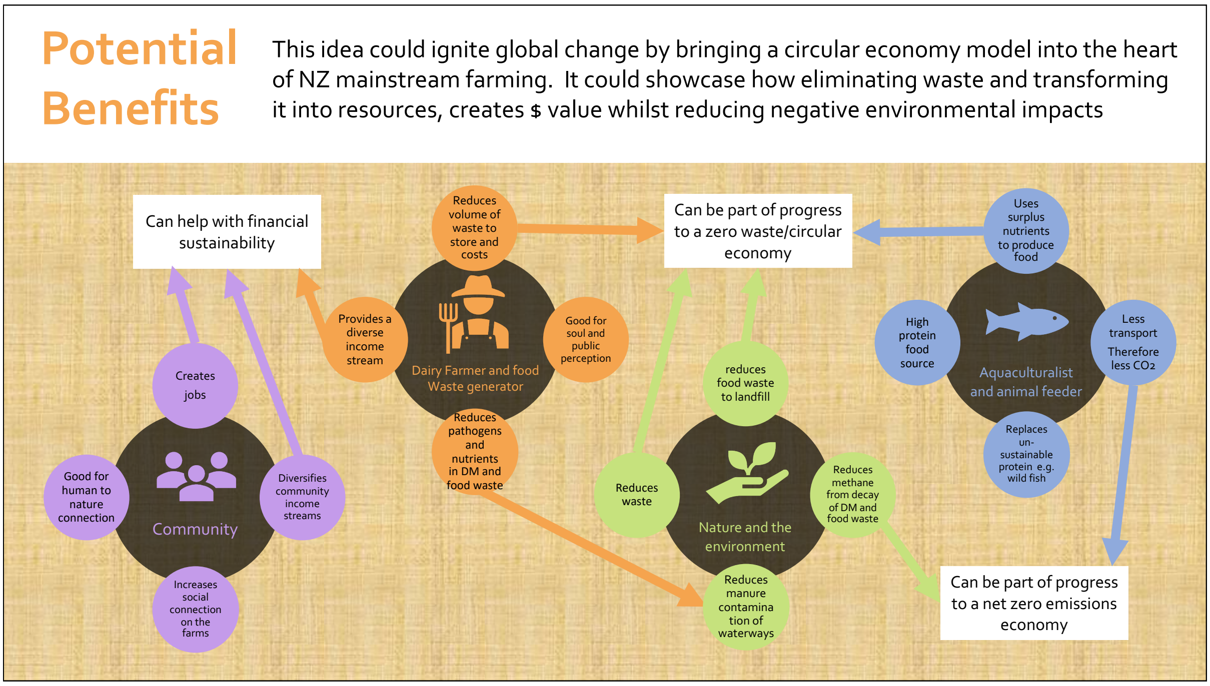
Note. I created this as part of the entry presentation for Callaghan Innovation's C-Prize which I entered in 2021 as a way of seeking feedback to validate the idea.

1.6.1 Potential benefits of this specific idea for answering the research question

I have chosen to investigate using BSFL to process the waste nutrients because of the potential additional benefits this option has over the others that I looked at. In addition to the benefits mentioned above, this idea would reduce food waste to landfill; provide a sustainable, high protein food source for aquaculture or poultry farms; and create a bioactive fertilizer/soil improver, that could be used to reduce chemical fertiliser inputs both on and off the farm. This fertilizer, made up of the frass and chitin from the larvae, is significantly drier and therefore lighter than the initial DM and food waste substrate, making it easier to transport. I go into greater detail about these benefits in the literature review.

Figure 5

Summary of potential benefits of this research for different stakeholders.



Note. Created for the C-Prize entry presentation (2021) by the author.

1.6.2 Value of the additional benefits of this idea beyond the research question

The proposed solution aims to create a circular economy in which so called 'waste' outputs are converted into useful resources that become inputs for other industries. In this idea the food waste and dairy manure become inputs to feed BSFL in the grower module and the outputs are black soldier fly prepupae and frass. Because the issues of food waste and fish food are significant, and the solution I am investigating could have an impact on these issues, I have chosen to go into detail about them in the literature review (Chapter 2), even though they are not central to the research question. This will also provide background information needed to inform the business opportunity.

1.6.3 How will this solution be innovative?

BSFL are now being grown in many countries using many biological waste streams and the idea is not, of itself, innovative although the development and take off is relatively new. The innovation will be in creating a circular economy business ecosystem in New Zealand around this idea. Therefore, it is the system that is innovative and there will be some innovation around creating the modules or selecting the most suitable available products at a scale and level of technology to be suitable for the predominantly pasture based dairy farming system in NZ. Also, to be able to grow BSF and BSFL all year round in the NZ climate range. There may also be innovation needed in the legislation to allow this to happen in New Zealand.

1.7 Community, industry, and scientific networks, that feed into this study

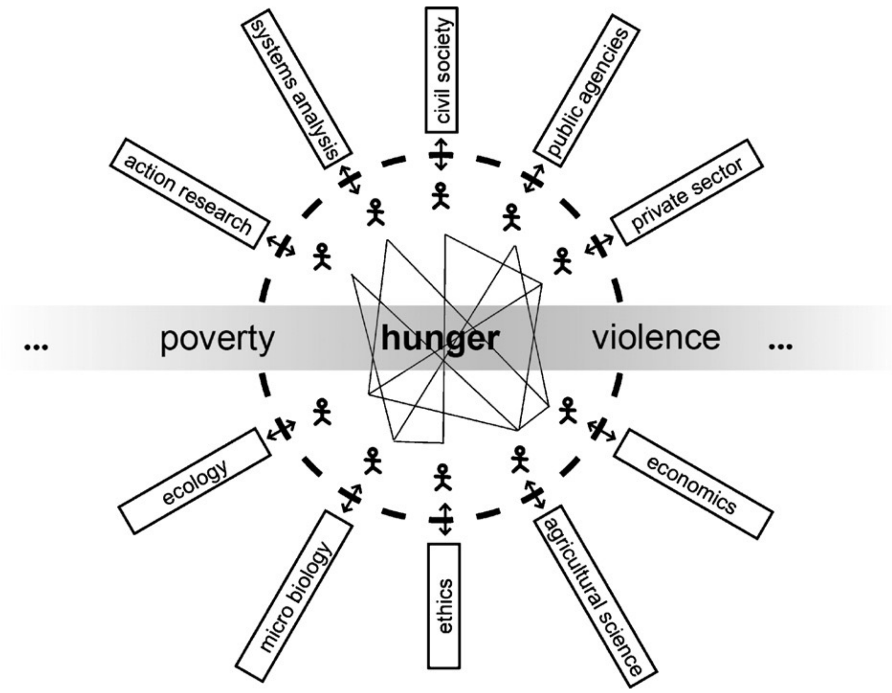
> ''Shared knowledge should lead to a shared understanding based on an absolute respect for the collective and individual Otherness united by our common life on one and the same Earth" (Nicolescu, 2002, p. 151).

This study would not meet TDR criteria without the input of a diverse range of people and groups sharing their experiences and knowledge; some as direct stakeholders in the proposed circular economy, and others as interested observers of the bigger picture. Three of my goals are around influencing change at a higher level by promoting the adoption of BSFL farming and circular economy in New Zealand (see Ch. 1.3.2). Accordingly, I'll work towards making this a multidirectional network where knowledge is shared all ways, within the ethical constraint of not sharing knowledge without permission and respecting participants' intellectual property.

Each of the actors below has ways of working and gaining knowledge. They also have values that come from the, often multiple, groups they are part of. Fleck (as cited in Pohl, 2011) proposed a theory that knowledge is developed and maintained by groups of people rather than individuals; he called these groups 'thought collectives' (p. 624). He posited that these groups have 'thought-styles' (p. 621), that determine their ways of looking at the world, perspectives, knowledge, and methods of working. Within groups' 'thought-styles' they have ontologies, i.e., how they perceive their reality, and epistemologies, i.e., their ways of gaining knowledge. Without being part of the group, it can be difficult or impossible to see the world as they see it. I have needed to keep in mind that each of these actors have their own goals that fit with their thought styles, and that these may contradict mine. This has required patience to carefully listen to what people are saying and resist the urge to put my point of view.

Figure 6

Thought styles contributing to knowledge, in transdisciplinary research



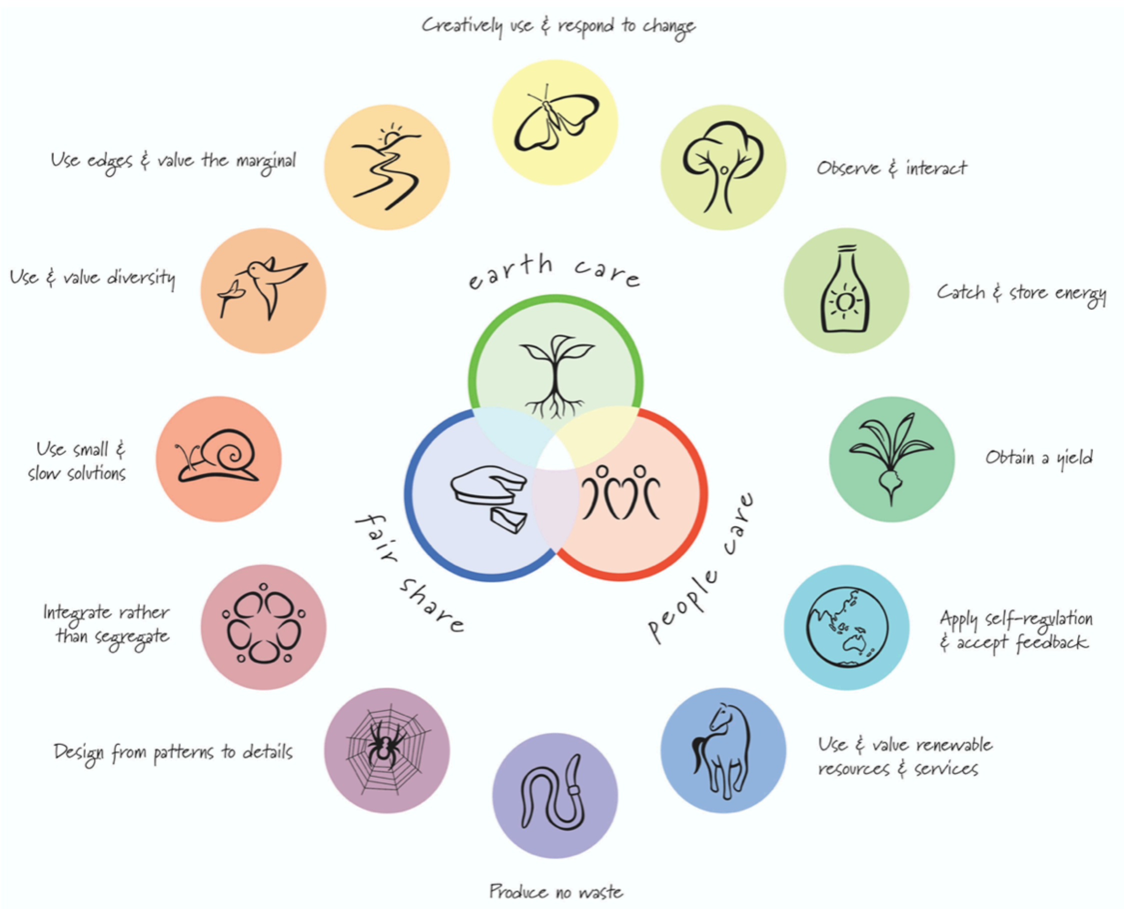
Note. In transdisciplinary research disciplinary thought-styles (represented by individual researchers) and thought-styles of further sectors of society (represented by individual actors) become interrelated and transformed through co-producing knowledge on a socially relevant issue. A transdisciplinary research project is the system of relations (black lines) built by the collaborative research process. From "What is progress in transdisciplinary research?" by C. Pohl, 2011, *Futures 43 (2011)* p. 622. Copyright 2011 by Christian Pohl. Reprinted with permission.

The following groups have all contributed to the knowledge collated in this research through sharing their various experiences and epistemologies. Background information that inspired this research came from Transition Towns Thames (T3) a group that works towards community resilience in the face of peak oil and climate change. The group has been involved in awareness raising and many projects around food security, waste reduction, healthy homes, and positive solutions.

The idea of looking at BSFL as a way of processing manure and food waste while getting a high protein animal feed came about five years ago from a friend with interest in permaculture, as a low-cost way to provide food for our chickens. Other friends have also grown BSFL as chicken feed or had the BSFL colonise compost toilets, where they reduce the volume of humanure rapidly. Permaculture is a term coined by Mollison (1979) from the words, permanent agriculture. Permaculture integrates ideas from a variety of sources, with many coming from indigenous ways of living, if they meet certain principles (See Figure 7). I have applied many of these principles to the solution scenarios.

Figure 7

Principles of permaculture



Note. From "Permaculture ethics and design principle image" by permacultureprinciples.com (n.d.) *https://permacultureprinciples.com/resources/free-downloads/#principles-poster*. C C license CC BY-NC-ND 2.5 AU.

Paul Kersens of Impact Hub Waikato, a global organisation with a goal of developing entrepreneurs with a social or environmental focus, conducted a workshop on the use of the Business Model Canvas combined with United Nations Sustainability goals as a way of planning for a business to work toward the common good. He was a business mentor for me while I investigated business models for the 804 paper. He suggested the use of a minimum viable product to gauge the desirability of a business idea and to keep initial goals manageable.

Dr Gina Lucci, a soil scientist at AgResearch, kindly agreed to be my industry mentor for this study after we met online at a regenerative farming Hui hosted by Impact Hub, Waikato. She spoke about an AgResearch project looking into the possibilities for Circular Economy in the farming sector. As creating a circular economy seemed to be a fundamental aspect of my research I asked if she would be an industry mentor for me because I had no connection with an existing industry, having come from the community. As a stakeholder, Gina has the scientific perspective, rooted in classical science, and experience of working in a government organisation. She also has the experiences and insights that come from placing these perspectives inside a circular economy view, which needs openness to collaboration and a big picture perspective.

I've been conducting informal interviews with people who grow BSFL. Neil Burrell is a scientist studying for a PhD at Auckland university. He has set up a business, Hexacycle, which has three BSFL farming sites in India. Bruce Miller from Grub's Up has a small part time family business growing BSFL. Until recently they were operating at a very small scale. They have had Waste Minimisation Fund money and are conducting research into how to grow and breed BSFL in the NZ climate, also what specialised products they can get from the larvae. Unfortunately, they have since ceased to trade which I think indicates that the technology for farming BSFL in the temperate New Zealand climate is not quite resolved yet (See Ch 2.6.2).

Information about food waste and how it is handled by local government, which has fed into insights for my scenarios, have come from working with the Thames Food Waste Resource Group (TFWRG), which was set up with the aim of reducing food waste going to landfill. TFWRG worked with Wintec based Design Factory New Zealand (DFNZ), at my suggestion, on ideas for educating people about food waste and has successfully worked with other resource recovery groups around the Thames-Coromandel district, and the Thames Business Association, to influence the Thames Coromandel District Council to put food waste collection into the waste contract. I hope to trial using BSFL to process food waste from Thames as part of scenario 2. Connections made through working with TFWRG will be useful when sourcing food waste for trials. Our shared goals of reducing: nutrient pollution; GHG emissions; and wasted nutrient resources has led to a mutually beneficial collaboration.

Dairy farmers have generously allowed me to visit their systems and ask questions, so that I can understand how some different systems work in the context of the farm, and have filled in a survey about their waste systems. This has allowed me to see which systems might best be adapted and consider how it might be possible and helped inform the questions for the survey. Their experiences and insights were combined with the data from the survey responses to form a picture of the waste systems and how farmers interact with them.

I visited a My Noke worm farm near Taupo, after we met with their General Manager through the TFWRG. The visit showed an interesting and successful example of a functioning circular economy that was cost effective i.e., cheaper than dumping in landfill. The worm farm processes multiple biological waste streams, including: sewage sludge; waste from dairy factories (DAF); paper pulp; Horticultural waste; business food waste; and green waste. The resulting vermicast is uses as a fertiliser by local farmers, including the farmer on whose land the worm farm is placed. I think this worm farming business will be a very useful case study (see Ch. 4.7) as it has similarities to the ideas I'm investigating and therefore adds to the information gained from the case studies of NZ dairy farm waste systems (Ch 4.1).

All these groups and individuals have contributed their thought-styles to this study.

1.8 What I hope to achieve personally from this research

My aims with this study incorporate personal goals at a detailed level and broader goals at a national level. In agreement with Pohl (2011) I am aware that these goals may on occasion be contradictory and that I'm unlikely to meet them all; also, that I may make progress in other goals not in this list. My primary goal is progress towards the establishment of an enterprise using BSFL to process dairy manure and other biological waste. My work for the 804 paper investigated how best to go about getting the information to create this enterprise, and this master's thesis is further progressing the research proposed in 804.

My secondary goals fit into the following categories:

Creating a product

- To have designed a functional home scale BSFL tub from mostly upcycled materials that I can use and/or sell.
- To have a colony of BSF that I can use to process food waste and manure from my local area and provide prepupae that I can feed to my ducks.

Personal mastery of skills

- To complete the Master of Applied Innovation and gain knowledge and skills of transdisciplinary research and create relationships to access the knowledge of academics from different disciplines.
- To have some marketable skills that will help me gain employment in reimagining a regenerative future for NZ. Note. *I'm not sure this role exists yet.*

Influencing change that benefits people and the environment

- To positively influence the awareness and adoption of circular economy in the waste and farming sectors.
- To positively influence the uptake of BSFL farming in NZ.
- To help progress the work of the Thames Food Waste Resource Group, which is encouraging the appropriate use of food waste through education and influencing local government.

1.9 Limitations of this study

This study has been subject to several limitations:

1. Unlike most action researchers I have come from outside of the industry I'm attempting to influence, also outside of the traditional external influencers. I.e. not involved in commercial farming or as a government scientist, rather as an interested member of the community. This has led to limitations of access to participants and a dependence on getting agreement to participate. The idea to develop an enterprise came about to create a vehicle which could hold the research within the criteria of the Master of Applied Innovation programme.

2. As I am looking at this issue in a multi-dimensional, big-picture way, I am unable to focus too deeply on any one area. The transdisciplinary framework allows for this wider exploration and Shrivastava et al. (2022) suggest that a multi-dimensional approach is essential to avoid partial solutions that damage the system.
3. I have discovered through the course of this research, that the duration of the master's programme is short in relation to the time that would be needed to conduct the scientific research, and develop or find the resources needed to establish this business. With this in mind I'll be working on creating a minimum viable product, and on developing scenarios that could be used to create interest in the idea of using BSFL to process DM and food waste at a larger scale. I'm also exploring the idea of supporting the fledgeling BSFL growing industry in NZ to collaborate in order to overcome the barriers that are stopping the industry taking off.
4. Within the time constraints of completing the Master of Applied Innovation, I have had to focus more fully on some aspects of the circular economy, that would be involved in creating such an enterprise, than others. I have focussed more on the DM biowaste stream, and how the circular economy might impact on dairy farmers. I have only touched on other biowaste streams and potential customers for the BSFL bioreactor products. There is a lot of work to be done on creating interest in BSFL products with potential customers such as the aquaculture industry, or poultry farmers, which I intend to complete after this Master study.

1.10 Summary of Chapter 1

In this chapter I have introduced the issue of surplus nutrients in the New Zealand and global context, and stated my position as researcher. I have outlined the research journey leading to the research question and idea, and introduced the stakeholders who have contributed. I finished with the limitations that became apparent through this process.

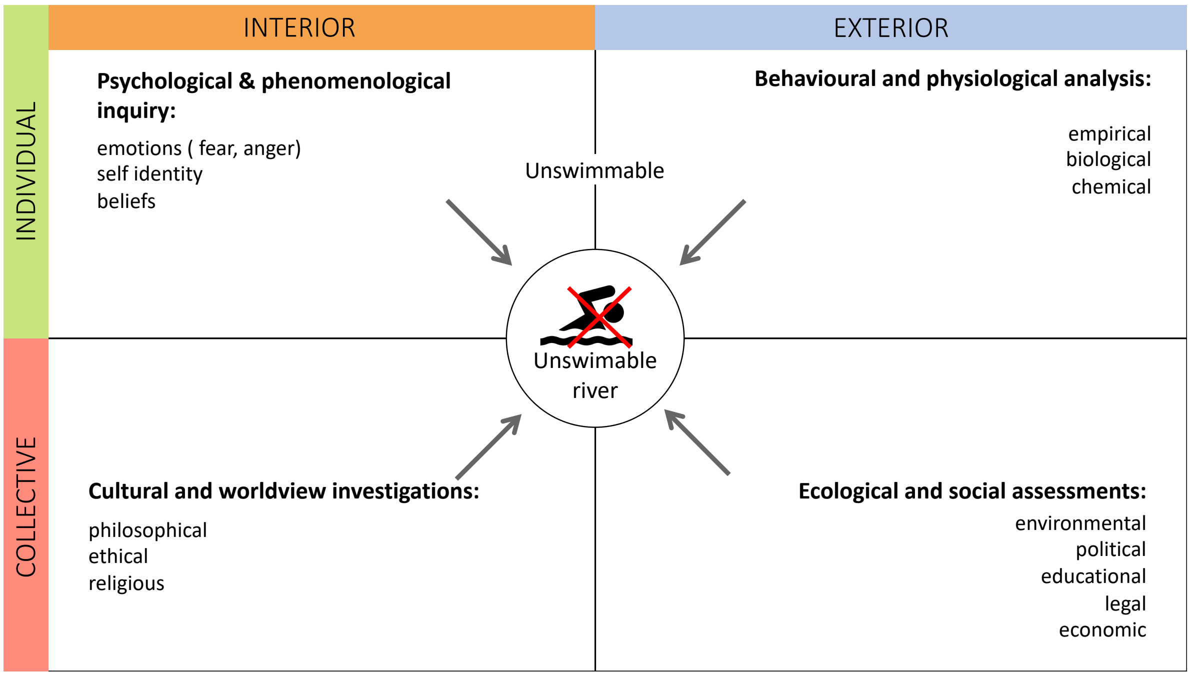
In the next chapter I delve deeper into the literature, on the theory of TDR as it relates to this project and on the context of the problem. I refer to my previous work on establishing an enterprise and probe the literature on BSFL, their potential as a business opportunity and the benefits of using BSFL to process biowaste.

Chapter 2 Literature review

This literature review reflects the discursive nature of this study which has come about because of the 'wicked' nature of the problem, the overarching transdisciplinary methodology, and the changes that have occurred due to limitations I discovered as the research progressed. Mitroff (1998, as cited in Shrivastava et al., 2022) proposed four dimensions present in 'wicked problems' "the scientific-technical, the interpersonal-social, the systemic-ecological, and the existential-spiritual" (Transdisciplinarity for the Anthropocene). As Shrivastava et al. (2022) recommend, I have researched aspects of all these dimensions for this thesis, and found that they are similar to the perspectives of integral theory. I drew an adaptation of Esbjörn-Hargens (2009, Figure 4) to help me analyse the different perspectives for the issue of an unswimmable river using an integral analysis framework (see Figure 8)

Figure 8

Integral Analysis Framework for an unswimmable river.



Note. Adapted from "An overview of integral theory, an all inclusive framework for the 21st century," S. Esbjörn-Hargens, 2009, (https://integralwithoutborders.org/sites/default/files/resources/Intro_Integral_Theory.pdf). Permission requested

Montuori (2013) suggests that transdisciplinary literature reviews can be overwhelming because of the large volume of material to investigate, and the range of fields involved; as such they are challenging to organise. The various fields have each had their own language and epistemologies to negotiate, so I have tried to explain these as simply as I can. This has been an iterative process, where insights from the research data have called for additional research to validate them,or to fill in gaps in the knowledge.

2.1 Theory of transdisciplinarity

A transdisciplinary approach has been used in this research because of the complexity of the issue of surplus nutrients. I considered that a big picture, multi-perspective investigation of the issue, would provide a greater depth of knowledge, which could help with developing a more comprehensive solution. Montuori (2013) states "A transdisciplinary literature review therefore explores how various theoretical frameworks shape our understanding of a topic, and inevitably both illuminate some aspects while obscuring others" (p. 50). I think this also holds true for the use of TDR methodologies to gather primary data.

Transdisciplinary research (TDR) came about to address some of the issues of classical science, such as the erasing of the subject, i.e., people and their perspectives, from the story, in an attempt to be objective (Nicolescu, 2010), and the increasingly siloed nature of academic disciplines and their limitations in real world, complex situations (Lang et al., 2012; Popa et al., 2015). It is built on a foundation that evolved from multidisciplinarity through interdisciplinarity (Leavy, 2016; Nicolescu, 2010), with inspiration from systems thinking and action research, and experimental and mathematical back up from quantum physics (Nicolescu, 1999). As a relatively new area of science, the exact nature of transdisciplinarity is still being debated (Pohl, 2011).

There seem to be two main approaches to TDR. Some practitioners view it purely as a pragmatic approach to solving problems in the life world, 'lebenswelt', a concept originally put forward by Edmund Husserl, (1858-1938, as cited in Hirsch Hadorn, 2008), with methodologies created specifically to the problem being researched (see Ch. 3). The other approach argues that it has its own theoretical framework and values. Nicolescu (2010) offered the following axioms for transdisciplinarity.

a. **The ontological axiom:** There are, in nature and society and in our knowledge of nature and society, different levels of Reality of the Object and, correspondingly, different levels of Reality of the Subject.
b. **The logical axiom:** The passage from one level of Reality to another is ensured by the logic of the included middle.
c. **The complexity axiom:** The structure of the totality of levels of Reality or perception is a complex structure: every level is what it is because all the levels exist at the same time (p. 24).

Within the ontological axiom, Nicolescu (2010) also placed the concept of the "hidden third" which contains the knowledge we cannot access, map or model. He calls it a "zone of non-resistance" (p. 1) as the possibilities within it create 'no resistance' to the (metaphorical) radar of our perception. He considers the hidden third to "correspond to the sacred" (p. 26) and that insights from it can be gained through spirituality, art and culture. Similarly, Chilisa (2012) suggests that for indigenous peoples, spirituality is a connection to the cosmos and a legitimate way to gather information and come to know. Other transdisciplinary researchers, who work in the more practical and less theoretical space, give another meaning for the 'zone of non-resistance', which applies to an openness in the mind of the transdisciplinary subject, i.e., the researcher. This allows them an acceptance of the possibilities in the 'hidden third'. "Non-resistance: become open to other perspectives, ideologies, value premises and belief systems, inherently letting go of how one currently *knows* the world" (McGregor, 2011, p. 2). McGregor's work suggests that we can only get insights from this 'hidden third' when we are open to knowledge which we cannot perceive directly from our level or perspective. This has been essential in finding out why the waste system approach is seen to be working on some levels and not on others.

The 'included middle' is central to the logical axiom, and is the point where A and not-A occur at the same time, i.e., the knowledge that is contradictory. In classical physics the 'included middle' is not possible, whearas it occurs within quantum physics (McGregor, 2011). For example, light is a wave on one level and a particle at another level. In the 'included middle' it is both a wave and a particle. In a complex, real-world, situation this allows us to accept contradictions. I investigated these axioms in more detail in my 801 paper. Although this research has had the purpose of working towards practical action in the real world, I have included the theoretical underpinning of TDR because it has been informative when analysing different perspectives of the issues and reflecting on my own ways of gaining knowledge.

2.2 The documented context of this issue

This section includes more detail on the context of the issue described in chapter 1, focussing on both direct and indirect issues relating to surplus nutrients from dairy farming and the proposed innovative resolution.

2.2.1 How did the problems of nutrient and GHG pollution come about?

The main factor influencing these issues is the number of dairy cows in New Zealand as a whole and their intensity in certain areas. There has been a 70% increase since 1994 (StatsNZ, 2019). The range of geographical locations where dairy cows are farmed has grown, and the mean intensity has risen from 2.3 cows/hectare in 1985 to 2.84 cows/hectare in 2020 (LIC and DairyNZ, 2018). This growth, along with a six-fold increase in fertiliser use in the last 25 years (Pinxterhuis, 2019), has led to increased pollution of land and waterways by leaching, and point source run off from dairy farming. GHG emissions, due to enteric methane from cattle digestive systems, and methane and nitrous oxide from decomposing DM, have also increased with the growing cattle numbers. Legislation regarding dairy waste is becoming stricter, and the cost of storage and treatment systems for DM has increased as these systems are required to be more sophisticated to meet new legislation. While dairy farms are not the sole contributors to waterway pollution, they do represent a significant source of it (Chobtang et al., 2016).

2.2.2 Environmental issues of dairy farming relating to this research

2.2.2.1 The issue of dairy manure (DM)

Animal manure in appropriate quantities forms an important part of an ecosystem, providing food for insects and plants. Yet, if the quantity of manure exceeds the capacity of the ecosystem to utilise it, it can create multiple environmental problems. The breakdown of DM releases compounds in solid, liquid, and gaseous states. Ammonia compounds (NH_4), and sulfur dioxide (SO_2) from excreta and nitrogen (N) fertilisers, can be spread around in dust and, along with nitrous oxides (NO_x) in excreta, have the potential to cause terrestrial eutrophication. Marine eutrophication can be caused by excesses of the above chemicals being released into water (NO_3) and into the atmosphere (NH_3 and NO_x). (Chobtang et al., 2016). To illustrate this, Zeldis and Swaney (2018) found that “for the Firth of Thames, 51% of total N and 85% of dissolved inorganic N supply originated from its agricultural catchment” (p. 1). NH_4 in excreta has potential to cause acidification of seawater as evinced by (Zeldis et al., 2022) in their research in the Firth of Thames, where they found depressed pH and oxygen content which “approached deleterious levels for macroalgae (corallines), and early life stages of sea urchins, sand dollars, abalone and New Zealand Greenshell® mussels” (p. 18). This has serious implications for food security and economic wellbeing in the Firth of Thames with particular cultural implications for Māori, as collecting kaimoana is an important part of their traditional practice and knowledge (Olsen, 2022).

The run-off and leaching of phosphorus (P) from manure, and P fertilisers, can cause freshwater eutrophication (Chobtang et al., 2016). Greenhouse gases (GHGs) such as nitrous oxide (N_2O) and methane (CH_4) released from DM have significant climate change impacts. Most of the menthane comes from enteric fermentation, however, a significant amount is released from the decomposition of manure. The New Zealand Ministry for the Environment (2022b) states that “Between 1990 and 2020, gross emissions increased by 21 per cent (13.6 Mt CO_2-e). This is mostly due to increased methane from growth in the dairy cattle population and carbon dioxide from road transport.” (What are our current methane emissions?) They suggest this is due to the increase in the dairy herd and the 693% increase in synthetic nitrogen use since 1990. The NZ government’s current targets are to “reduce biogenic methane emissions by 24 to 47 per cent below 2017 levels by 2050, as well as 10 per cent below 2017 levels by 2030” (Ministry for the Environment, 2022b, p. 9).

2.2.2.2 Impacts of fertiliser use

Chemical fertiliser use has been increasing on dairy farms. The Waikato region has many dairy farms and Waikato Regional Council statistics give figures for nitrogen use of 36 kg N/ha/year in 1997-98; 109 kg N/ha/year in 20011-12 and 128 kg N/ha/year in 2019-2020 (Waikato Regional Council, n.d.). Dairy farming currently uses around 49% of all fertilisers; 67% of all nitrogen fertiliser and 34% of superphosphate sold in New Zealand (StatsNZ, 2022)

There are many issues associated with the use of chemical fertilisers. Nitrogen based fertilisers contribute to marine and terrestrial eutrophication, and acidification of soils (Chobtang et al., 2016). High nitrate levels are linked to health impacts in humans such as Colorectal cancer (Richards et al., 2022) and pre-term births (Chambers et al., 2021).

Environment Waikato (2008) found that, in the Waikato, 30% of groundwater sites under dairy farms did not meet Ministry of Health guidelines for safe drinking water.

Phosphorus fertilisers contribute to freshwater eutrophication (Chobtang et al., 2016) and increase cadmium levels in soils (Yi, 2019). In New Zealand, heavy cadmium contamination of soils correlates with dairy farming (StatsNZ, 2017). Phosphate rock is non-renewable and there is no synthetic alternative so it could potentially run out having severe implications for future food production unless we change the way we farm (European Commission, n.d.).

There are significant financial costs in buying fertilisers. Foote et al. (2015) estimated that New Zealand spent around NZ $503 million on imported fertilisers in 2012. With fertiliser use increasing, and the current war in Ukraine causing a dramatic increase in fertiliser prices, I think these figures will now be substantially higher.

2.2.3 The need for sustainable farming

In 2015, the United Nations General Assembly (UN-GA) adopted 17 goals for sustainable development. The second United Nations Sustainable Development Goal (UNSDG) is to "End hunger, achieve food security and improved nutrition and promote sustainable agriculture" (UN, n.d., p. 1). A joint agency report on global current progress towards this goal indicates that since the goal was proposed the situation has worsened in most areas, despite world governments allocating US$650 billion per year to the food and agriculture sector (FAO et al., 2022). They state that agricultural systems need to be transformed to overcome the climactic, political, and economic challenges to global agriculture. Unsustainable agricultural practices have led to biodiversity loss, pollution, loss of important ecosystems, soil loss and changes to the water cycle (Clay et al., n.d.).

2.3 Innovative solutions to the problem of excess nutrients in the environment

Regenerative agriculture has been defined as “a conservation and rehabilitation approach to food and farming systems” (Wikipedia, n.d.). It has become the new ‘sustainability’. Williams (2020) states “Sustainability is great, but it only brings a holding pattern and cannot fix already degraded environments” (as cited in MacIntosh, 2020, p. 2). In the past few years there has become increasing interest in regenerative farming practices to solve some of the issues of dairy farming. This is evinced by the number of regenerative farming groups that have started in New Zealand. These inform farmers of regenerative practices via webinars, and provide peer support in the form of field days. There has also been increasing interest from the media, with mainstream farming programs such as Country Calendar often highlighting regenerative farms. An internet search of regenerative farming in the NZ media returned 125,000 results (13 August 2022). The complex nature of this issue means that this enterprise is just one potential part of the work that needs to be done to make dairy farms regenerative. There are many others including: regenerative grazing practices such as longer stock rotation that allows land to go ungrazed for longer periods of time, so that plants grow taller and soil depth increases. Increasing the diversity of pasture plant species is a method being used to give resilience to different climatic conditions, and increase biomass by stacking plants with different ecological niches. Dung beetles are being introduced to farms to bury animal manure, thereby reducing the likelihood of nutrient runoff. Many regenerative farmers are working on reducing their use of chemical fertilisers, and have found it has improved their soil and saved them money. Some are reducing the number of cows per hectare, and finding that they can increase productivity with fewer cows. Dairy farmer Miah Smith reported significant animal health improvements by putting some of these methods into practice (Engelhart et al., 2020).

Whole catchment restoration has become more commonplace, with catchment wide planning to benefit the local waterways. Actions include riparian planting: for biodiversity; habitat; nutrient and sediment capture; management of silt and other sediments: and retiring land to nature. A few farmers have been implementing silvopasture, which involves growing trees in pasture for a variety of reasons, including diversity; shade; nitrogen fixing; adding compost with fallen leaves; timber: and stock feed (Engelhart et al., 2020). Others are experimenting with feeding cows feeds that reduce or eliminate enteric methane production. E.g. some seaweeds (Kinley & Fredeen, 2015) and linseed (Guyader et al., 2015). Research in this area is underway around the world.

I think these changes will be more likely to work if they sit within far bigger systemic changes, such as:

- Putting regenerative values at the heart of our economy.
- Including all the costs when calculating the financial value of an industry.
- Having a financial system that is not as reliant on debt.

2.3.1 What NZ dairy farmers have been doing to work on this problem

Dairy farmers in New Zealand are making many improvements in how they manage DM and fertiliser impacts, including whole farm nutrient budgets using the Overseer[FM] application, which also reports on GHGs. They are investing in increasingly sophisticated waste treatment systems, to capture and manage more of the farm's effluent and DM, and many now use of hard stands in wetter weather or times when plant feeds grow slower due to cooler weather. The increase in effluent capture has also led to a significant increase in storage, for effluent collected from milking sheds and hard stands. Rollo et al. (2017) estimated that on average an extra 12% of manure was being captured then compared to the six percent in the early 2000s, making a total of 18%. My current investigations lead me to believe that this percentage is still rising.

Riparian planting and keeping stock out of waterways has been encouraged, with many regional councils offering funding for fencing and trees, for example the Waikato Regional Council (WRC) 'Clean Streams' programme (Waikato Regional Council, 2020). Other organisations, such as Dairy NZ and MPI, provide advice and resources (Ministry for Primary Industries, n.d.).

In some areas communities and regional councils are working with farmers on whole catchment improvements, such as reinstating wetlands and riparian planting. Some farmers are going further, and working on regenerative farming methods mentioned above.

Many of these changes are due to government legislation aimed at reducing nutrient leaching from dairy farming. My conversations with dairy farmers, and analysis of the larger system, have given me some insights into why the changes to legislation, in combination with other factors affecting dairy farming, have not resulted in reduced nutrient leaching, and have sometimes been counterproductive.

2.4 Other environmental issues relating to this thesis

The solution I chose to investigate has many potential benefits beyond the issue of dairy manure and dairy farmers, so I've added some details about the other issues the BSFL enterprise may help to address.

2.4.1 The issue of food waste

The proposed black soldier fly larvae (BSFL) enterprise would also make use of food waste in the feed substrate, so I researched the issue of food waste. Christian John et al.

(2016) estimated that food waste accounts for 17% of New Zealand's total waste stream with a further eight percent of other organic wastes. It accounts for around 40% of household waste, by mass, (Yates, 2013) and is generated in many other industries e.g. farming, brewing, supermarkets and restaurants. Food waste, contained with other waste, contaminates recyclables. Most food waste ends up in landfill where it causes health risks, due to being a food source for pathogens, causes odour, and attracts scavengers and flies. Decomposing food waste generates methane, which contributes to global warming at 28-36 times the rate of CO_2 over a 100-year period (EPA, n.d.). Estimates from the US (EPA, n.d.) attribute 15.1 % of all human related methane emissions in the US to municipal solid waste landfills, and Webb (2020) estimates that more than 1.5 million tonnes of greenhouse gas emissions were generated from decaying food waste in New Zealand landfills. The above figures for the proportions of food waste and other biological waste suggest that at least two thirds of that methane are from food waste. From a financial perspective, it is expensive to put food waste in landfill as it is wet, and consequently, heavy. Unfortunately, I was unable to find research that estimated these costs in New Zealand. Food waste contains potentially valuable nutrients that could provide food for plants and animals. However, these nutrients can also cause problems through leaching or run off.

2.4.2 The issue of sustainable high protein feed sources

BSFL can be used as a high protein feed ingredient for many animals including: poultry; reptiles; cats; dogs; pigs; and fish. It could potentially replace fish meal and oil, or soy meal and oil, which are common ingredients in these feeds. Feeding fish is a growing problem because global aquaculture is increasing faster than any other food producing industry (Katya et al., 2017). Wild caught fish, either as whole fish, fishmeal, or fish oil, are the main source of food for fish in aquaculture. In 2009 approximately 63% of all fishmeal and 81% of all fish oil were used this way (Natale et al., 2013). This use of wild caught pelagic fish has been linked to negative impacts on human food sources, and impacts on food webs. There has been increasing use of zooplankton, such as Antarctic Krill, for fish food, despite little research being done on the potential impacts this will have on the marine ecosystem (Natale et al., 2013).

Plant based feed ingredients for fish, predominantly soy meal, and soy oil, are being used as an alternative high protein feed. Unfortunately, they do not contain some of the necessary nutrients, particularly polyunsaturated fatty acids, that carnivorous and marine fish need. They also contain other antinutrients that negatively affect health and growth. Consequently, additional processing is needed to make them suitable as fish feeds. Plant based feeds often have high needs for freshwater, and land, which has led to deforestation, pollution, and increased use of genetically modified organisms (GMOs) (Caruso et al., 2014; Tschimer & Kloas, 2017).

2.5 Setting up a business using black soldier fly larvae

In 804 I analysed some tools for setting up a business including variations of the business model canvas and the value proposition canvas (see appendix B). The tools that seemed the most relevant had many points in common with TDR as they involved defining a problem, known as the opportunity, and investigating it at multiple levels and perspectives before seeking solutions. I adapted some that seemed appropriate for the business I wish to establish.

Many of these tools will be more relevant after the completion of this masters due to my discovering that other things need to be in place before the establishment of the business. They may be of benefit for getting funding for a trial.

Literature on black soldier flies and their larvae, has been included for the purpose of informing the design of a temperate climate BSFL farm and to investigate the environmental and economic potential of a business based on farming BSFL on biowaste, specifically DM and food waste. It has directly informed my early experiments with my colony, and the prototyping of basic infrastructure. I include research on how BSFL farming is being used in different ways globally, with a variety of techniques and an expanding range of products.

BSF, *Hermetia illucens,* originate in the Americas, native to tropical, sub-tropical, and temperate regions, and are now found in many countries around the world. They breed naturally on moist organic material such as carrion and manure, which the larvae eat as part of ecosystem nutrient cycling. They are commonly found in agricultural settings due to livestock wastes and favour compost and rubbish dumps in urban areas. They are also common in areas with poor sanitation (Diclaro II & Kaufman, 2009).

They are naturalised in northern New Zealand and their larvae are often visible, in the summer and autumn, in compost or rotting biological matter (see Figure 9). The advantage of using a naturalised species is that there will be no need to go through the long and expensive process required to ensure a new species is safe to be introduced. BSF are considered to be a non pest species and are not recorded as disease carrying organisms or as vectors for pathogens (Caruso et al., 2014).

Figure 9

BSFL in my compost in April.

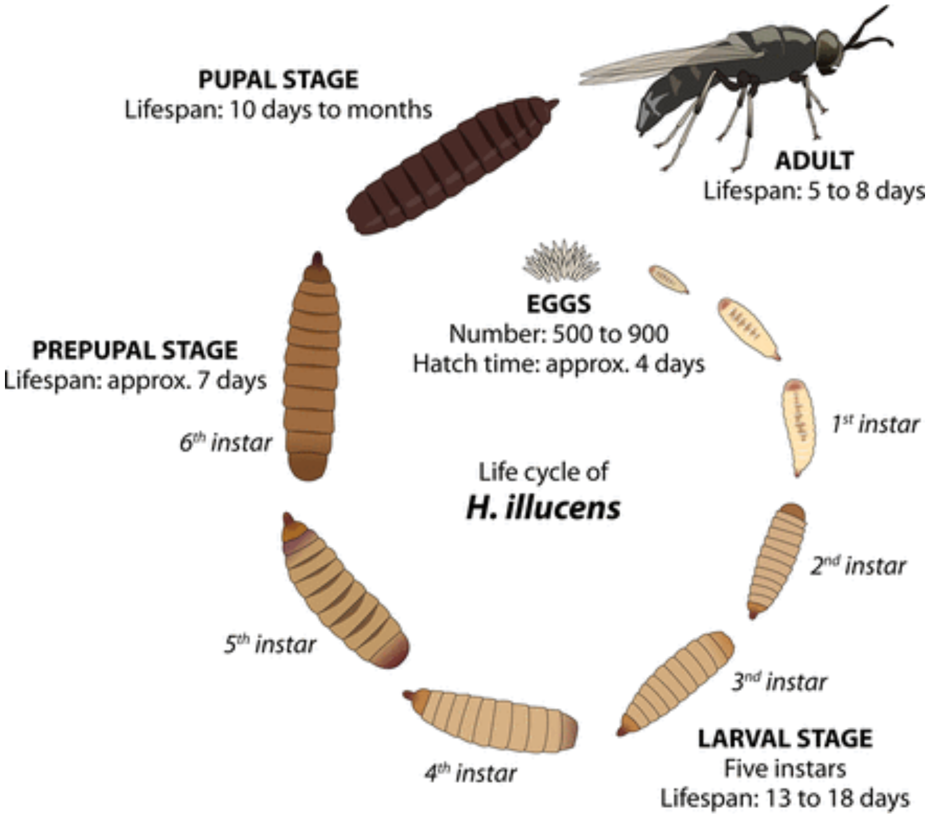
Note. There were many BSFL still present on June 2nd. Photo taken by the author in April 2021.

The lifecycle in Figure 10 shows that adult BSF vary greatly from the larvae, and that there are many stages in the lifecycle. Each of these stages has different needs and characteristics to consider. The amount of time the BSF remain at each stage is dependent on environmental factors such as food quantity; nutritional value; temperature; humidity; and light intensity (Caruso et al., 2014).

Adult BSF are very short lived. They do not eat at this stage except for sometimes drinking nectar (Caruso et al., 2014) because their mouthparts are not functional for other eating. This makes them particularly suited to domestication as they do not travel far or pester humans or animals and they are not known to spread diseases as they are not moving between food sources, as many other flies do (Caruso et al., 2014). Their purpose at this stage is to reproduce. The adult female lays many very tiny eggs, approximately 1mm long, in crevices and this tendency can be exploited by placing items with crevices in the breeding area so that the female lays her eggs in a place they can easily be collected. The BSF larvae hatch after a three-day incubation and start eating nearby organic matter. They are voracious in the larval stage, which takes 21-24 days. In optimal conditions, they can reduce the volume of their food source by between 40 and 80%. They can eat a wide variety of organic matter due to strong mouth parts, a unique range of powerful digestive enzymes and the enzymatic activity of microbial flora in their intestines. (Caruso et al., 2014; Lalander et al., 2019).

Figure 10

Life cycle of H. illucens.



Note. From "Microbial Community Dynamics during Rearing of Black Soldier Fly Larvae (Hermetia illucens) and Impact on Exploitation Potential" by J. De Smet, E. Wynants, P. Cos and L. Van Campenhout, 2018, *Applied and Environmental Microbiology,* 84(9), p.2. Copyright 2018 by J. De Smet, E. Wynants, P. Cos and L. Van Campenhout. Reprinted with permission.

At the prepupal stage the larvae try to get somewhere dryer and, if they can, they will leave the feed substrate. This characteristic has been utilised in many of the BSFL growing systems around the world as it can be used to get the prepupae to partially self-harvest. By having a ramp out of the substrate container, the prepupae will remove themselves from the substrate.

2.5.1 Summary of benefits of using BSFL to process food waste and DM

In my 804 paper I looked at the business opportunity in growing BSFL, including the potential benefits to dairy farmers, fish farmers and food waste generators (see appendix B, section B.1.1). I have summarised the findings here with some updated information.

Foote et al. (2015) estimate it is between 2 and 600 times cheaper to reduce nutrients at source than clean them up when they have been leached. BSFL are particularly good at making use of the nutrients in biowaste so that far less are lost as GHG's and leached into water (Lindberg et al., 2022) than with other forms of piling or composting (Figure 12). They process most biowaste very quickly if it is not too fibrous, with some BSFL farms having batches processed in less than two weeks (Entoprot; Entocycle;) although it takes around three weeks for a mix of DM and food waste (Rehman et al., 2017). Worms process waste much slower, with the season in New Zealand taking nine months to a year (Quintern, 2022). Therefore a smaller area of land is needed for BSFL farming. The harvested BSFL can be fed directly to a range of animals and fish, or dried and pelleted as an ingredient in feeds. They can also be pressed to extract the oil and separate the protein. With a 2:3 mix of DM and food waste as the BSFL's feed substrate they have a feed conversion ratio of 4.1 and reduce the mass of the waste by approximately 75% wet weight (Rehman et al., 2017). Processing by BSFL also reduces many of the pathogens found in biowaste. The residue, which is a mix of insect frass i.e. manure and cast off exoskeletons, and residual waste, is a slow release fertiliser and good soil improver due to high beneficial microbe levels (Beskin et al., 2018; Green & Popa, 2012; Liu et al., 2019). It is not suitable as an instant fertiliser as the microbes tend to use up surplus nitrogen which can slow plant growth. Nethertheless, this can be an advantage if applied to soil after harvest, to mop up excess fertiliser, which will then be released slowly. The long term benefits of BSFL Frass in soil have not yet been fully researched. However, initial studies suggest that the nitrogen immobilisation period would decrease if the frass was used in successive seasons. Beesigamukama et al. (2020) report that the presence of enzymes and growth hormones, including auxin and gibberellins, and plant growth promoting organisms in insect frass grow crops with deeper and wider roots, which imply potential to grow soil, thereby sequestering more CO^2, and bringing up nutrients from the subsoil.

For dairy farmers, a BSFL biodigester could potentially provide an income from the sale of BSFL as animal feed; sale or use of frass as a fertiliser; and the fee for taking food waste. The additional nutrients coming to the farm in the food waste, could replace those that leave in milk. If the biodigester were retrofitted to an existing system, the storage area released by processing the DM quicker could be used to store the brought in food waste, and, if the farm had yet to put in larger DM storage infrastructure, the storage area needed in a BSFL system would be less, potentially reducing the cost.

Benefits for food waste generators include providing a viable alternative to dumping food waste in landfill or composting it with the potential for certain food wastes to acquire a value (Jucker et al., 2020) (Singh & Kumari, 2019). For Animal or fish farmers, BSFL are an effective alternative to environmentally damaging high protein feeds such as fish meal and fish oil, and a more digestible and environmentally friendly protein source than soy (Tschimer and Kloas, 2017; Katya et al., 2017), with additional benefits of having hypoallergenic and anti-inflammatory properties (Petfood Forum Europe, 2021; IPIFF, n.d.; Protix, n.d.). For all these customers it could reduce transport costs, because there are always local sources of biowaste. It would also provide satisfaction and positive feedback by improving the environmental performance of the above industries.

2.5.2 Summary of ways to optimise BSFL growth and benefits

Table 2 shows some of the factors to consider in the design of the BSFL grower module. There are other factors, and interactions between factors, that I will investigate further at a later stage. I have collated information from several sources, and where they have different results, I have included a range or taken a middle ground to get the best consensus.

Table 2

Factors to consider for BSFL farming

Method/factor	Reason	How this enterprise might take this into account
Temperature: In temperate parts of the world BSFL are inactive or less active in the winter. The optimal temperature to grow BSFL is between	This range gives sufficient energy for the BSFL to move and not so high a temperature as to endanger life.	A means of keeping the temperature in the optimum range will be needed therefore the growing will have to take place indoors. This could

25 and 37.5°C. (Carina et al., 2018; Chia et al., 2018; UNC Institute for the Environment, 2013) although newer research suggests that temperatures over 30 °C may be detrimental to BSFL (Yong et al., 2018)		be a heated greenhouse, an existing building, or a shipping container. The module will need to include a heat source; ideally one that uses renewable energy.
Humidity: BSFL will cope with a wide range of humidity and will grow well at between 30 – 90% humidity with optimum being around 70%. (Chia et al., 2018; UNC Institute for the Environment, 2013)	The larvae need sufficient moisture to be able to move in the substrate and not so much that they cannot breathe through the spiracles in their exoskeletons.	Sensors may be needed to check the environmental conditions, such as temperature, humidity, and pH, for the BSFL. These could be used to automatically initiate changes and/or to ensure that there is a warning if conditions are too far from optimum.
Mixing dairy manure with food waste at a ratio of 2:3 (depending on the type of food waste). This example used soy curd residue (SCR) which is fairly high in protein (Rehman et al., 2017)	DM alone had many lignin fibres which were hard for the BSFL to digest; adding SCR made the substrate more easily digested. This resulted in a much greater waste reduction rate and the residual frass had a good structure and nutrient level making it a better fertiliser than with either the DM or SCR alone. The DM and SCR mix had a better balance of nutrients than either alone. Jucker et al. (2020) also found that "balanced diets allow an optimal growth". The mix of DM and SCR balanced the pH. DM alone resulted in an alkali substrate and SCR alone tended to become acidic. When mixed the DM buffers the pH to around 6.7. the nutrient balance and pH achieved with the mix produced a higher larval mass.	Some experimentation would need to done to test mixes using food wastes that are more readily available in New Zealand. Jucker et al. (2020) found that the growing feed substrate affected the development time, biological traits and mortality rate of the BSFL. This would be a good area for the stakeholder community including the dairy farmers, support person, BSFL customer and possibly some academic support, to work on together (see section 6.2.4). The online community could post their yield results and other data to grow the community knowledge on the best food waste streams to mix with the DM.

	With co-digestion of DM and SCR more of the water in the substrate was utilised than with DM or SCR alone, resulting in a dryer frass mix at the end which would be more hygienic; lighter to transport and there would be less leachate to deal with.	
Mincing the food waste into smaller parts: Many of the larger scale BSFL growers use a grinder or a mulcher to break the food waste down into smaller pieces prior to using it a substrate for BSFL. (Exocycle, 2019; A. Riihimaa, personal communication, April 12, 2022).	Give a greater surface area for the BSFL to access the food. This would also give a greater surface area for microbes which also help digest the food waste.	The need for this would depend on the food waste used.
Adjusting the moisture content of food waste or DM: Depending on the moisture content of the feed substrate, some BSFL growers set up a system to reduce the moisture content of their feed prior to using it as substrate. (Exocycle, 2019) Entoprot uses drier feed such as waste grain and has a very enclosed system which heats up with the action of the BSFL. They add water to their feed substrate. (A. Riihimaa, personal communication, April 12, 2022).	There are many reasons to pre-dry certain feed substrates such as fruit and vegetable waste. • To achieve a moisture content that is suitable for the BSFL. • To reduce the mass of the waste prior to transport. • To make the substrate more hygienic to handle. • To result in a drier frass that is lighter and easier to handle.	Depending on the system used in the dairy farm for collecting the DM there may be a need to reduce the moisture content. Often the manure is collected in wash down water although some hard stands use a scraper to collect the DM. It is becoming more common now to have systems that partially separate the solids from the liquids. For this enterprise it may be useful to work with farmers that have this system in place.
Adding appropriate microbes to assist with the digestion of the lignin in the DM. (Rehman et al., 2019)	BSFL have difficulty digesting the lignin from DM and consequently leave a high proportion of the substrate undigested. Rehman et al. (2019) experimented with different combinations of	Research this area further in the future. After the lean start up.

	lignocellulotic exogenous bacteria and found that all mixes trialled improved the outcome measures of BSFL including survival rate, development time, bioconversion rate, manure reduction rate, food conversion rate and nutrient utilisation.	
Depth of substrate: BSFL do well with a substrate around 20-23 cm. (UNC Institute for the Environment, 2013)	Depth of substrate is important because too shallow a substrate can leave them exposed to external conditions and too deep a substrate leads to anaerobic areas where they do little bioconversion.	A regulated environment would probably minimise the problems of too shallow or deep a substrate.

2.5.3 Farming BSFL in a temperate climate

Although there is a lot of literature and many videos and blogs on how to grow BSFL on a home scale or in tropical climates there is much less about the technical specifics of growing them on a larger scale in a temperate climate. I think this is partly because the technology is more complicated and not fully developed and partly because larger companies are protecting their intellectual property for commercial reasons. There is literature on what the BSFL need but not on the ways to create those conditions at an industrial scale, in a cost-effective way.

From my conversations with small scale entrepreneurs, who have been working on this, I intuit that they are not there yet, with the technology and processes that will enable medium to large scale farming of BSFL in all seasons, in a temperate climate. Some are close but have reached a point where their businesses will either fail or take off. One New Zealand company has closed this year (2022), after problems getting flies to emerge from the pupae. Another company in Finland has stated that they will either fall or fly this year. A British company is seeking to buy the technology from the Finnish company.

There are a few very large-scale commercial enterprises growing BSFL in temperate climates for example Protix in Holland seems to operate from a very large climate-controlled warehouse farming the BSFL in the stacked boxes system using a very high technology breeding system and innovating in multiple ways including a selective breeding programme

(Protix n.d.). Enterra, a company based in British Colombia, appears to have a similar BSFL farming system (Enterra, n.d.). Both these companies use pre-consumer food waste to feed their larvae, reflecting what the current legislation allows.

2.5.4 Developments in the global knowledge and use of BSFL

Interest in farming BSFL has increased in the past decade, and accelerated rapidly since I started this study in early 2020. A Google search (13th July 2022) of 'Black soldier fly farming' returned 4,460,000 results, and much research is being conducted through higher education establishments. I have also observed an online, informal, peer education movement, which has become increasingly sophisticated in the past two years. In 804 I illustrated how BSF were being domesticated around the world at different scales and levels in 2020 (see appendix C).

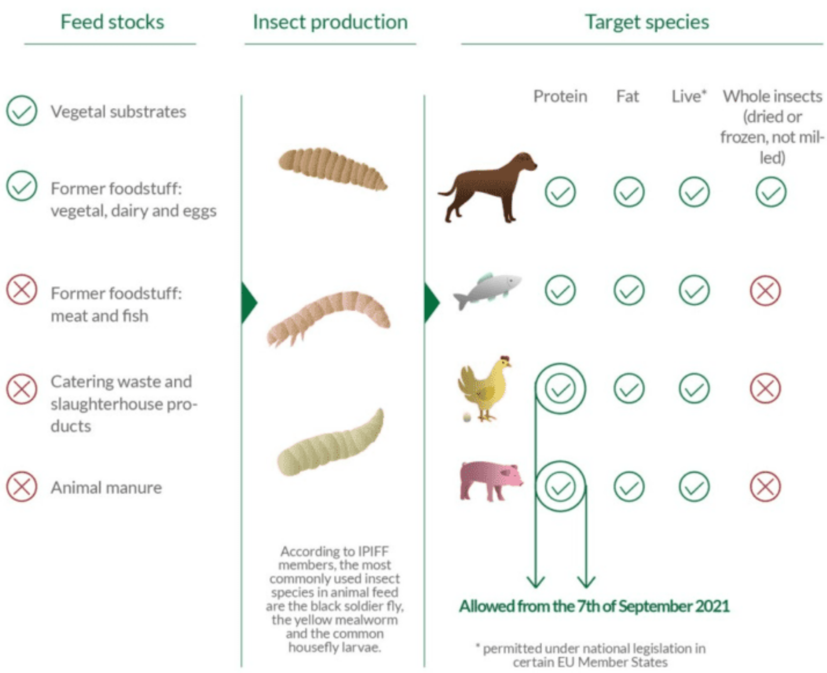
Although black soldier fly larvae (BSFL) have been used as a source of protein in animal feed with increasing frequency in developing countries, the uptake in developed countries has been relatively slow due to more cautious and restrictive regulations. However, considerable new research to investigate the safety of BSFL as a feed, and ways to mitigate any risks, suggests that a tipping point of mainstream acceptance of BSFL as a viable animal feed ingredient, may soon be reached.

Legislation has been changing rapidly in the USA and Europe. For example, in 2016, BSFL were included in the approved species' diet for salmonids by the Association of American Feed Control Officials (AAFCO) and in June 2021 they approved the use of dried BSFL in Adult dog food after research found that BSFL have anti-inflammatory properties that make it beneficial for older dogs (Seo, 2021; Tyler, 2021). AAFCO states that "BSFL is the only insect product that has successfully gone through the AAFCO ingredient definition process" (Hays, 2021)

In Europe legislation allows some use of BSFL feed ingredients. In July 2017, European Union (EU) regulations allowed insect proteins to be incorporated in fish food formula. Figure 11 shows that their regulation is specific about the feed substrates that BSFL eat.

Figure 11

Summary of current (2021) EU legislation on feeding insects to animals.



Note. From "Since September 2021, the possibilities to feed insect proteins to certain animal species are unlocked, thanks to the lifting of the EU 'feed ban' rules," by International Platform of Insects for Food and Feed (IPIFF), 2021. https://ipiff.org/insects-eu-legislation/. Copyright 2021 by International Platform of Insects for Food and Feed (IPIFF). Reprinted with permission.

These changes to legislation, and new research, have cleared the way for the use of BSFL in animal feed; they are now an ingredient in Nestlé, Purina and Mars pet foods (Petfood Forum, 2021). A Rabobank report (de Jong, 2021) estimated the 2030 demand for insect protein to be 500,000 tonnes/year, fifty times the 2021 market of $10,000 tonnes, with BSFL predicted to be the most useful insect farmed.

2.5.5 Other uses for BSFL and BSFL products.

In addition to the use of BSFL for animal feed, and frass for fertiliser, there are other uses that are currently being researched and trialled. I include them here as some may be a potential alternative market for BSFL until the New Zealand legislation about feeding insects to animals catches up with that of other developed nations. They may also suggest a potential future market.

BSFL have an approximately 40% fat content and this can be extracted for biodiesel whilst using the high protein residue for animal feed. This has the potential to replace other, environmentally damaging sources of biodiesel (Wong et al., 2020). Jung et al., (2022) found that the BSFL biodiesel met the EU and Korean biodiesel standards.

BSFL are proving to have various medicinal properties. Their fats are now being used as a skincare ingredient for their high lauric acid content and anti-microbial properties (Sibu n.d.) and they have been shown to reduce enteritis and lower inflammatory markers in farmed sturgeon (Kumar et al., 2021). Lee et al. (2018) demonstrated that BSFL in feed protect broiler chicks from *Salmonella gallinarum*, and improved their growth rates.

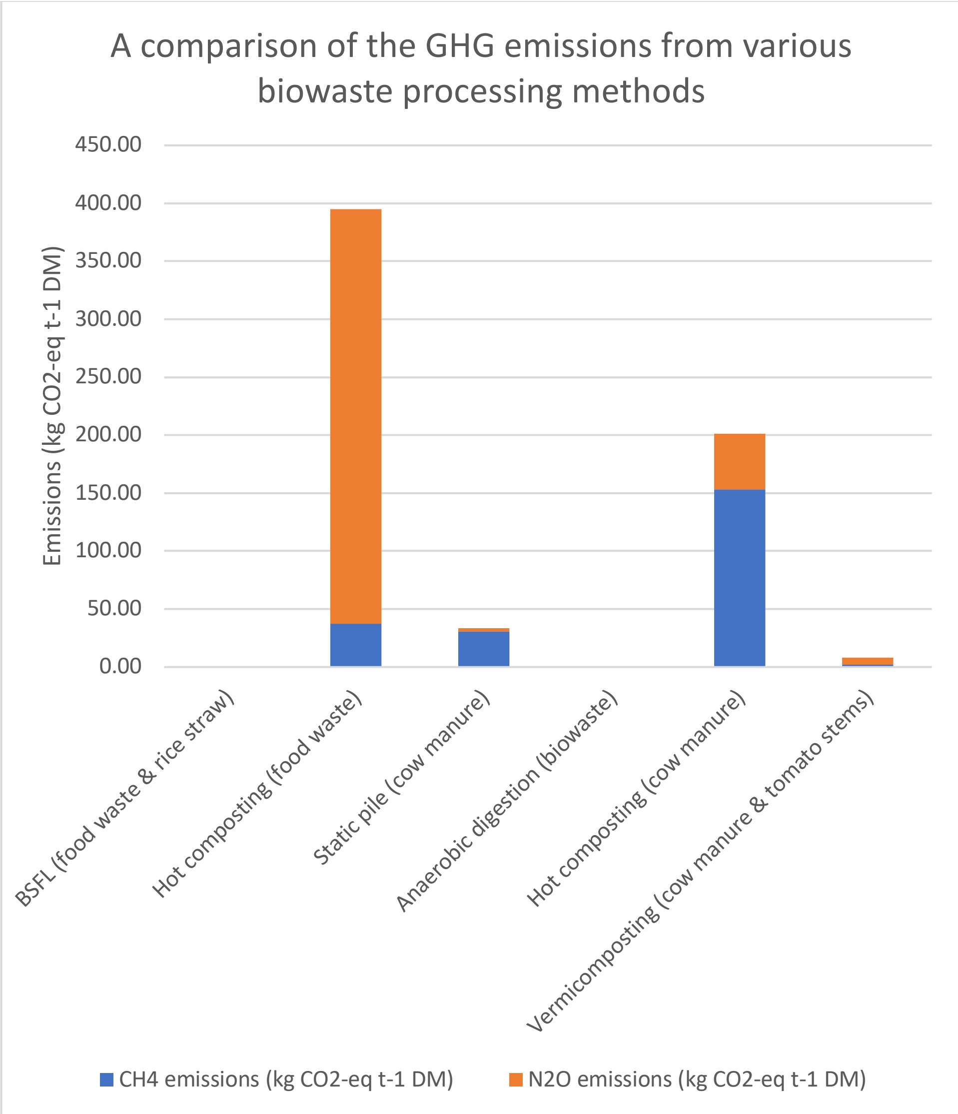
Frass has mostly been used as a fertiliser and soil improver but there has recently been research into its use as animal feed. Yildirim-Aksoy et al., (2019) found that feeding catfish a diet with up to 30% BSFL frass increased weight gain, compared with their usual diet.

2.5.6 Benefits of BSFL processing of biowaste compared with other methods

With manure and food waste being the biowaste that I'm investigating as potential feed substrates for BSFL, I decided to research how different methods of processing these waste streams compare in terms of greenhouse gas (GHG) emissions (see Figure 12). CO_2 emissions were not included, as recommended in Ministry for the Environment (2022a), due to their being biogenic. The above data came from a variety of sources (see Appendix D), chosen because they were relevant to the waste streams considered in this thesis and because the data came from actual measurements where possible. Figures for anaerobic digestion came from Ministry for the Environment (2022b). A variety of units had been used in the source data and had to be converted to comparable units. I have chosen to use kgCO2-eq t-1 dry matter, as compatible with IPCC and MFE reporting of GHG emissions. There was a wide range of conditions and results in different studies therefore this graph is indicative.

Figure 12

Methane (CH_4) and Nitrous oxide (N_2O) emissions from different biowaste processing methods



You can see from the above graph that processing with BSFL produces significantly less GHGs that other composting methods, particularly hot composting, and that it produces 120 times less GHGs than static composting of cow manure, which is what happens to most of the DM solids.

Although I did not include the CO^2 in the above graph, so that I could be consistent with the IPCC standard due to its biogenic nature, I still think it is worth considering the carbon sequestration potential of processing with BSFL because the climate does not differentiate between biogenic and anthropogenic CO^2. Perednia et al. (2017) quantified the potential amounts of CO^2 that could be sequestered by processing with BSFL as follows:

> If one were to take the 31.7 million tonnes of un-recycled food waste produced annually in the U.S. and use BSFL to recycle it, the insects would sequester 1.98 million tonnes of CO^2 that would otherwise be released into the atmosphere, while producing about 2.28 million tonnes of valuable BSFL dry matter (p. 7)

If one were also to consider the potential carbon sequestration by processing other biowaste streams with BSFL then that would be a significant reduction in GHGs.

2.6 Summary

In this chapter I looked at the literature, on the theory of TDR as it relates to this project, and on the context of the problem, and found it to be an appropriate approach. I touched on my previous work on establishing an enterprise, and explored the literature on BSFL, their uses and potential as a business opportunity, and the benefits of using BSFL to process biowaste. This shows that it has great potential, both economically and environmentally, although the technology still needs to be improved to be fully reliable in a temperate climate. In Chapter 3 I will discuss the approach, methodology and methods I chose to gather and analyse my primary data, with the reasons for my choices.

Chapter 3 Research design and methods

In this chapter I cover the research paradigm and how it has led to the methods used to gather and analyse the data that informs this thesis. I discuss why the overarching theoretical approach/paradigm is transdisciplinary research (TDR) and why pragmatic action research (PAR) was chosen for the methodology. I introduce a wide range of methods and instruments that have been used for different aspects of this research, including literature review, pilot interviews, surveys, follow up interviews and a case study to gather data, and systems analysis and thematic analysis to analyse the data. I also examine why and/or if these approaches were suitable for the purpose.

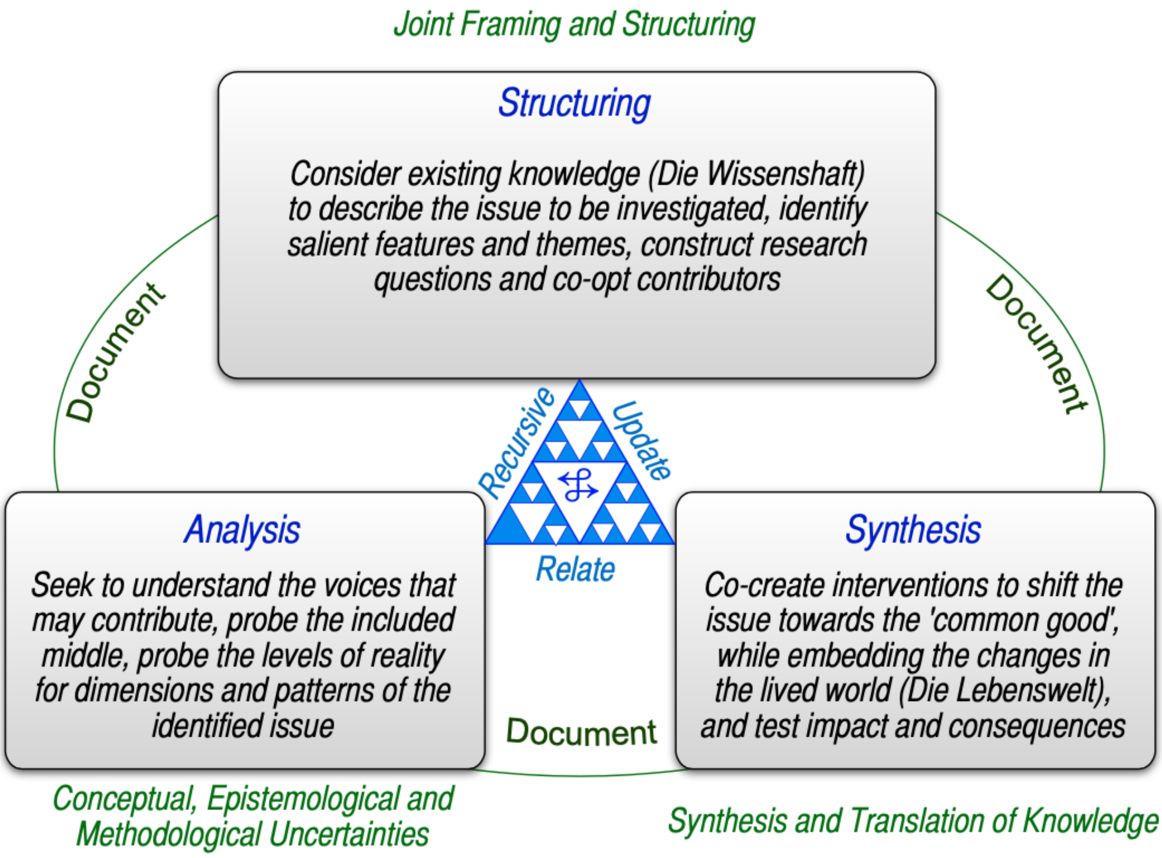
3.1 Research design

This research was designed based on the need to both investigate a wicked problem, and work towards a resolution that could be implemented through an enterprise. The idea of using black soldier fly larvae (BSFL) to process the dairy manure, (DM) was proposed prior to starting the Master of Applied Innovation, and this thesis has looked at whether the proposed idea would feasibly address the problem, and if so, how it might be implemented in a way that meets the needs of the various stakeholders. As suggested by Leavy (2016) I considered things such as whose perspectives, and what aspects, were being left out of the design; what I might be missing; which disciplinary knowledge I should bring in; and whether I had considered relevant cultural and disciplinary perspectives. This approach is also congruent with Ken Wilber's integral theory, which gives a useful framework to ensure we cover the different aspects of the topic (Esbjörn-Hargens, 2009). Pollution in waterways is a significant effect of surplus nutrients in the wrong place, which is an important aspect of this wicked problem. I also revisited Leavy's above questions, and the integral theory diagram, during data collection.

The complex nature of the problem required that it be inspected from multiple perspectives, to gain a comprehensive overview of what is happening. Data from these multiple sources needed to be analysed to help inform an innovative resolution. I considered that as the research progressed it might raise questions that required different approaches to access more data, or analyse the existing data, and accordingly, planned for an iterative, recursive, process, adapting to the findings and needs of the moment, as suggested by Roodt (2020) see Figure 13.

Figure 13

Transdisciplinary Research as a Recursive Process



Note. From "Transdisciplinary Research Process 2020," by H. Roodt, *ResearchGate*, 2020. (https://www.researchgate.net/publication/341894177_Transdisciplinary_Research_Process_2020). CC license, CC BY-SA 4.0.

I also considered my research paradigm, and how the ontology and epistemology behind this research led to the research design (see table 3). The last row shows why the ontology and epistemology chosen, suit the problem and the proposed innovation, and the strategy and instruments that were used to conduct the research.

Table 3

Chosen research paradigm

Paradigm	Ontology	Epistemology	Methodology	Methods	Instruments	Sources
How are we looking at this?	What is reality?	What and how can I know reality/knowledge?	What approach can we use to get knowledge?	What procedure can we use to acquire knowledge?	What tools can we use to acquire knowledge?	What data can we collect?
Pragmatism	Reality is constantly renegotiated, debated, interpreted, in light of its usefulness in new, unpredictable situations	The best method is the one that solves problems. Finding out is the means, change is the underlying aim	Transdisciplinary research, Pragmatism, Research through design (to a lesser extent, so far)	Pragmatic action research Mixed methods, Design based research (more in the next steps) plus potential to develop new methods	Combinations of qualitative and quantitative methods from many disciplines	Whatever and whoever will help define and solve the problem + my own experience
What this approach means for this thesis	I chose this ontology because the issue of surplus nutrients is complex, with multiple stakeholders and often widely differing points of view	The above epistemology is suitable because this problem requires an action based approach that works towards addressing it	TDR, Pragmatic action research, Design research (mostly as a next step after the masters is complete)	Quantitative research Qualitative research	Survey and Literature review Survey; Interviews; conversations; case study; System thinking and modelling; Thematic analysis; Science; Prototyping	Literature, Dairy farmers and farming organisations, Government scientists, BSFL farmers, observation

Note. Adapted from "The research paradigm: Methodology, epistemology and ontology – explained in simple language," 2015, S. Patel. (https://salmapatel.co.uk/academia/the-research-paradigm-methodology-epistemology-and-ontology-explained-in-simple-language/). Originally adapted from Hay (2002, p.64) and Crotty (1998).

3.2 A transdisciplinary approach

> "Include things, don't leave them out, look at things in their context, include everything. (Pullman, 2019, Ch. 23)

In the literature review I looked at the theory behind TDR, which provides useful principles for the practice, which I will discuss here. In this research I have used a transdisciplinary approach, because of it being a wicked problem (Lawrence et al., 2022), there being a variety of, often contradictory, world views (Zuber-Skerritt, 2001), and the aim of serving the common good (McGregor, 2011; Nicolescu, 2010). Looking at this issue through a single disciplinary lens would give an incomplete view which might be taken to be the truth (Montuori, 2013). For instance, A reductionist scientific lens might view dairy farm waste systems as successful based on their ability to make water cleaner or capture manure. However, the reductionist approach overlooks other important perspectives, such as the economic view, that considers the high cost of these systems and the resulting pressure on farmers to generate more income, or the psychological view, that recognizes the potential stress this issue poses for farmers. Shrivastava et al. (2022) state "When problem solvers focus on one dimension of the problem at hand and develop one-sided, partial solutions, it is likely that they destroy the healthy functioning of the whole system or seriously damage it" (p. 2). A transdisciplinary approach has allowed for a more holistic view of this problem.

The way I have conducted this research fits with Montuori's (2013) four main dimensions of Transdisciplinarity (see table 4).

Table 4

How this thesis fits with Montuori's dimensions of transdisciplinarity

Montuori's four main dimensions of Transdisciplinarity	How my research fits with the dimensions
"Inquiry-based rather than discipline-based	Multiple methods and sources, to investigate the issue. The inquiry has led to the methods.
integrating rather than eliminating the inquirer from the inquiry	Making known my influences, underlying assumptions and how I came to my insights.
meta-paradigmatic rather than intra-paradigmatic	A wide range of approaches used from positivist scientific to qualitative, drawing on systems dynamics with thematic analysis to combine data from different sources and analyse it.
applying systems and complex thought rather than reductive/disjunctive thinking" (Montuori, 2013, p. 46).	Use of system thinking to analyse the issue.

TDR has been defined in many ways, so for this inquiry I will use Jahn et al (2012), who defined transdisciplinarity as a ''critical and self-reflexive research approach that relates societal with scientific problems; it produces new knowledge by integrating different scientific and extra-scientific insights; its aim is to contribute to both societal and scientific progress'' (as cited in Popa et al., 2015, p. 46). Reflexivity is the ongoing process of critically evaluating where the research is coming from, in terms of values and epistemology, and what is being done, with methods being adjusted if the evaluation shows it to be necessary, both at the individual research level and at the institutional/organisational level (Harrison & Roodt, 2022). From my perspective, I think this means stating, and staying aware of, my position and values, as recommended by Zuber-Skerritt (2001) and considering where other stakeholders are coming from; adjusting my methods if they are not working for stakeholders or are not providing the data needed to inform a solution and feeding back what I have learned to the organisations and individuals who have contributed.

Popa et al. (2015) state that there is a "need to combine conventional consensus-oriented deliberative approaches to reflexivity with more open-ended, action-oriented transformative approaches" (p.45). In table 5, I show their four transdisciplinary approaches and how I have used aspects of them in this thesis, and will continue to use them in the ongoing project.

Table 5

How the four types of transdisciplinarity have been used in this study

	Descriptive-analytical	How used in this study	Transformational	How used in this study
Epistemic	Complex systems approach *"modelling of complex sustainability problems"*	• Literature on BSFL • Statistics about the problem of surplus nutrients • Systems diagrams • System archetype diagrams • Anylogic computer based system model of a BSFL bioreactor based on a dairy farm	Technocratic transition management *"scientific and technical knowledge are seen as the core element in informing and guiding policy making and social action"*	As in the complex systems approach + • Scenarios • Recommendations for action to transform the dairy farm waste system to a BSFL based bioreactor
Social	Extended peer community *"integrating scientific and extra-scientific expertise from the relevant stakeholder communities and linking scientific problems with societal problems"*	As above + sourcing qualitative and quantitative data from • Dairy farmers • BSFL entrepreneurs • Worm farmers • Environmentalists •	Critical-transformational *"emphasizes the need to couple the public debate on values and objectives with a critical inquiry into the intellectual and value commitments of the dominant scientific discourse, and on the institutional and power structures supporting it"*	• Considering the values and objectives of all stakeholders to inform the scenarios and recommendations • Respecting Maori worldview as treaty partners • Collaborative development of the idea (in the next steps)

Note. Adapted from "A pragmatist approach to transdisciplinarity in sustainability research: From complex systems theory to reflexive science," F. Popa, M. Guillermin, T. Dedeurwaerdere, 2015, *Futures*, p.50, (DOI 10.1016/j.futures.2014.02.002). Adapted with permission.

Initially, I intended to be further along with the critical transformation as described in table 5, yet, the limitations of time on this study, and the delay in progress with the chosen solution space have meant that this aspect, of jointly creating the change with stakeholders, will be carried out after this thesis is completed. I think this collaboration will be essential in implementing a solution, as research has shown that many scientific advances are not implemented due to a lack of stakeholder buy in (Rieple & Snijders, 2018). Their findings back up an insight from my initial conversations with dairy farmers, that they do not like being told what to do by people who do not understand their context. This will have implications in the next steps where I will work on establishing a collaborative group to continue developing the idea of using BSFL to process biowaste. There will need to be a non-hierarchical structure, where participants work on their chosen aspect of the project and are equally valued and contribute "equally but differently" (p.11) to solving the problem (Zuber-Skerritt, 2001). My choice to use a less academic writing style comes in part from a value of inclusion, which fits with the transdisciplinary ideals discussed above. As a teacher, I experienced how some methods of presenting knowledge act as a barrier to understanding, and also as a barrier to connection and trust between the writer and the audience. With this in mind I have deliberately kept my writing style less formal and more authentically my own.

3.3 Methodology - Pragmatic Action Research (PAR)

> "Pragmatism, when regarded as an alternative paradigm, sidesteps the contentious issues of truth and reality, accepts, philosophically, that there are singular and multiple realities that are open to empirical inquiry and orients itself toward solving practical problems in the "real world" (Feilzer, 2010, p. 3).

The issue of surplus nutrients is a 'real world' issue and with this thesis I aim to inform a practical resolution. Traditionally action research is used by practitioners to improve their practice and influence others' practice, whilst working on a real world problem; it does not generally include quantitative research (McNiff & Whitehead, 2006; Zuber-Skerritt, 2001). For this thesis I considered that some quantitative research would be essential, to create a fuller picture of the problem, provide the necessary detail to make the computer model as accurate as possible and to inform the technical aspects of creating a BSFL bioreactor, along with qualitative research to look at the psycho-social aspects affecting the problem, and adoption of potential solutions. PAR is a form of action research that allows for the multiple and mixed methods that I used in this research (Feilzer, 2010). Mixed methods research is where qualitative and quantitative data are collected and analysed to get different aspects of the topic, and to triangulate data on the same aspect from the different methods, to validate or help interpret it (Leavy, 2016; Roulston, 2010; Wurtz, n.d.). I used mixed methods through most aspects of the data collection and analysis.

As with more recent iterations of TDR, reflection and reflexivity are key processes of PAR (Greenwood, 2007; Lawrence et al., 2022). The pragmatic methodology has allowed for changes to be made to the methods in response to researcher insight, for example, where I decided to use systems analysis, or as negotiated by stakeholders, for example, the choice of face-to-face interviews, which fits with the collaborative nature and ethics of TDR. It also has the benefit of being able to work with multiple different agendas (Greenwood, 2007).

Using the wide variety of methods and tools has allowed me to explore the problem from multiple angles and levels. The biggest insights have come from informal conversations and from using methods that were not in my original plan but seemed intuitively to be appropriate. PAR has allowed for this flexibility, and I think I would have a lesser understanding of the problem had I stuck to one or two methods.

3.4 Ethics and Treaty adherence

I completed, and had accepted, a low-risk human ethics application, to comply with Wintec's institutional ethics policies (see appendix F). I considered the farmers, and other people I would interview to be low risk as they were all adults. On the other hand, I did keep in mind the controversial nature of the topic of pollution and the psycho-social pressures dairy farmers have been experiencing (DairyNZ, 2020) and ensured I carried information about mental health services, such as 'Farm Strong', for farmers, in case my questions triggered a stress response.

All farmers, and the My Noke representative, that I interviewed or surveyed formally, were given an information sheet and signed a consent form (see appendix G), copies of which are stored in password protected areas on my computer or locked in my office. I did have informal conversations with people, prior to starting the Master of Applied Innovation programme, and during the thesis. I have protected the anonymity of interviewees and respondents, using their roles and a letter instead of their names, whilst presenting and analysing the data.

I also completed an animal ethics form for my BSFL growing trials (See Ch. 4.6). I was informed that it was good practice, but I would not need it until I reached the stage of testing the BSFL as an animal feed for my ducks, because animal ethics approval is not considered necessary for insect trials. As I did not reach the stage of trialling BSFL as an animal feed, I have not included the Animal Ethics Application here.

This study fits into the context of Aotearoa, New Zealand, and as such needs to meet the terms of the Treaty of Waitangi, Te Tiriti o Waitangi, which grants dual sovereignty to the British Crown and to Māori. I acknowledge the rights of Māori as tangata whenua and will therefore seek guidance and approval, through the appropriate Māori channels for the proposed idea. As part of this process, I have joined a group studying and peer learning how to become Tangata Tiriti, i.e., to honour the Treaty of Waitangi. As a citizen of New Zealand, I am 'tau iwi', i.e., a partner in the treaty. I also attended the 4th 'Aotearoa New Zealand Sustainable Development Goals Summit Series' webinar, with the theme 'Māori, Indigenous and flax root community perspectives', to gain insights into Māori perspectives of whenua (place), kai (food), and kaitiakitanga (guardianship), and how these are affected by threats such as pollution, and lack of inclusion in decision making (Nikau, 2022; Olsen, 2022). This has helped me consider how loss of kaimoana (seafood), which can be a significant issue from nutrient pollution (Zeldis et al., 2022), affects more than just the loss of food. It also affects traditional cultural practices (mātauranga Māori), such as family collecting seafood together (Olsen, 2022). This knowledge has helped me consider the importance of reducing nutrient pollution.

I stayed aware of acting ethically whilst interviewing people, particularly because I was not able to record the interviews due to noisy environments, and sometimes not able to take detailed notes as we were walking around. I wrote up the notes as soon as possible after the interviews, and tried to stay true to the points made by the interviewees. Roulston (2010) suggests that it is acceptable to use field notes in this way.

3.5 Writing style

My practice has, to this point, mainly been based in the community, either involved in education, advocacy or governance. I have chosen to write in an accessible writing style so that I can share what I've learned with the people who have contributed to the research or who may be interested in taking it further, or taking action based on the findings. In my experience as a teacher I have found that an overly formal academic writing style can be a barrier to understanding and thus to implementation of the ideas generated by the research.

3.6 Instruments and methods of data capture

As my chosen methodology was PAR, I used a variety of instruments and methods where appropriate to the data I needed to inform my project.

3.6.1 Pilot Interviews and initial farm visits

I decided to visit three dairy farms, to conduct pilot interviews to get a more complete picture of the systems used, and how they fit into the farm context. They provided an opportunity to have less formal conversations with farmers, in order to gain some initial insights to feed into the survey questions, as suggested by Roulston (2010), and to observe the systems for myself. I asked some quantitative questions, from a written form, to gather details about the type, cost and capacity of the farms' waste systems (see Appendix E), and allowed the conversation to arise from what I was observing or being told as we walked or drove around the farm. As we were walking around in a noisy environment I took brief field notes, and wrote them up as soon as possible afterwards (Roulston, 2010). I analysed the pilot interviews using abductive reasoning to work out how the observations and findings related to theory (Feilzer, 2010), which led me to systems analysis (see Ch. 3.6.1). I used insights gained by analysing the pilot interviews to inform the questions for the survey.

3.6.2 Prototyping

I initially built a simple prototype of a BSFL tub so that I could grow the BSFL that I had purchased and build up my colony. I used a process of investigating what other people had used by conducting an internet search, and thinking about what I had available, that I could use to make the first prototype, quickly and cheaply, as suggested by Hartford (2012) and Dam and Siang (2020). I then used trial and error to see what worked for me, adapting the design as I evaluated it.

I planned to use the prototype as a container for growing the BSFL, so that I could have BSFL to use for experiments to gain some simple quantitative data about how fast and how completely BSFL can process waste, and what they can process. This data would have been compared with data from literature, (see Ch. 2.6).

I also needed a tub that I could use as part of a kit to give to dairy farmers to trial growing BSFL as a proof of the concept, to develop interest in the idea. I planned to involve the participants in the prototype development so that we could develop the idea together, gaining a sense of collective innovation, of working together to achieve something, as recommended by Rieple and Snijders (2018). I did not get to the stage of testing the prototypes with dairy farmers during this master thesis, yet, I will at a later stage of the wider project.

3.6.3 Surveys

I considered that using a survey would give me the potential to access more participants, from a wider area, than interviewing alone, and would reduce costs (Saris, 2014). I created a mixed method survey/questionnaire, using Qualtrics software (see appendix E), and included some questions to gather quantitative information about the farm waste systems, and others to gather qualitative information about farmers' interactions with them. I also included an attitudes and values question to give me insights into the respondents' worldviews. I used a combination of closed and open questions; the closed to get a quick response or one that could be analysed statistically, and the open so that respondents could expand on their responses and give reasons. Some questions were chosen to help fill any gaps in data from the literature review, when I considered that the findings might help inform this research.

When writing the questions, I considered how to avoid leading the answers, by balancing opinion questions so as to provide equal opportunities for a positive or negative response, and by using a feature of Qualtrics to randomise the order of questions where respondents were asked to choose the statements that applied to them (Saris, 2014).

When analysing the data, I considered whether the respondents' data matched findings from the literature review, as this would help to triangulate the findings, to validate them.

3.6.4 Follow up interviews

I interviewed two of the farmers who had taken the survey and had agreed for me to contact them again. These were to follow up, after analysing the survey data, to get deeper information about areas that I felt were missing, or not telling the whole story (McGrath et al., 2019). I particularly wanted to follow up a hunch from questions about farmer satisfaction with their waste systems (see Ch. 4.3). The interviews took place face-to-face at the request of the interviewees.

3.6.5 Informal conversations/interviews

I had informal conversations with representatives of five groups of people relevant to my inquiry. These were: three people involved in developing businesses around BSFL, who gave me information about their experiences to help inform my own project; three people involved in regulation such as MPI and local and central government, to find out ways of interacting with their systems and get suggestions of the support they could give; two people involved in dairy farm research, for their findings and suggested contacts; many people involved with food waste who have shared information both during this thesis and prior to this; and a representative of the Bioresource Processing Alliance, to find out about funding opportunities to support science around BSFL. I recorded the information by taking notes, either at the time if I was able to, or as soon as possible after the conversation.

3.6.6 Case study

Although case studies are not considered an action research method, I decided that case studies are useful in this situation as they could provide insights that, with suitable analysis, and comparison between the case study and the potential solution, could feed into the solution to the problem. Looking at the isomorphs, i.e. points of similarity within the different situations, could provide ideas for aspects of a solution that could be translated into the problem area we are working on, to synthesise a better solution.

3.6.7 System modelling

Modelling is a method of trying things out with less risk or cost than testing them in the real world (Borshchev & Grigoryev, n.d.). In this study computer modelling has provided a way of testing ideas that I was unable to test in the real world due to problems of getting my BSFL colony established, which limited the prototyping I could do with the dairy farmers. I needed a way to demonstrate the potential of BSFL waste processing to prospective customers. As such, the model has become an iteratively evolving outcome of this study.

Senge (1990, p. 313) uses the term 'microworlds' to describe models where time and space are compressed. He suggests their use for running experiments, to see the consequences of decisions. Models can be built to simulate existing systems, and then adapted to test innovations to the system, or used to create new systems. In the process of building the model, the system is simplified, as we decide which details are relevant to the problem we are trying to solve. There are many different types of models, from mental models; flow diagrams; spreadsheets; the CLD diagrams above; physical models, to computer simulations.

3.6.7.1 Computer modelling

I started researching computer modelling when it became apparent that I would be unable to get a colony established, to the level where I could grow sufficient BSFL to give to farmers, to prototype a simple BSFL farm. I needed a way to demonstrate the concept, and economic and environmental potential. This research has included learning the Anylogic software from the books "Anylogic in Three Days" (Grigoryev, n.d.) and "The big book of simulation modelling" (Borshchev & Grigoryev, n.d.).

Computer simulation can be particularly useful for modelling dynamic systems, which have features such as "non-linear behaviour; memory; non intuitive influences between variables; time and causal dependencies. All above combined with uncertainty and large numbers of parameters" (Borshchev & Grigoryev, n.d., p. 4). They also have the advantages of using less unwieldy calculations and are more persuasive than numbers alone.

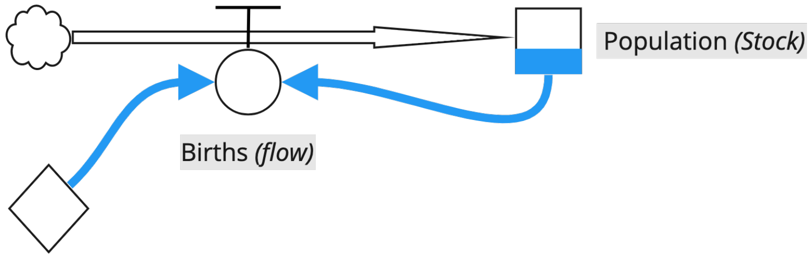
Models can be highly abstract, operating at a big picture, strategic level, to very detailed and accurate, or anywhere in between. They can start at the macro level and details can be added as they are needed or discovered.

3.6.7.2 Stock and flow diagrams

Stock and flow models are a quantitative tool of system dynamics (Connolly, 2020). They can be shown in diagrams similar to causal loop diagrams but with the addition of quantitative data. This makes them more suitable for modelling systems at a more detailed level, with more rigour and accuracy. To do this each variable needs to be given a unit of measurement (Arondson & Angelakis, n.d.) because the model generates quantified results. Stocks are the variables that can accumulate or be run down. Flows are the actions that increase or deplete the stocks. They depend on time.

Figure 14

Example of a stock and flow diagram



Note. Adapted from "Step by step stocks and flows: improving the rigour of your thinking," by D. Arondson and D. Angelakis, n.d.(https://thesystemsthinker.com/step-by-step-stocks-and-flows-improving-the-rigor-of-your-thinking/). Copyright n.d. by Daniel Arondson and Daniel Angelakis. Permission requested.

Computer based modelling can allow for more complex stock and flow diagrams with variable parameters. These show the rates of change of the various elements of the system, and measure the variables. A 'digital twin' is an advanced type of model that uses real time data. It is used to help with decision making.

3.6.8 Additional data needs and capture approach

I decided not to discount other means of data collection that offered insights into this thesis. These included observation of farm waste systems, and other biowaste processing systems, that gave me an opportunity to compare systems, and learn from them. Informal conversations with stakeholders gave insights that might not have come out in formal settings (Roulston, 2010), and serendipitous insights from unexpected or unknown sources, which helped with understanding situations that occurred. Personal discussions with academic supervisors, industry mentors and other academic or stakeholder sources helped to get the big picture, and suggest resources and opportunities.

3.7 Methods and instruments of data analysis

3.7.1 Systems thinking, system dynamics and system archetypes

> "A system is a set of things – people, cells, molecules or whatever – interconnected in such a way that they produce their own pattern of

behaviour over time" (Meadows, 2008, as cited in Connolly, 2020, p. 6).

I initially used basic system diagrams as a way of recording observations made whilst looking at the waste systems in the context of the farm. I then investigated the conventions for system diagrams, to formalise my sketches. I started researching systems dynamics after a conversation with a dairy farmer, during a tour of their waste system, gave me a hunch about why the increasing legislation on dairy farm waste systems might be having unintended consequences that were preventing the legislation from working. Justin Connelly of Deliberate, a collaborative research consultancy, ran a workshop at the Design Factory as an introduction to systems thinking (Connolly, 2020), and kindly offered to have a further conversation about it, and to check my system thinking. Dr Henk Roodt, my academic supervisor, shared his experience of system modelling, and introduced me to the modelling software, AnyLogic. Clemens Dempers has assisted with the Anylogic modelling approach (https://cloud.anylogic.com/model/bb5ce616-61f0-4503-adaa-d6d751595cf7?mode=SETTINGS).

Systems thinking became a valuable tool for investigating why the system did not appear to be working, and the literature on system archetypes provided parallels that would inform my thinking.

Systems dynamics evolved from the concept of industrial dynamics, a methodology proposed by Forrester to investigate strategic issues and inform policy in organisations. In the 1960s, Forrester researched how feedback loops influenced the dynamics of industrial systems, and later, urban, and socio-ecological systems. Unlike control engineering, which inspired system dynamics, he also factored in soft variables such as beliefs or morale, if they influenced the system (Dangerfield, 2014).

Systems thinking uses diagrams to help map and analyse systems, to see what within the system structure influences the behaviour of the system over time. Systems thinking, and system dynamics, use both qualitative and quantitative data. The concept of system thinking contributed to the idea of TDR (Nicolescu, 2010).

3.7.2 Causal loop diagrams

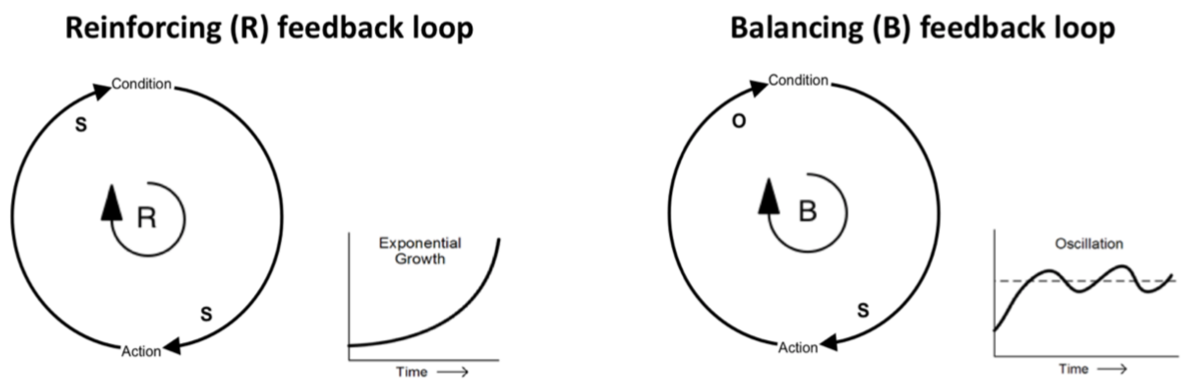
Causal Loop Diagrams (CLD) are an important qualitative tool of systems dynamics. They are often used to show the system at a high level. These have been included in this review as they were used as part of the analysis of the findings from my first pilot interview. CLDs use the concept of feedback, a core construct of system dynamics (Connolly, 2020). There are two types of feedback:

1. Reinforcing, which causes things to grow or accelerate in either virtuous or vicious cycles.
2. Balancing, where the system is creating stability. These can also be positive, if stability is the goal, or negative, if the system is resisting a needed change.

Delays are also represented in causal loop diagrams because time gaps between actions and consequences make the system hard to read (Senge, 1990). Figure 15 shows the two types of feedback loops as causal loop diagrams, with the behaviour over time sketch graphs they create. The oscillation in the graph of the balancing feedback loop is caused by delays in the system.

Figure 15

The basic building blocks of a system diagram



Note. From "Thinking in systems: An introduction to systems thinking using system dynamics," by J. Connolly, 2020, figure 7. Copyright 2020 by Justin Connolly. Reprinted with permission.

3.7.3 Systems archetypes

Senge (1990) took CLD diagrams further by looking at the patterns that occur in systems. He uses systems archetypes for the most common patterns. He states, "The purpose of the systems archetypes is to recondition our perceptions so as to be more able to see structures at play and to see the leverage in those structures" (p. 95). About twelve systems archetypes have been identified: two of the most common and relevant to my research being:

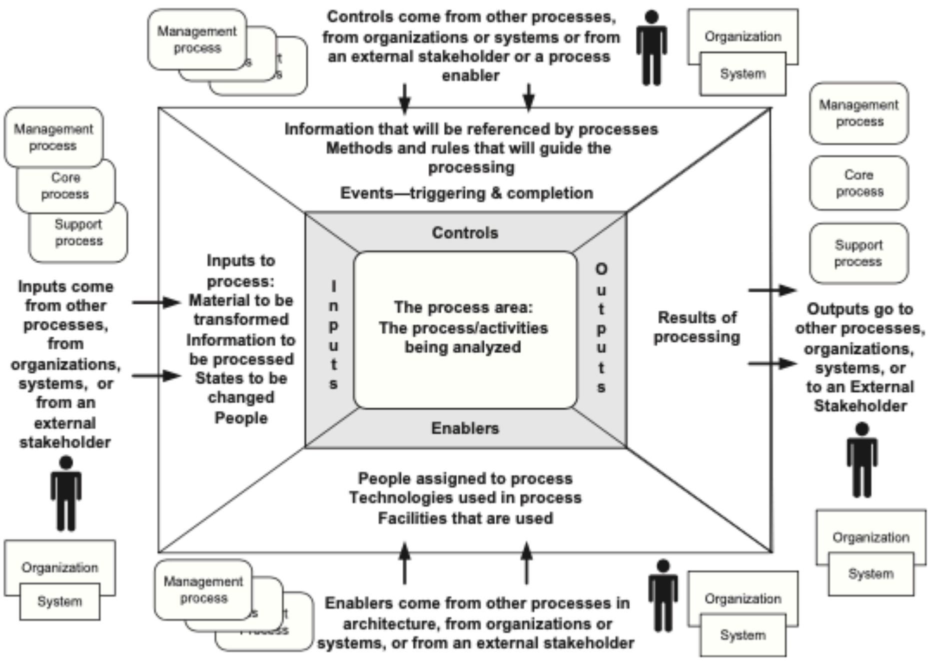
- "Limits to growth" (p. 95) – A spiral of growth creates unintended side effects that slow down the growth.
- "Shifting the burden" (p. 104) – An underlying problem creates obvious symptoms. The underlying problem is challenging to solve so people find an easy, short-term solution to the symptom, but not the underlying cause, which continues to worsen the problem.

3.7.4 Process modeling and analysis

Process modelling is a tool for investigating process problems. In this study I used this tool as a planning guide for scenario 1, to avoid problems initially or in the future. Many of the process modelling tools are presented as specific to certain industries such as software engineering, Whereas, Harmon (2014) process scoping diagram seems more flexible to a variety of processes. He states that "a process scoping diagram helps you analyse the relationship between a given process and its environment" (195). The diagram can also be used to show problems in any of the four sectors: inputs; outputs; controls; or enablers, and these problems can be further defined, solutions suggested, and scope adjusted if necessary.

Figure 16

Elements of a process scoping diagram



Note. The small figures represent people, rectangles represent organisations or systems and rectangles with rounded corners represent processes. Figure from P. Harmon, 2014, Business process change: A guide for business managers and bpm and six sigma professionals. Elsevier Science & Technology, p. 196, Figure 8.11. Copyright 2014 by Paul Harmon. Reprinted with permission.

3.7.5 Thematic analysis (TA)

Thematic analysis is an instrument that is generally used in qualitative research (Braun & Clarke, 2019). In this thesis I use it to analyse qualitative data from eight different groups of sources about dairy farm waste systems and how farmers interact with them. I have chosen a reflexive TA style because PAR is a reflexive methodology, and I wanted the flexibility to use the instrument as seemed most appropriate at the time and iteratively adapt themes as I explored them. Braun and Clarke (2019) state "reflexive TA procedures reflect the values of a qualitative paradigm, centring researcher subjectivity, organic and recursive coding processes, and the importance of deep reflection on, and engagement with, data" (p. 10).

In TA data from many sources is collated around themes that are generated by the researcher as the data is thoughtfully analysed (Braun & Clarke, 2019). Using TA gave me the opportunity to "swim in the data", as suggested by M. Moore (personal communication, June 23, 2022) as a way of adding rigour to my analysis, by getting to know the data well so that I did not miss themes due to subconscious confirmation bias.

Reflection My natural analysis process is very intuitive, with a lot of the data processing happening in my subconscious and coming out as intuition and insights. Heisenberg (1942) considered this a legitimate way of gathering the knowledge from between levels, stating "Only an intuitive thinking, could bridge the abyss between old and new concepts" (as cited in Nicolescu, 2010). This subconscious process makes it difficult, Nicolescu (2010) would say impossible, to prove where insights have come from. For me the T A is an attempt to add more evidence to my insights, to gain academic validity for them.

Although TA is considered a qualitative method; when presenting I displayed the qualitative data along side the quantitative data in themes, to see where they reinforced or contradicted each other.

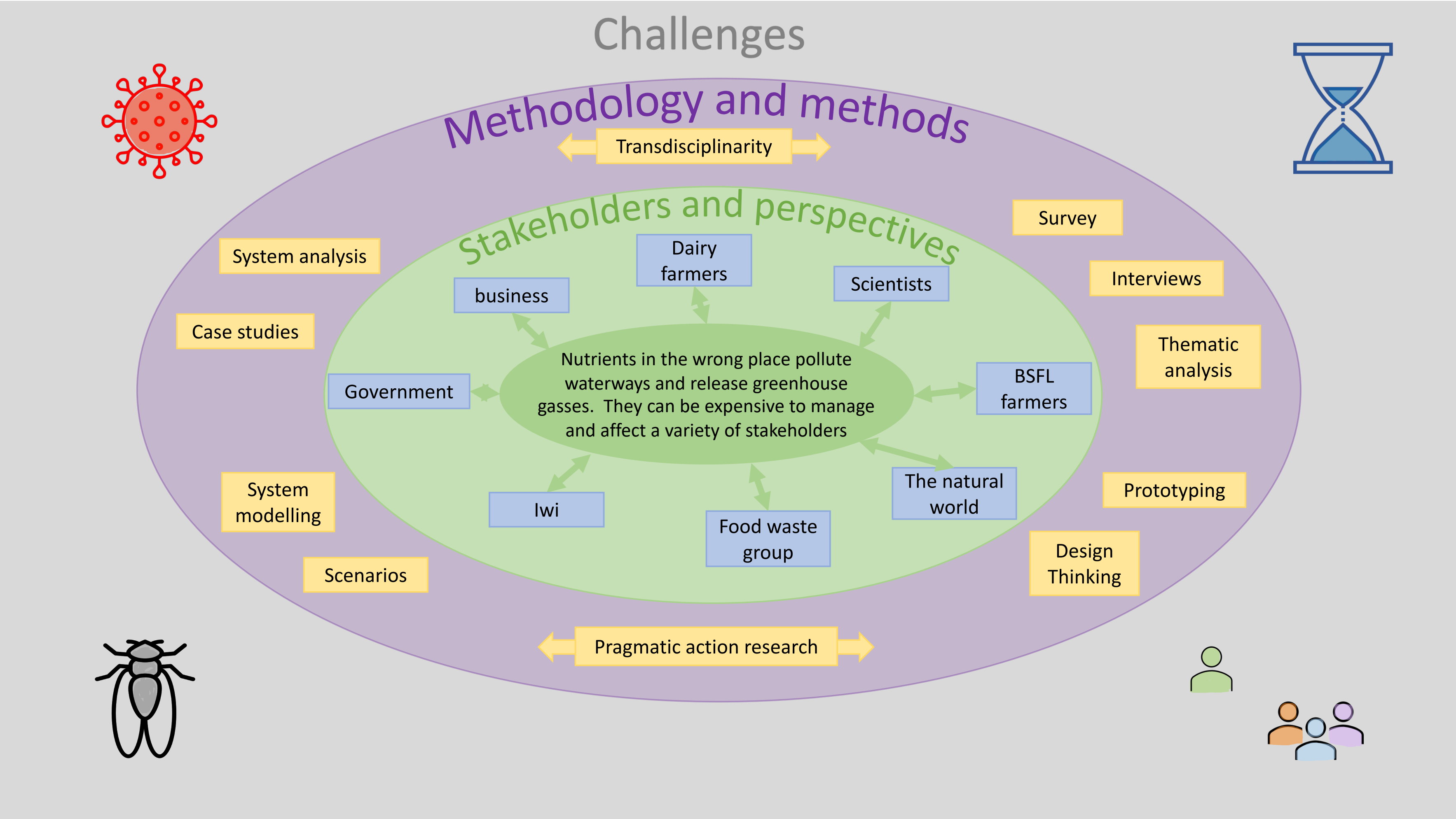
3.7.6 Summary

In this chapter I have discussed the research design, TDR approach, PAR methodology and methods and tools I used to collect and analyse data for this thesis. Figure 17 shows how the methodology and methods sit within the context of the problem, and the situation within which the research was carried out.

In the next chapter I will explain what I did to collect data, and the findings gained. I will describe how I analysed the data using the various methods and tools above.

Figure 17

How the methodology sits within the context of the problem



Note. Slide taken from a presentation I gave at the Sustainable Futures Symposium at Wintec, Te Pukenga (2022)

Chapter 4 Data collection, analysis and synthesis

In this chapter I report on my data collection, and the findings of the primary data, acquired following a typical pragmatic transdisciplinary approach in which I gathered data from various sources in an exploratory fashion. I used a recursive process of reframing, analysis and synthesis, in which insights from data led me to refer to previous findings. As my literature review progressed, I wanted to test some of my understanding in the real world and felt that visiting some dairy farms and interviewing farmers would be a logical place to start. I wished to interview the farmers to see how their perception of the waste system and nutrient issues matched the quantitative data in the literature. The pilot visits gave me insights to how the waste systems worked in context of the farms, and the conversations with farmers helped inform the survey questions, and gave me unexpected insights into why the current waste systems are not solving the problem of nutrient pollution. This led me to use systems analysis to delve deeper into these insights.

At this point I had also started setting up for growing a BSFL colony. The combination of COVID lockdowns, and problems in the colony I was purchasing the BSFL from, meant that I was unable to get my colony established in time to carry out the more practical experiments on growing BSFL, and I was also unable to visit farms. I started computer modelling a BSFL system based on a dairy farm to make use of the time in lockdown. This gave me a way to run experiments, and make projections using data from the BSFL literature, which I revisited. I continue to update this model as I gain new understandings of data and improve my model programming skills.

I ran a survey to get a larger data sample about factors of waste systems that might influence the design of an alternative system, and see if there were consistencies in how farmers felt about their systems. Farmers reported surprisingly high levels of satisfaction with their systems and, while analysing the data, I had an intuition that I needed to find out more about this as it did not match with the insights from the pilot interview.

I conducted follow up interviews with two of the survey respondents in which I learned more about what motivates the farmers, and how they feel about their waste systems on the level of regulation, and think about the systems' effectiveness at solving the issues of nutrient pollution.

The wide range of approaches used have contributed to the various data needed to inform the setting up of the BSFL enterprise, and prepared me for the co-creative phase I intend to follow in my practice after this study. I illustrate how the data were analysed, and then synthesised to make sense of them, in a way that would contribute to the development of an innovative outcome.

4.1 The pilot interviews and farm visits

> "Small changes can produce big results – but the areas of highest leverage are often the least obvious" (Senge, 1990, p. 63)

The initial plan for the pilot interviews was for farmers to show me around their waste systems so that I could understand the different systems better, and see how they fit into the context of the farm, with the aim that this might provide insights into possible leverage points in the system. I experienced difficulties with this as it was hard to be on site when a suitable person was there, and COVID lockdowns, and bereavements, combined with the times I would be in the area, also made this difficult.

4.1.1 Visit to a farm with a weeping wall effluent system

I visited a large dairy farm with a very large weeping wall effluent system, which had the capacity to store the DM for up to two years. The person I was supposed to meet was not onsite, so I checked, and was allowed to look at the system unaccompanied, and take photographs to ensure my memory was accurate. This had the advantage of giving me time to think through the system without being distracted. Unfortunately, I have yet to manage to get more specific information such as the capacity and cost of the system, or the levels of satisfaction with it.

I used the observations and photographs to feed into a simple diagram (see Figure 18), and included pictures, and photographs to make it easy to see the specific infrastructure, as this would be useful for considering if it might be amended to farm BSFL.

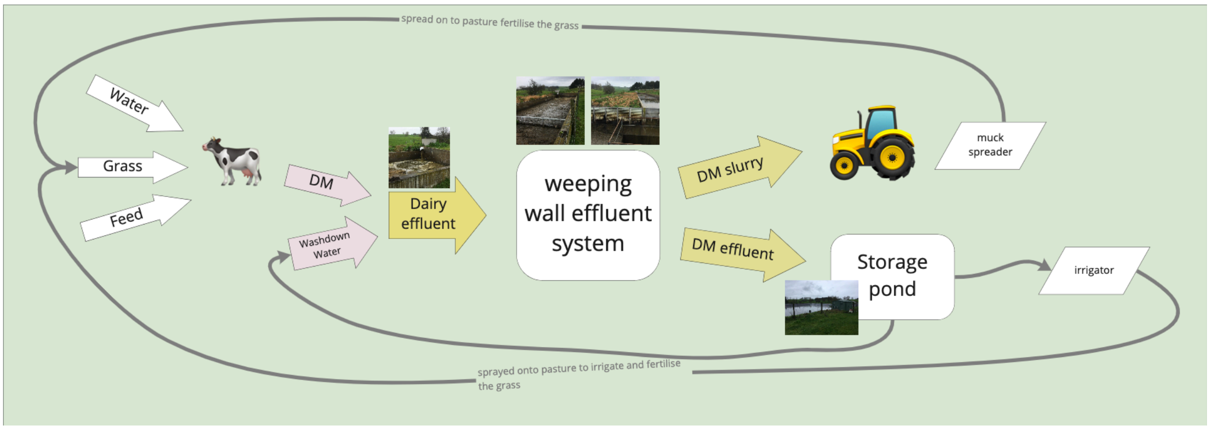
4.1.1.1 Results of the visit

My observations show that there is already a circular economy within the dairy farm, as shown by the effluent being returned to the pasture via the irrigator, and DM being spread with a muck spreader.

Figure 18 shows a simple diagram of the weeping wall DM separation and storage system on a large dairy farm.

Figure 18

Weeping wall effluent system



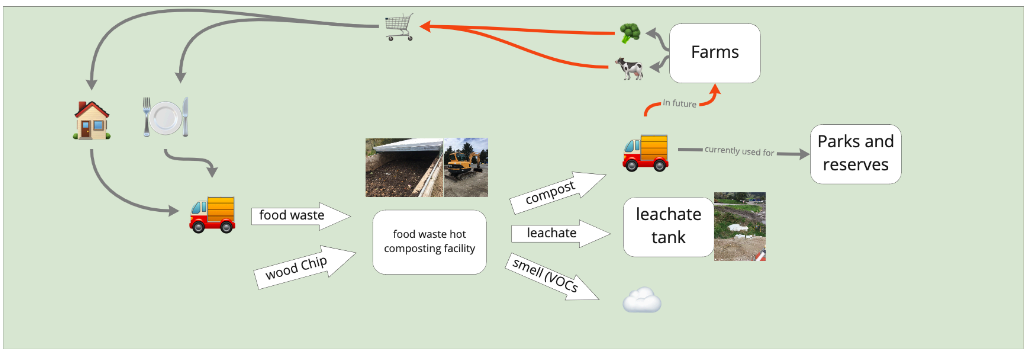
Note. The effluent system filters most of the DM from the liquid effluent using a mesh screen, then a weeping wall, which is a series of closely placed slats. The system is divided into two halves which are used turn-about, with one half used for storing and further drying the effluent prior to spreading it on the paddocks with a muck spreader. I have used photographs in this diagram as they illustrate the similarities more easily than a standard system diagram.

Serendipitously, I also happened to visit a food waste composting facility, in my capacity as a member of the TFWRG, and could see the similarities with the systems, although they are used quite differently. The infrastructure in this domestic food waste, hot composting facility has many similarities to the effluent system in Figure 18, although they are used differently. The trough in

Figure 19 is used for hot composting, a much faster process than the slow piling and long-term storage in the trough in Figure 18.

Figure 19

Domestic food waste composting facility



Note. Domestic food waste from the kerbside collection, and woodchip, is spread in the concrete trough using a digger, and turned to generate a hot compost, which is currently used in council parks and reserves.

4.1.1.2 Analysis of the system

When looking at the food waste composting system, I mentally compared it to the weeping wall and concrete trough dairy effluent system, and had the insight that they were very similar systems, and that there might be some potential to make more use of the large and expensive infrastructure in the dairy effluent system. Figure 20 shows a direct comparison between parts of the two systems. I drew Figure 21 as part of a process of validating this insight and envisioning the details that would need to be changed to make it work.

Later consideration of the issues of growing BSFL in a temperate climate (see Ch. 2.6.2) lead me to believe that this would be challenging to overlay on the existing infrastructure. Nethertheless, I do not think it would require many changes to overlay worm farming or, with the addition of a roof like the one in

Figure 19, hot composting. Having since investigated the greenhouse gas emissions from different composting systems I would probably reject hot composting. Other waste streams, such as food waste, could be added to these alternative systems, with the following benefits:

- Increasing the use of the infrastructure.
- Generating another income stream from taking food waste.
- Reducing the costs of making an alternative system for the other waste streams.
- Bringing extra nutrients to the farm that can be added to the soil to replace those removed in the milk.
- Having the potential so sell some of the processed waste as fertiliser.
- Many of the barriers that make setting up new waste processing systems will have already been overcome by the dairy farm effluent system, such as:
    - Being far enough from residences to reduce the issues of smell.
    - Having a water treatment system in place to prevent discharge to ground water.
    - Thus, meeting the legislation around discharge to air and groundwater.

In Figure 20 I compare the weeping wall DM separation system I saw on the first pilot visit, with the Ruapehu District Council's food waste hot composting system. There are many similarities between the two systems.

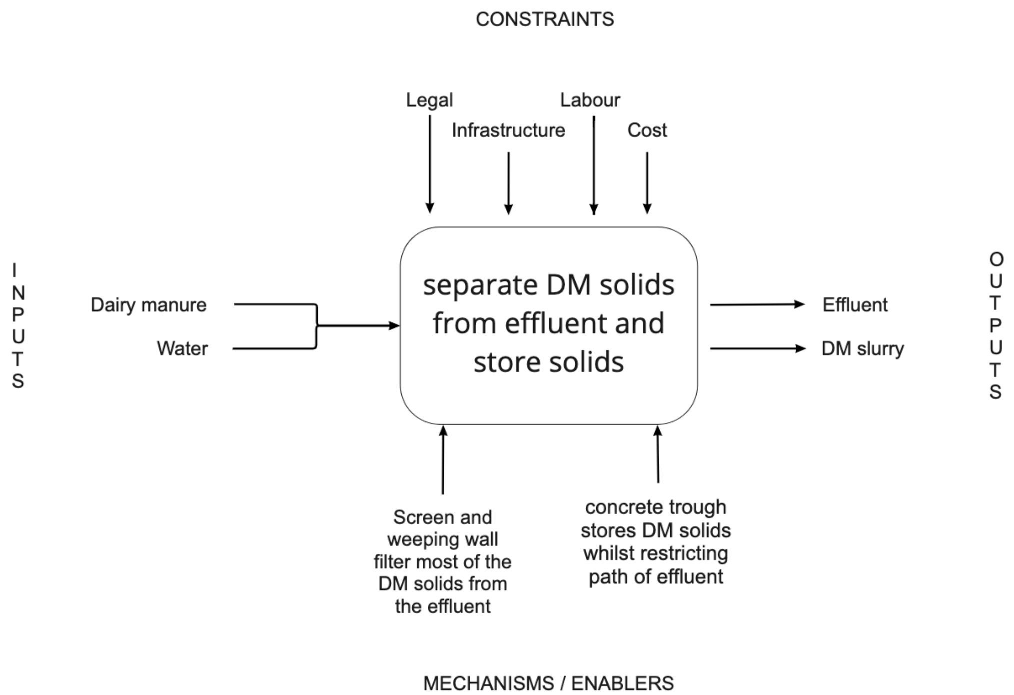
Figure 20

Comparison of the infrastructure of the 2 systems

I also drew a process scoping diagram of the dairy farm waste system, to show how the process sits inside the wider system (Figure 21). This initial diagram is based on the information I gained from my visit to the site, and some thought about what the constraints might be. This was later followed up with a more detailed analysis of the process with data from my varied data sources, as they were collected.

Figure 21

Simple process scoping diagram of the weeping wall effluent system



Note. Diagram based on the IDEFO box and arrow function modelling graphics (IDEF, n.d., Figure 1)

4.1.2 Visit to a dairy farm with a range of systems for collecting waste

I visited a dairy farm on the Hauraki Plains which had Four DM and effluent collection systems. I was shown around the site by farmer A, a female dairy farm owner. I asked questions about how the system worked, and gave the farmer a questionnaire to fill in to get some quantitative data, including the number of cows, and the type and costs of the waste systems (see appendix E). We also conversed informally as we travelled around the site.

Effluent from the milking shed washdown was collected in sumps, where the liquid drained out and was pumped to a lined effluent pond. The Largest sump had a vibrating screen at one end that was supposed to filter out the liquid, but I was told it did not work, resulting in the sump having to be emptied much more often than it should. The farm was on flat land so a gravity fed system would not work. They also had a large feed pad with a roof. The cows were kept on the pad for 1-2 hours per day, depending on how wet the paddocks were. They were fed supplementary feed, and the manure and urine was scraped off into a concrete sump. The sumps were emptied by a contractor two or three times per year, except the large sump which was being emptied more often due to it not draining as it should.

The waste systems themselves did not offer any insights beyond those in the previous farm visit, whereas the informal conversations as we travelled around the farm provided useful information, which led to valuable insights. I was unable to record the informal conversations due to the noise of the milking shed, and was not taking notes as we were walking around, so I wrote up notes as soon as I left the farm.

4.1.2.1 Results from this visit

After getting the answers to the question about the up-front costs of the waste system, which combined was around $1,000,000 on top of the costs of the original system, I had a hunch to ask how they managed to cover the costs of their system. The answer was by increasing the size of the herd. The body language suggested the farmer was aware that this defeated the object of the improved waste systems. This is due to most of the manure and urine falling on the paddocks rather than being collected in a waste system. This validates my thought that cost is an important factor for farmers, and any change to the system would need to either reduce costs or increase income.

The farmer commented about how climate change was affecting the farm. She said that they do not get the grass growth they used to, and need to put on more fertiliser, and bring extra feed onto the farm. I think the extra cows would also have this knock-on effect, as illustrated in Figure 22.

I asked about the consent process for the waste systems, because this would also be an issue for alternative systems. She said that the engineering firms provide a generic consent, and Fonterra helps with this too.

When asked how farms that do not have these sophisticated systems, manage their waste, she said that they need more labour as systems must be emptied more frequently. As a result, these farms have lower up-front costs and higher labour costs**.** Reflecting on that, I understood that this increases ongoing costs. However, comments from family members in dairy farming might suggest that some of these labour costs are reduced to the farm owner by contracts that involve workers working long hours on fixed salaries, or sharemilkers managing the waste as part of their agreements.

I asked about how the farmer might feel about an alternative system that could involve bringing another contractor onto the farm, and she said she would be reluctant to add new processes that increase the complexity of the system.

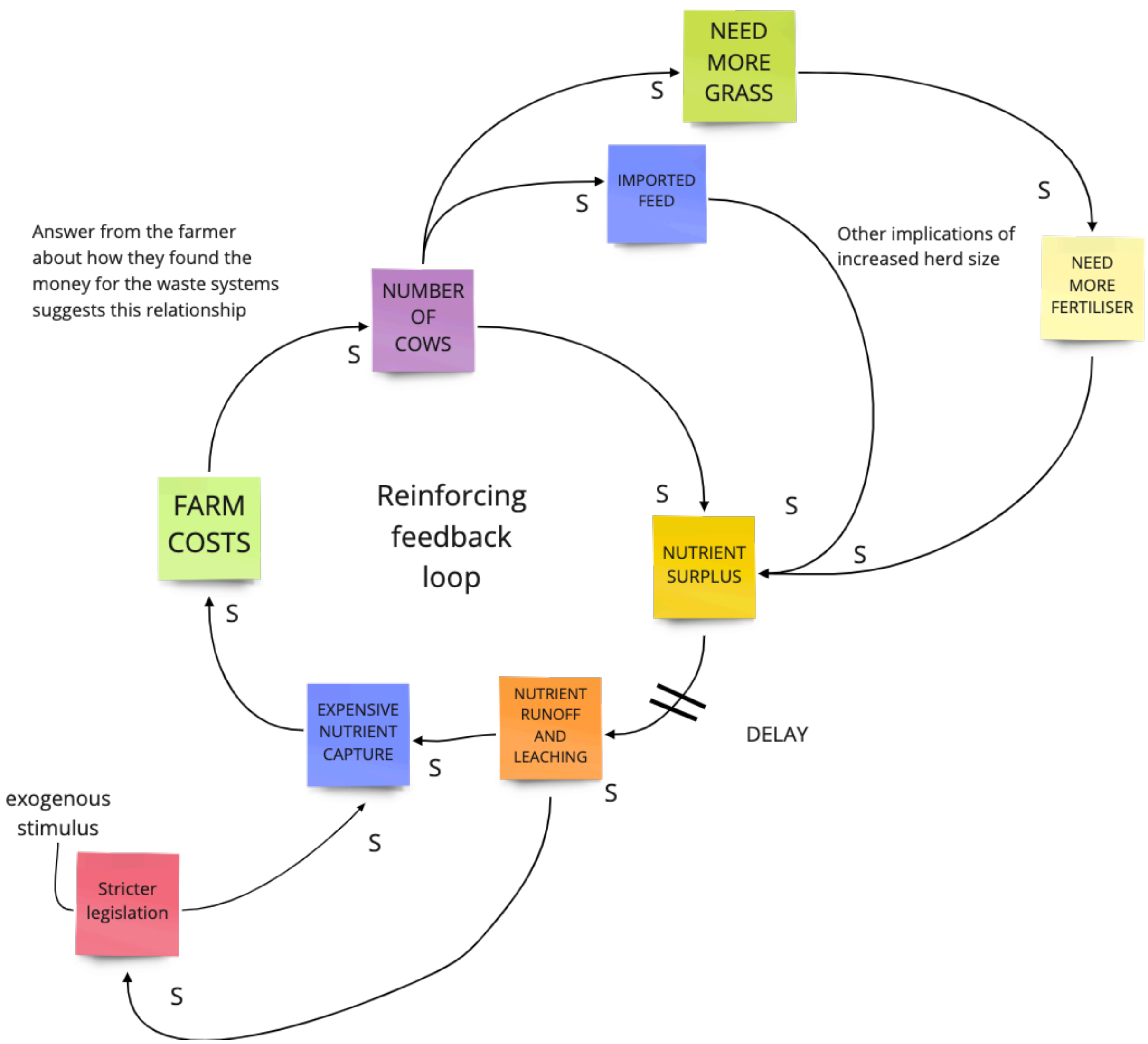
4.1.2.2 Analysis of insights from the informal conversation

The farmer's comment about how they found the money for the waste systems on the farm, by increasing the size of the herd, gave me the insight that the current regulations, driving the increased sophistication of dairy farm waste systems, are having unintended consequences that are making the problem worse. A timely workshop on systems thinking suggested this might be a way to check the validity of this insight, and explore its further implications. Pragmatic action research allows for investigating and using additional tools if they seem more appropriate than the tools being used currently (Greenwood, 2007), so I reviewed some literature about Systems Thinking (see Ch. 3.6.1)

After exploring the tools of systems thinking, I decided that a causal loop diagram (CLD) would help give insights into cause and effect in this situation (Figure 22).

Figure 22

Causal loop diagram to show relationship between higher costs and herd size.



Note. The S next to the arrowheads indicates a 'same' relationship i.e., that the impacted factor moves in the same direction as the causal factor.

Senge (1990) states that "today's problems come from yesterday's solutions" (p.57). The CLD in Figure 22 illustrates how the stricter legislation, which is a government intervention to increasing nutrient pollution from dairy farming, inadvertently causes the nutrient pollution to increase. This is because increasing the herd size has implications beyond the waste systems as they often only capture a small percentage of the waste. Rollo et al. (2017) estimated a mean of 18% waste capture, although my survey results (see Ch. 4.3.1), and my conversation with farmer A, suggests that this percentage is probably increasing. While the systems may be efficient at treating the effluent and/or storing the solids they capture until they can be spread on pastures at an appropriate time, the fact remains that most of the urine and manure will fall directly onto the pasture. This is not easy to measure on the farm. The downstream effects of this on water quality do not provide direct feedback to the farmer, because they are treated as externalities (Foote et al., 2015), and as Senge (1990) points out, people are not very good at learning from consequences they do not directly experience.

The siloed and simplified nature of classical science has meant that there is a limited focus on the bigger picture. In a conversation I had with a government scientist about this situation, I heard that many scientists are not interested in whether the system works in context if their part can be proven to work in the controlled environment of the laboratory. Senge (1990) also observed that the specialisation, and compartmentalisation of knowledge was a barrier to making systems work. This understanding is shared by Leavy (2016) and Shrivastava et al. (2022).

The above situation likely feeds into, along with other increases in farm costs, the increasing dairy cow numbers; from 3.4 million in 1990 to 6.3 million between 1990 and 2019, an increase of 84% (StatsNZ, 2021). It would also feed into increasing stocking rates which have gone from 2.62 cows/hectare in 2000 to 2.85 cows/hectare in 2016 (Longhurst et al., 2017). Stocking rates have since gone up again to 2.86 cows/hectare in 2021 (LIC & DairyNZ, 2021). The increased cow numbers, and higher stocking rates, are likely contributing to the overall worsening of the nitrate/nitrite, and total nitrogen pollution of waterways (StatsNZ, 2022), which is happening despite the stricter legislation.

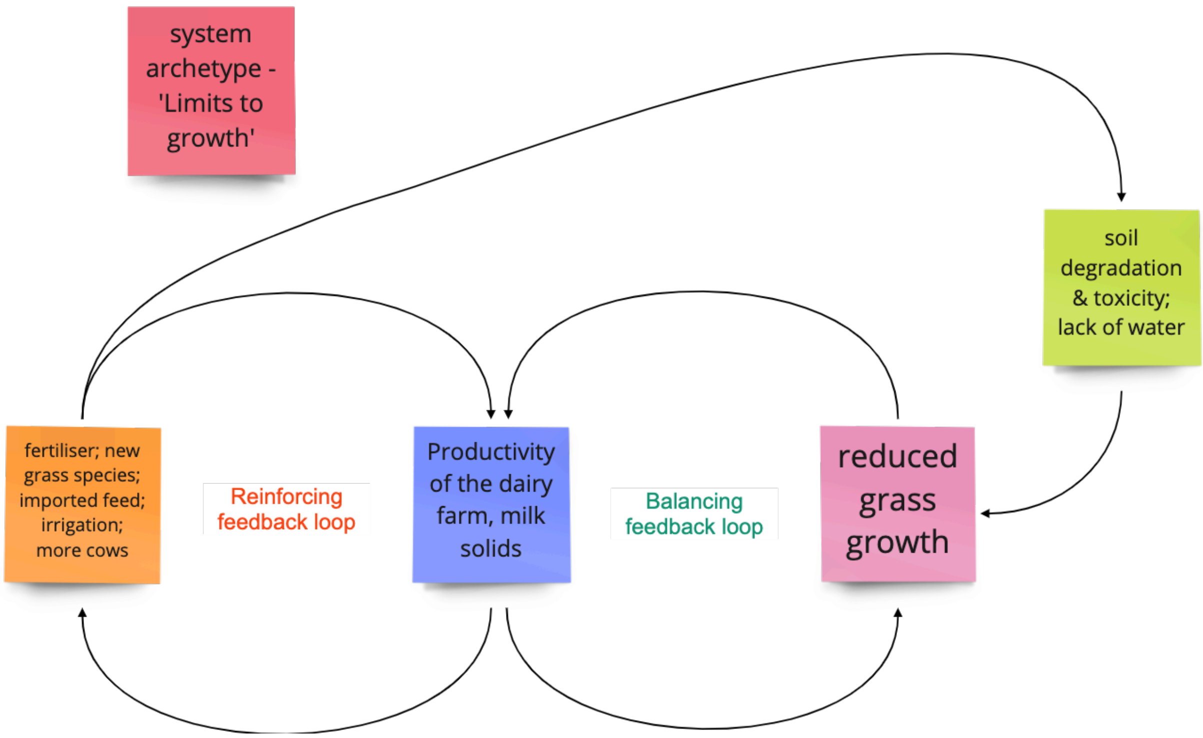
I decided to further interrogate these insights by looking at whether the situation in Figure 22 fitted a systems archetype, so that I could use it to help identify high and low leverage points as suggested by Senge (1990). This system meets a lot of the criteria of the “shifting the Burden” archetype (Senge, 1990), in that many groups are working hard to solve this problem, which is getting worse over time. Feelings of helplessness are showing up in many stakeholders, not least the farmers, who are experiencing the strains of having to cope with frequent changes to legislation whilst being aware the legislation is not working, and that they are becoming unpopular because of it. In a Dairy NZ survey, farmers were asked a multiple-choice question about “The biggest causes of mental health challenges for those in the dairy industries. 60% of farmers said regulation changes. 59% of farmers said financial concerns. 59% of farmers said the perception of dairying in the media and with the public" (DairyNZ, 2020, p. 6). These increasing rates of farmer stress, and suicide are likely a symptom of this.

The problem of nutrients in the wrong place, leading to unswimmable rivers, is complex, and it is hard to control the various factors that feed into it. Legislation was enacted in an attempt to control one factor, the waste capture systems. This seems a simpler solution because it is measurable. It appears to work because it can be measurably making the effluent cleaner or keeping it contained. Unfortunately, as I mentioned above, most of the DM and urine is not captured by these systems.

I drew Figure 23 to show how dairy farming fits the 'limits to growth' archetype as environmental degradation has created multiple limits to growth. The other archetype that has led to the problem of surplus nutrients in the wrong place is the 'shifting the burden' architype (Figure 24). I have included both system architypes as they both provide insights into possible leverage points that might reduce the problem.

Figure 23

How limits to growth affect dairy farm productivity

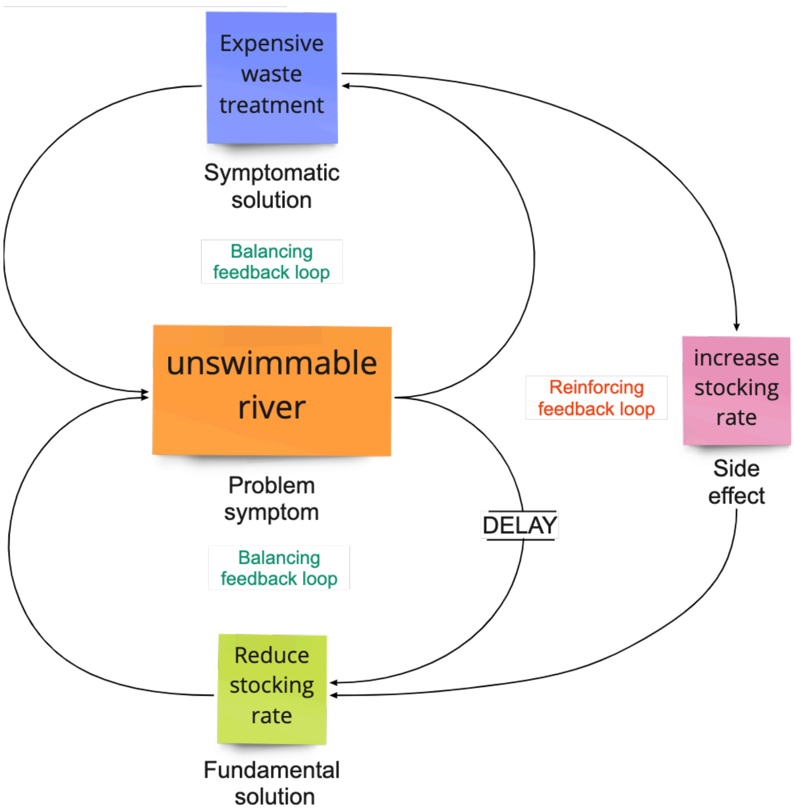


Note. Diagram adapted from Senge (1990, p. 103).

Figure 23 shows that as productivity increases there is more money to spend on things that increase productivity such as fertiliser. This in turn increases the productivity. Many of the solutions that increase productivity in the short term also have unintended side effects that degrade the environment. This in turn reduces productivity in the longer term.

Figure 24

"Shifting the burden" story for the situation in Figure 22



Note. Diagram adapted from Senge (1990, p. 112).

The expensive waste capture and treatment systems are one area of the symptomatic solutions that have been instigated, with the aim or reducing nutrient and pathogen pollution of rivers. It shows how a side effect of the solution, i.e. increasing the number of cows to provide more income to pay for the waste system, defeats the fundamental solution that would solve the problem.

Senge (1990) mentions other features of this architype. One that has been at play in the situation of unswimmable rivers has been that of “eroding goals” (p. 108), which happens when solutions do not work. Under the previous National government there was an attempt to change the water quality standards so that a standard of ‘swimmability’ for bodies of water was reduced to 'wadeability'. This became an election issue with significant push back. The Shifting the burden system archetype can also result in "unintended shifts in strategic direction" (Senge, 1990, p. 107). An example of this, which came up in my conversation with the farmer, was her observation of a gradual push in NZ dairy farming, from pasture based dairy farming to a more industrial, off pasture system with more time spent on feed pads or in herd homes, as a way of reducing the nutrient load on paddocks. This is contrary to the key marketing message about NZ dairy products being pasture based and natural. From my childhood in the UK, I remember the Anchor butter advert jingle "We are lucky cows, we chew the cud and browse. 'Cause we're eating up our greens, it makes our butter taste supreme" (Anchor butter, 1989). I think that if we keep heading towards a more intensive dairy farming model that point of difference could be lost.

4.1.2.3 Sub-conclusions

The implication of this analysis for a possible solution is that cost is likely a leverage point, and that by either reducing the cost of the waste system or gaining an income from it, one might be able to reduce the push for increasing stocking rates, thereby reducing the nutrient surplus causing leaching onto the paddock. Another potential leverage point is increasing the capacity of the system to use more nutrients. This would involve increasing the complexity of the system. Natural ecosystems are generally much more complex than man made systems which tend towards being monocultures. In a complex ecosystem such as a rainforest, excess nutrients would provide niches for other living things. Regenerative farming techniques (see CH 1.1.2) may also be part of a more fundamental solution to the problem, as they tend to increase the capacity of the farm to use excess nutrients, by increasing soil life, and varying pasture species or introducing more trees. Increased natural processes, for example processing of manures by insects, also help make natural nutrients more available to plants thereby reducing the need for synthetic fertilisers.

In scenario 1 (see 5.2.1) I include a systems diagram showing how the scenario could alter the system, by working on fundamental solutions.

I had two other farm visits which did not add much to the insights beyond illustrating that there is a great deal of variation in dairy farm manure/effluent systems, and often multiple systems within a farm, and that these systems depend on the context of the farm such as the existing infrastructure and the topography. Another observation from these visits was that farm workers are working long hours, which suggests they may not be open to additional workload. This may impact on how the business is set up; perhaps it would be better as a separate business, overlaid on the infrastructure of the dairy farm, and using DM, but with its own staff.

4.2 Other conversations that have provided insights.

Many Informal conversations have provided information and contributed to insights for this study. I have included these insights, along with those from the other instruments and methods, in Table 6, which shows the insights, where they came from, the implications of them, and how they fed into the decisions made in this research.

4.3 Survey/Questionnaire

I conducted an online survey of dairy farmers, which contained both quantitative and qualitative questions (see Appendix H). The aim of the quantitative questions was to get information that would help me find out what systems they currently use, and what sort of price to aim for, for the BSFL based system, as these data have implications for the level of technology that could be included, and would be useful in comparing the current systems to the potential BSFL system. These questions were to give me a gauge on how much time and money dairy farmers spend on their waste systems, so I could get an estimate of spend per cow. I collected estimates on how much DM was captured in each farm, as this would be needed to work out the quantities of inputs for the BSFL system, and consequently, what size to make the system.

I also needed qualitative information; some of which was to find background on the dairy farmers such as attitudes and values, whereas others were specific to their experiences and level of satisfaction with their waste systems. The survey results would provide insights for the value proposition, which would in turn feed into the Business Model Canvas.

The survey was sent out 10 times over dairy farmer groups on Facebook, and emailed specifically to farmer contacts I had been given by Bob Longhurst from AgResearch, who works with dairy farmers around waste and nutrients. Other contacts passed on the survey link to their dairy farmer associates. Despite getting the survey out in many ways between April and July 2022, I received just two responses via social media and eight responses from leads. The greater number of responses from leads illustrates a limitation to working from outside the industry. I also suspect that the COVID pandemic has left people tired, thus less inclined to respond to requests from strangers.

Table 6

Insights to decisions for this research

Decision	Sources	Insight	Implication	Innovation
To look at waste nutrients as the issue.	• My background in environmental science. • Research for the Seagull Centre. • CRN hui.	• Nutrients in the wrong place and/or form cause significant environmental problems • They are a waste of needed resources.	There is a need to investigate this topic.	look into BSFL as a way of processing waste.
To look at this from an enterprise perspective.	• Wintec. Need to meet the criteria of the Masters as an alternative to having an industry Mentor.	Need to be able to apply the learnings	needed to find an industry partner or look at forming an enterprise.	Enterprise model to be created in collaboration with the dairy farmers.

• To focus on researching what systems and conditions would need to be in place for a business to become viable.
• To look at scenarios of how the businesses might work when the technology is there in order to create interest to help get emerging BSFL companies over the inertia.
• See if we can get a group together to collaborate in creating the industry in NZ.
• look into the possibilities of getting a trial to happen, using technology from the Finnish company as it seems to be closest to getting the tech right.
	• Conversation with BSFL farmer B. from an NZ BSFL farm about being close to giving up because of:
	  • waste not being valued
	  • legislation unhelpful
	  • cost of getting a business established even with funding
	Note. *They did finally give up.*
	• Findings of protein organisation about lack of cooperation being a barrier to progressing the industry
	• Some businesses are close but in the stage where their businesses will either fail or take off.
	• One NZ company has failed this year after problems getting flies to emerge from the pupae.
	• Another in Finland has stated that they will either fall or fly this year. **Note.** *They have since become very busy.*
	• Another in Britain is seeking to buy the technology from the Finish company.
		The environment may not yet be there for a business to be financially viable.	May not be able to get a business up and running. Especially in the Master's time scale.	

To take a systems look at the DM/food waste situation.	• Visit to dairy farm farm to look at the Weeping Wall effluent filter system. Seeing how it is huge yet mostly used for storage. • Visit to Ruapehu District Council's food waste hot composting plant which was very similar to the WW system above.	Existing dairy farm effluent/waste systems could be overlaid, retrofitted to do more with the waste	• Could be a transitional way to make more use of the existing infrastructure before looking at a full redesign. • A way of offsetting the cost of the infrastructure. • A way to change the form of the nutrients to be more accessible to plants and less likely to be leached.	Get a big picture look at the systems in their context.
Needs to be a solution that either reduces costs or makes money.	Conversation with farmer A during pilot interview. I asked about the costs of the waste system and then had a hunch to ask how they found the money. She told me they ran more cows to pay for it.	Government legislation aimed at reducing nutrient leaching, has led to more expensive waste systems. Farmers pay for these by putting more cows on the farm. This leads to more urine and manure on paddocks, more fertiliser use and more imported feeds, which leads to increased leaching on the farm. These are unintended consequenses.	The current legislation isn't working to reduce nutrient pollution.	Turning waste into resources that create value and income.
Try to get this concept into the open. share at the Council and community board meetings and at the next circular economy conference. Try to share with procurement people too.	General conversations over my time in the Community Recycle Network and Zero Waste Network zoom meeting. A presenter from Otago University said they had created a fixed price contract. This encouraged the contractor to be creative about reducing waste.	Contracts are very important. The most common waste contracts pay per tonne of waste. They usually have reducing waste as a KPI.	These goals oppose each other and the reducing waste will not happen whilst they are paid for the amount of waste they process.	Ensuring the research results get to people who can use them.
As above.	• Conversation with Justin Connolly, the Systems Dynamics expert. • Conversation with M. from MyNoke worm farms. He gave the example of the anaerobic digester that has currently cost $50,000,000 and is not even built yet but still leaves a high volume anaerobic waste product that has to be got rid of and is not as good a fertiliser as worm castings whereas the worm farm has cost $2,000,000 and is up and running producing good fertiliser. • Zero waste webinar looking at alternative waste contracts. Otago University's contract that is fixed price so waste company rewarded for reducing waste.	Government tends to employ consultants. These consultants are paid a proportion of the cost of the project. Contract wording has significant implications for results!	Government tends toward solutions that are reliant on big infrastructure and are expensive.	As above.
Work on encouraging people in the BSFL industry to cooperate. There may not be anyone left in the BSFL business to collaborate with or who is interested. Consider collaborating with the company in Finland. Use the scenarios to generate more interest and collaborators.	NZ protein alliance conference notes about factors delaying the growth of the insect industry and conversation with B from G an NZ based BSFL farm. Lack of engagement with my email about the idea of collaboration from the other company growing BSFL..	Cooperation may be a better way to progress BSFL waste processing in NZ than competition. Especially with pushing for changes to regulation an probaly with creating a market for BSFL products.	Lack of cooperation may cause some businesses to go under before the conditions become right to succeed. **Note.** *One has now disappeared.*	Collaborate on overcoming the barriers to BSFL farming in NZ.

4.3.1 Results of the survey/questionnaire

The results are presented in the survey report (see Appendix I). After processing the data through Qualtrics and Excel to obtain the information that will be useful for this study, I have summarized the results. The raw data is still available in my Qualtrics file, and the additional calculations are available in Excel.

I received ten responses, although one of them was mostly incomplete, from 9 men and one woman. The ethnicity of respondents is hard to determine as they used different words. European/Pākehā = 5; New Zealander/Kiwi = 2. Three chose not to give an ethnicity. Nine out of the ten were farm owners, and one was a farm manager.

The number of milking cows on the farms surveyed varied from 232 to 1300 with a mean number of 609 milking cows/farm, which is higher than the Dairy NZ and LIC (2021) reported mean of 444. I decided that spend/milking cow on waste systems was the most useful measure I could get from the data, so I calculated this for each farm for both the upfront costs and the ongoing costs. The total number of milking cows across the nine farms was 5477 with 1726 non-milking cows. The number of milking cows varied from 252 to 1300 with a mean number of 609. Only one farm had non-milking cows; it had 1726.

Participants gave estimates of the percentage of effluent and DM captured by their effluent systems, which varied from seven to 100%. The estimated mean percentage collected, at 36%, was significantly higher than the five percent suggested for that captured in milking shed washdown water (Chobtang et al., 2016), and the 18% estimated by Rollo et al. (2017).

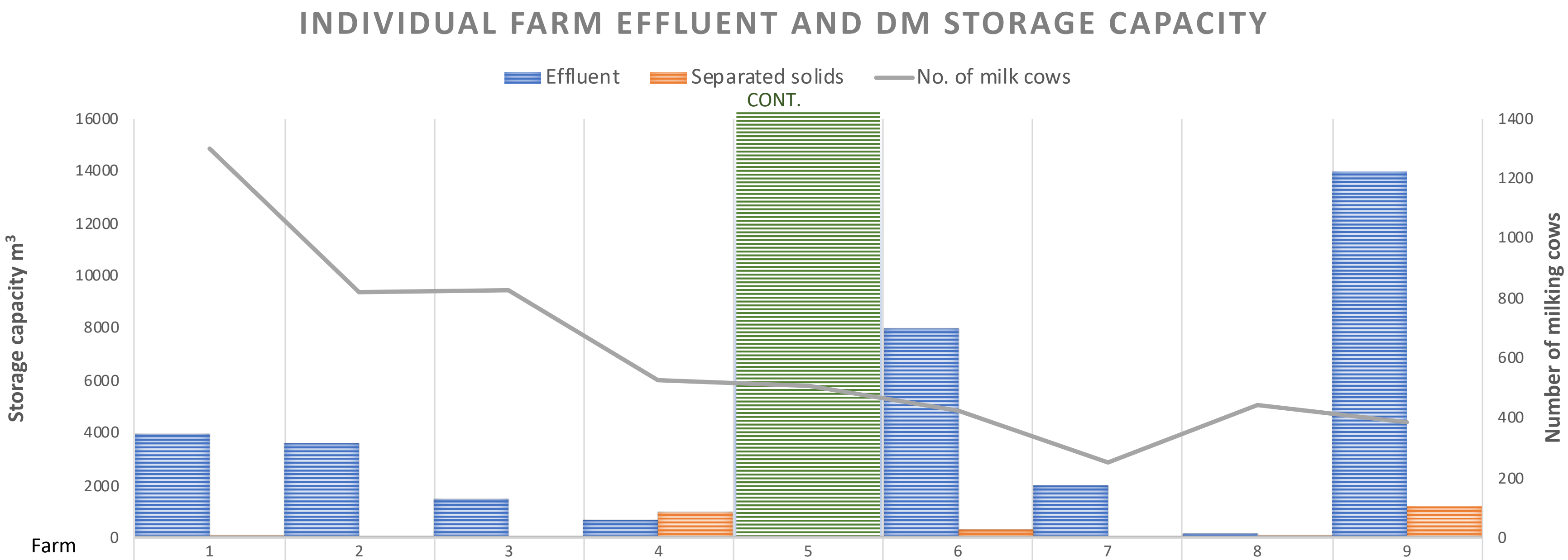
The storage capacity on the farms, for effluent and DM, was very variable with a range of 0-2,000,000 m3 for effluent. The figure of 2,000,000 m3 seems unfeasibly high, and I think the respondent may have given the capacity in litres by mistake, which would make a capacity of 2000 m3. This would be much more likely for an effluent pond. With this correction, this gives a mean effluent storage capacity of 220 m3 and a range of 0-1200 m3 for DM storage capacity, with a mean of 254 m3.

Figure 25 summarises the storage capacity of the nine surveyed farms and how it relates to the number of cows and the percentage of DM collected. In Farm Number Five, the storage capacity was much greater than that of the other farms at 172,000m3. This was because the animals are housed for half the time, and 55% of the waste was collected. The combined effluent and DM are mixed with woodchip before being stored. To make the graph readable, I have not included all of Farm Five's storage in the graph, but it is in the table.

The minimum upfront spend per milking cow on the waste system was $70.22, and the maximum was $788.95. The mean was $252.15. The ongoing costs per milking cow per year were minimum = $6.15; maximum = $43.95, and mean = $18.04. These amounts were farmer estimations of costs. In Figure 26, I summarise the costs of the dairy farm waste systems per milking cow, for each farm, with other relevant information such as the systems used and hours of labour. Some of the labour costs were presented as hours of labour per week, so I estimated the cost by multiplying the hours per week by the living wage, as of July 2022 * 52 weeks, to get an annual cost.

Figure 25

Summary of farm waste capture and storage on nine farms



Farm	1	2	3	4	5	6	7	8	9
Effluent	4000	3600	1500	688	^ 172000	8000	2000	200	14000
Separated solids	30	0	0	960		300	0	50	1200
No. of milk cows	1300	818	826	523	507	424	252	442	385
% DM captured	7	15	30	20	55	27	30	100	Not Stated

Figure 26

Summary of surveyed farm waste systems

Farm	1	2	3	4	5	6	7	8	9
Upfront spend/cow	$161.54	$79.46	$70.22	$168.26	$788.95	$518.87	$198.41	$135.75	$597.40
Ongoing spend/cow/year	$6.15	$9.17	$32.08	$22.94	$11.83	$23.58	$23.46	$13.57	$43.95
Waste systems	Lined E. Pond Screw press Stone Trap Saucer	Lined E. Pond Stone trap	Lined E. Pond Irrigator	Lined E. Pond Weeping wall	Lined E. Pond Herd home	Lined E. Pond	Herd home Chanel	Lined E. Pond Separating screen	Unlined E. Pond Weeping Wall Feed Pad
Labour on waste system hours/week	0-3	4-7	8-11	0-3	8-11	0-3	4-7	0-3	0-3

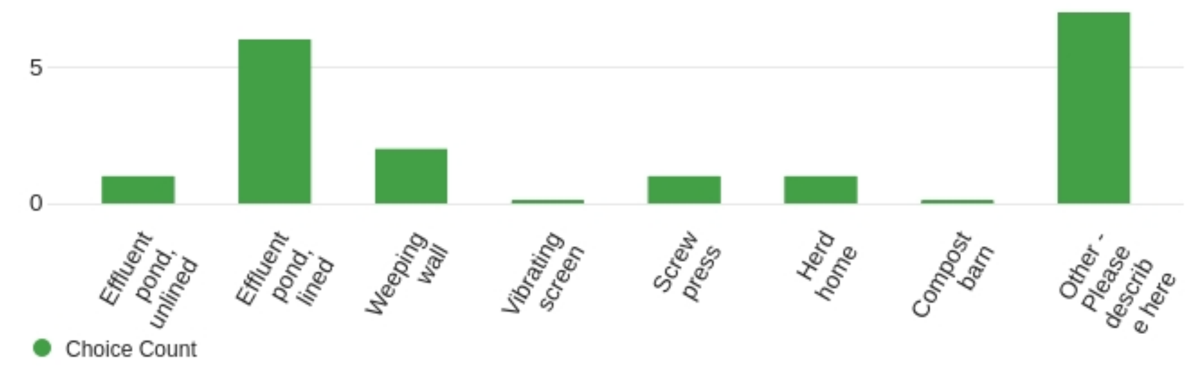
You can see from Figure 27 that there was a wide range of waste systems on the farms with most farms having more than one system.

Figure 27

Dairy farm DM/effluent systems across the 9 farms surveyed

Q4 - What are the dairy manure/effluent system/s you have on your farm? - please click on each system - Selected Choice

9 Responses



Q4_Other - Please describe here

7 Responses

Other - Please describe here - Text

Stonetrap
Saucer

off yard to stone trap to saucer and then goes into clay lined storage pond which holds 3.6 million litres or 90 days storage

travelling irrigator that can bypass pond if conditions are appropriate for spreading. The effluent goes into a concrete bunker for air travelling irrigator

Covered wintering pad, effluent scraped into pond. Cows calve on woodchip which is then spread on paddocks. 172000cu (approximately)

chanel

Seperating screen

Feed pad uncovered with flood wash into a settling pond through a weeping wall.
The feed pad is 60% finished

Note. Extract from the Qualtrics report for the Dairy Farm Waste Survey

Questions 11 and 12 looked at how farmers felt about their systems and why. The expressed levels of satisfaction with their systems were higher than expected, with most farmers saying they were satisfied. The reasons given for being satisfied mostly focused on ease of use, reliability, and compliance with regulations.

Questions 19 and 16 looked at what factors would influence farmers to change their systems and what they would change about them if they could. These questions aimed to gain insights that would feed into the design of a BSFL-based system. The most influential factors were 'cost' and 'improved environmental performance', followed by 'time it takes to operate', then "Ability to be retrofitted onto your existing system". There was a little interest in the potential to generate income, but for half the farmers, it was their least influential factor. The things they would change were very specific to their systems, although they fit into four categories:

1. Expanding the effluent coverage on the farm to better spread out the nutrients.
2. Storing more solids to be able to spread them to other areas of the farm.
3. The ability to make a second use of the water to save water.
4. Better composting of stored solids (compost barn system).

The attitudes and values question aimed to find out what motivates farmers, as this has implications for the design and marketing of any new system. Respondents were asked to click on the statements that applied to them. The most commonly selected statements were 'I work hard to improve the environmental performance of the farm' and 'I like to balance profitability, environmental care, animal wellbeing and life/work balance'.

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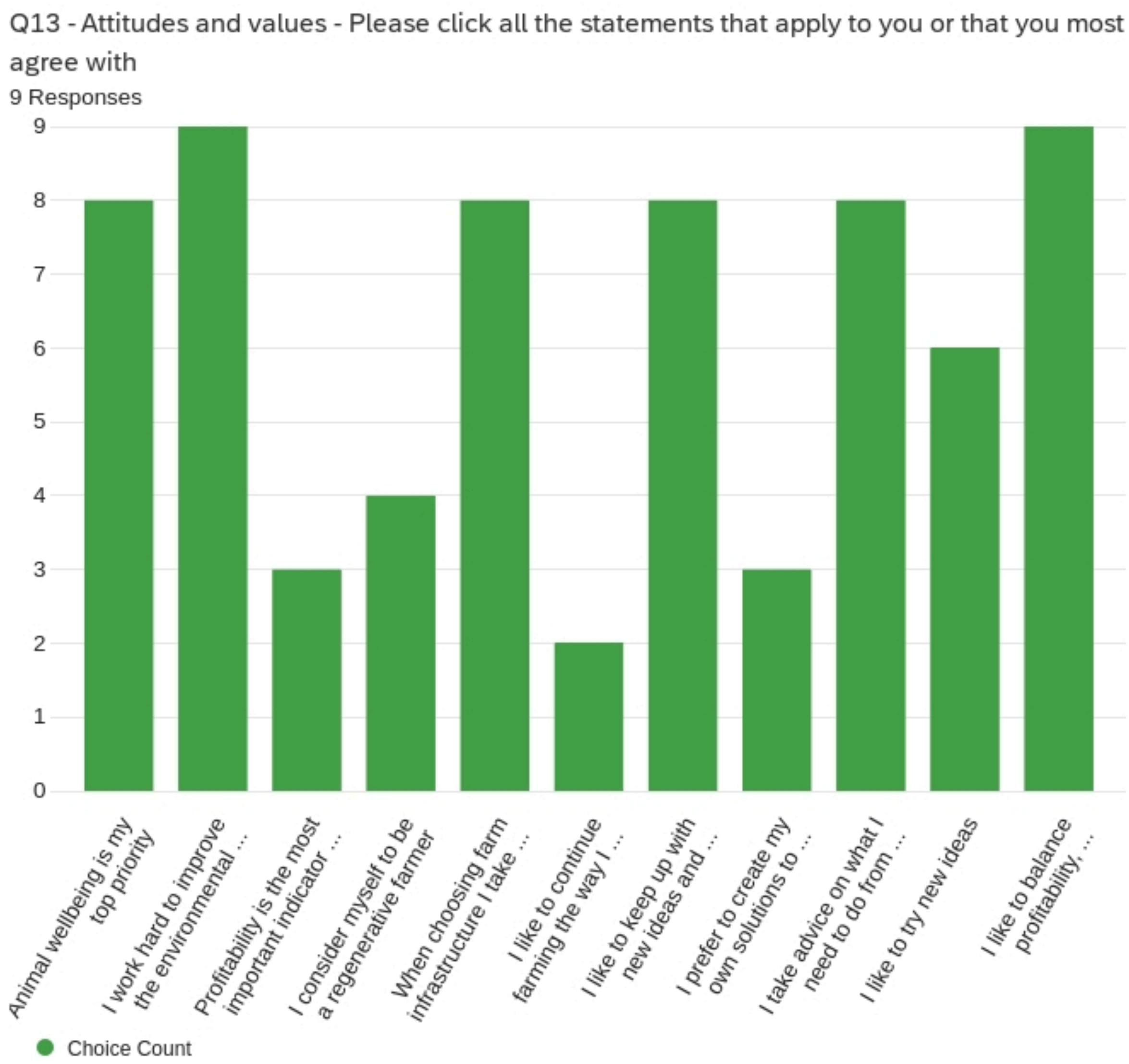
Figure 28

Attitudes and values expressed by farmers in the survey



Note. Taken from the Qualtics report for the Dairy Farm Waste Survey.

4.3.2 Analysis of the survey

In this section I analyse the results of the survey, looking at each question in turn. The Demographics questions suggest that most dairy farm owners and managers are European men, although this is difficult to confirm in the survey data due to inconsistent language used for ethnicity. A look at MPI (2020, p.41-45) statistics shows that 67% of the dairy workforce are male and 33% female, although these statistics do not differentiate between production workers and processing/commercialization workers. The data on the qualifications of women in the dairy sector suggests that more women might be involved in the processing and commercialisation side. The ethnicity profile shows that 67% of the dairy production workforce identify as European and 14% Māori or part Māori. These data suggest that European men may be the main market sector that the BSFL biodigester enterprise will need to convince. It would be good to get perspectives from other demographics to compare results.

The number of milking cows per farm was higher than the 2020 statistics (LIC & DairyNZ, 2021), which may imply that farmers with more cows are more interested in changes to the waste system and therefore more inclined to participate in a survey.

The mean percentage of manure and urine collected by the waste systems was higher than the 18% estimated by Rollo et al. (2017). *Note*. I mentioned this in the follow up interview with farmer C and he was surprised when I said that milking sheds collected approximately 5% of urine and DM (Chobtang et al., 2016), whereas he had estimated 27% collection from his milking shed. This suggests that farmers may overestimate the percentage of urine and DM collected in their waste systems and consequently think that less manure and urine falls on pasture.

The mean DM storage capacity, of the nine farms, 254m^3, suggests that if the systems were retrofitted to include a BSFL biodigester, there would be plenty of space available to store brought in food waste for the two to three weeks between batches. There would be less DM to store as it would be processed much more quickly than in the existing systems. Stored food waste could be pretreated with microbes to reduce smell and prepare it for the biodigester, as suggested by Wong et al. (2020) and Rehman et al. (2019).

Figure 26 shows that dairy farms spend significant amounts on their waste systems. They must find the money for this from their income, which comes from the sale of milk solids. Even with the cheap loans that were offered when the effluent storage regulations came in, this would add to farm costs. A certain amount of additional milk solids could come from increasing the productivity of the cows, as has been happening in New Zealand. There has been a record 3.1% increase in milk solids per cow in the 2020/2021 season over the previous season (DairyNZ, 2021b), and an increase of approximately 55% milk solids per cow since 1992 (Dairy NZ, 2021 statistics). Part of this increase may come from increased grass growth due to the increase in fertilizer use (Pinxterhuis, 2019), and part may come from increasing use of feed supplements. An MPI report states that since 1990-91 “On a per cow basis feed eaten has increased 0.85 tonne … to 4.72 tonnes dry matter per cow in 2017-18”

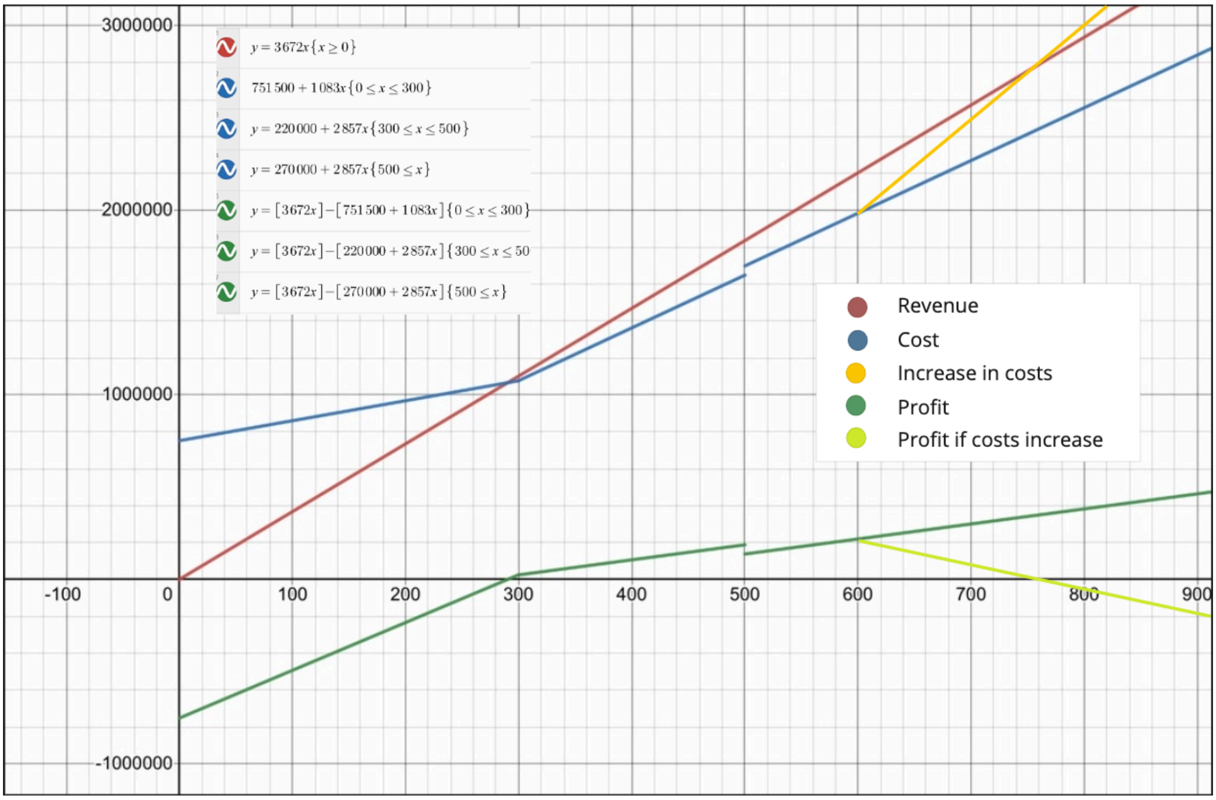
(DairyNZ Economics Group, 2019). Both factors would also add to farm costs. Some of the increased productivity may have come from better genetics (Coleman et al., 2010). However, the implication of higher farm costs is the need to increase the number of cows on the farm.

There will come a point at which increasing the number of cows will not be viable for purely economic reasons, let alone the environmental ones as suggested by Foote et al. (2015). Schmitz (2012) demonstrates the relationship between the quantity of an item sold and the impact on revenue, cost, and profit. I have adapted his diagram to sketch how this applies in the dairy farming setting and how it is affected by the additional costs that are generated as the quantity of cows increases (see Figure 29). I used data from DairyNZ (2021a, p. 26) and Howard (2022) to inform this projection. It is not the full picture and contains assumptions and estimates. However, it does give an indication of how, up to a certain point, increasing the number of cows increases the profit, as the fixed costs become a smaller proportion of the revenue, and then, as the capacity of the farm to feed the cows naturally is exceeded, other costs come in, such as imported feed and fertiliser. Then, as the farm needs a more expensive waste system, the costs increase further. These cost increases correspond to Senge's "Limits to growth" system architype. Howard (2022, p. 1) estimates the mean costs per kg of milk solids to be 22% higher in August 2022 than in 2021 at $8.66/kg milk solids, with the milk price being estimated at $9.25/kg milk solids. For instance, it would only take a drop in the milk price or a small increase in inflation to per cow costs, represented by the yellow line in the graph, to make the farm unprofitable. This projection does not take into account the costs that are currently treated as externalities, such as the costs of pollution, which are currently carried by the taxpayers or the environment. However, as farms become expected to pay more of these costs, their profit margins will decrease until they are no longer profitable.

This graph supports my belief that a proposed solution will need either to reduce farm costs or add to farm income in order to benefit the dairy farmers as well as the environment.

Figure 29

Graphs of Revenue, Cost, and Profit Functions for Dairy farm with a milk solid price of $9.25/kg



Note. Graph in the style proposed by Schmitz (2012, figure 1.2). At 300 cows I've assumed the farm needs to bring in feed and fertiliser to feed the additional cows and at 500 cows I've assumed that a more expensive waste system is needed. I could not find an estimate of the fixed costs, so I used an estimate of 50% of total costs for illustrative purposes.

The wide variety of waste systems on the farms in the survey suggest that the proposed idea will need to be able to work with a variety of systems. The famers generally expressed higher levels of satisfaction with their waste systems than I expected. However, the reasons they gave around being satisfied with their systems - i.e. that they were compliant with legislation - made me wonder if they were truly satisfied. I think they might be experiencing similar feelings to those I had whilst getting eco buildings signed off as compliant. Before the buildings were signed off, I felt angry and frustrated at the prescriptiveness of the rules and how some were not serving any purpose in my context and were adding significant expense and complication. After the buildings were signed off, I felt relief. Because of this thought, I decided to ask about the satisfaction levels at the follow up interviews.

The farmers' answers to the question about the factors that would influence them to change their systems suggest they would choose an innovation that reduced costs and improved environmental performance. This suggests that a BSFL-based system would be acceptable. The changes they would make suggest that they like to make use of the circular economy within their farm.

The attitudes and values question suggests that they value the environment, their animals, profitability and lifestyle, and are open to new ideas and following advice. My conversations with farmers suggest they will follow advice if they see the sense in it but object to following advice if they perceive it to not fit with their context.

I drew a table to help me see if there were gaps in the questions, then filled it in as I got the results, and analysed them to see if they were giving me enough information, and if they were telling me what I thought they were (See Appendix J).

4.4 Follow-up interviews

The follow-up interviews were aimed at clarifying some of the answers given in the survey, and filling information gaps identified while writing the survey report. I interviewed two survey participants who had expressed willingness to be contacted further, and gave them the choice of a face-to-face interview or an internet-based one. Both chose to be interviewed face-to-face. I took notes in both interviews as it was too noisy for recording. Therefore, the farmers' responses were paraphrased. I know there are disadvantages to this in terms of what I chose to write down. However, I think the farmers were more comfortable being interviewed on their own turf and may have been more open. They seemed keen to give their points of view face-to-face. Consequently, I obtained more useful information like this than from the survey, especially when it came to the more contentious area of waste system legislation, and what annoyed them about farming.

4.4.1 Interview with farm owner of farm nine

I conducted the interview with farm owner B whilst driving to his waste system and walking around looking at the different parts of it. I was only able to take brief field notes at the time, and wrote them up as soon as possible afterwards. Farmer B expressed suspicion of my motives with his first comments, which were about how unpopular dairy farmers have become, and how he wanted to meet me in person so he could judge whether I would be fair or not. He emphasised that they are a commercial enterprise and they need to make money.

He then showed me their new system which had been built when he filled out the survey but at that point had not been connected to the system. He and the sharemilker both like how the new feed pad and its flood-wash works. He also showed me their weeping wall system that has the capacity to store solids for approximately three months. These systems cost approximately $150,000 each. They put them in to be compliant with the regulations.

They spread the collected DM, from the two systems, on the paddocks, where it gives extra fertility lasting for about three months. It is particularly beneficial on the maize paddocks. They use the maize, and silage cut from the farm, as their supplementary feed which means they do not need to buy feed in. Cows are fed on the feed pad for one and a half hours per day, so he estimated they collect another 6% of DM on top of that collected in the milking shed.

I asked some general questions to find out more about motivations for farming. He grew up on a dairy farm but did not originally want to be a farmer. He loves machinery and came back to farming and loves the variety of jobs he gets to do and is determined to find a way to keep going. He has a farm worker who looks after the cows, but he feels proud of the cows being in good condition. He gets annoyed with people from cities and the government not understanding what they do and how hard they work and feels they are not treated with much respect. He objects to being called a factory farm when cows are on pasture and healthy. However, he is a commercial farmer and has to make money.

I asked about "what the government is trying to achieve with the nutrient management regulations". He answered that "the government want to get rid of all dairy farms" but he would keep on going whatever it took. He feels that there is no-one taking into account the carbon that is takes from the atmosphere by the photosynthesis of pasture. And that if they were genuinely wanting dairy farming to continue, they would be more responsive to solutions that farmers create. For example, he tried to import a methane-reducing feed additive, and the government would not allow him to. He's not sure if the government understands what happens on farms, and said they have an agenda of trees. "They want to replace all the cows with trees". He thinks they do not see the bigger picture. He believes that the government surrounds themselves by people who think like them. He acknowledged that he was in a similar position, of being surrounded by farmers who think like him. He also expressed scepticism about anthropogenic climate change.

4.4.1.1 Sub-conclusions from interview with farmer B

Farmer B had been working hard to find solutions to GHG emissions and recently spent a significant amount on new waste systems but feels that his efforts are unrecognised. He and his friends are disillusioned by the government's response to nutrient pollution and climate change as they feel it threatens their lifestyle. They think the legislation is not effective and unfairly penalises farmers whilst benefitting forestry. He would like autonomy to work out his own interventions to GHG emissions. I think his scepticism about anthropogenic climate change comes from his feelings that it threatens a lifestyle that he loves.

4.4.2 Interview with the owner of farm six

In the interview with the owner of farm six, I interviewed farmer C in his office in the milking shed. It was noisy, so I could not record the interview, but I was able to make detailed field notes. Like farmer B, he also expressed suspicion of researchers because he was worried about their agendas, and what they might do with what he tells them.

He also grew up on a dairy farm and had left farming to work with tractors and machines. He got back into farming ten years ago and loves it, especially the flexibility, being outdoors, learning the skill of growing good grass, and is passionate about improving the soil. He's not so keen on the cows, so his farm worker looks after them. He loves being able to have time with his children and the family interactions of working together on the farm.

When asked what annoys him about farming, he said there are a few frustrations rather than annoyances. The main one is lack of technology sufficiently sophisticated to give the detail he wants to fully understand how to improve the soil as much as he would like to. He showed me a couple of applications he uses to manage the grass growth and soils: one showed all the paddocks and uses satellite imagery to judge the grass growth. He could see how some parts of the paddocks showed better growth than others even though they had the same treatment. He wants to know why, but it is too expensive to get every area of soil tested individually. He'd love it all to be monitored, and he'd like to know more real time detail on the soils so he can save on inputs. He uses the data map to give him as much information as possible.

He told me about his lined effluent pond. He has daily effluent pumping from a sump with a travelling irrigator, which is brilliant and covers about 25% of the farm, that he does not have to fertilise. He has a lined pond that allows him to store effluent in winter to pump out in the summer, which takes about a week in January. At that time, it is an asset that gives him a couple of rounds of grass growth. I asked if he thought the pond was good value for money and he said he did not think so because it did not recycle as much water as he would like. So, he still has to pay for a lot of water. They bought the system ten years ago in response to the law change that prevented them pumping out effluent in wet weather. They had to have 90 days storage for effluent. He understood the need for that law, unlike later ones. They paid for the effluent system with a cheap loan that banks were giving for this purpose. They paid it off over 6-8 years from their cash flow, i.e. from farm income from selling milk solids.

I asked about his aspirations for the farm and he said he would like to be able to spread the effluent over more of the farm as he has not needed to use phosphate or potassium for 20 years and only a little urea on the paddocks that get the effluent. He said his collected manure goes onto the maize paddocks in spring. Maize being the supplementary feed.

I asked what the government was aiming for with the regulations on water quality and nutrient management, and he thought older regulations were aimed at reducing run-off of nutrients in wet weather. He thought these were sensible regulations aimed at bringing the worst farmers up to standard. He does not think the newer regulations are working because he thinks they are slowing down the better farmers, and “the new regulations seem to be about slowing down the front end,” i.e. the farmers with better practice. He thinks “they seem arbitrary,” i.e. they are applied even where there is not a problem. He thinks there are so many rules, and they create more work, and there are double ups, such as having to report all the fertiliser inputs to the regional council, although they already give them to Fonterra. He stated that “The Regional council does not do anything with the data”. He thinks the government is attacking the good guys. “The rules do not reflect the context. For example, some paddocks need more fertiliser than others and will not leach, whereas others leach more easily”

Farmer C does not feel the government knows how to get the results it wants. He liked the outputs-based rules, which were what Overseer was for. He liked it even though it was complex as it reflected more of what happened on the farm. It was logical even though not perfectly accurate. He thinks that the input-based regulations, about how much fertiliser can be put on, do not reflect the context. He worries they may have the unforeseen consequences of having the maximum used as a target. He thinks they are using the inputs because they are easy to measure, but the measurements are not very useful. Measuring outputs is much more useful but harder. Overseer is complicated, but at least it measured results. He also thinks the technology is not quite there yet for showing complex biological systems in a computer model. He thinks a basing the regulations on getting farmers to use best practice would be a more effective way of getting the results they want, rather than more rules.

At the end of the interview farmer C said I was welcome to contact him again if I needed more information.

4.4.2.1 Sub-conclusions from interview with farmer C

Farmer C sees that some legislation to improve the worst farms is appropriate but thinks that legislation that does not reflect the context of the farm is unfair. He had many suggestions about a fairer system of legislation and would like the opportunity to work on his own ways of dealing with the issues of nutrient pollution and GHG emissions. Like farmer B, he has worked hard to improve many aspects of his farming practice but is frustrated by constantly changing regulations that do not make sense to him. A more detailed analysis of the follow up interviews occurs in the Thematic Analysis (Ch. 4.5)

4.5 Thematic analysis of Dairy farmers' experiences of the effluent /DM systems

I chose to use Thematic Analysis to explore the data from the follow-up interviews, and as a way of synthesizing it with the data taken from the pilot interviews, questionnaires, and informal conversations with dairy farmers. To do this, I put the paraphrased answers and comments from farmers A. B. and C. on virtual post-it notes on the Miro application and initially grouped them into topics, which gave me a starting point for coding (see Appendix K).

Braun and Clarke (2022) define coding as "The process of exploring the diversity and patterning of meaning from the dataset, developing codes and applying code labels to specific segments of each data item" (p. 53). Using their suggested process, I created codes and reclustered the data around the relevant code labels, with some data items being clustered in multiple codes (See Appendix K, Figure 49). I then re-examined the data to find the shared meanings, which were refined into themes. These themes were then used to formulate insights and consider implications (see Table 7). I then reflected on other data, such as that from the literature review and my general experience and knowledge of the topic, to see how my farmers' viewpoints matched or opposed other viewpoints, and the quantitative data where relevant.

Some of the themes were interesting, although less relevant to my particular purpose with this thesis, or gave insights about areas that I have little control over, such as legislation and government. However, when synthesized with other information or considering parallel situations, they have offered some insights. I have attempted to include the insights that could be useful when designing the BSFL based innovation.

Table 7

Table showing how themes led to insights in the TA

Theme	Evidence	Insight	Implication
Farmers value their unique lifestyle	• love being outdoors. • Love the flexibility. • love interaction with family working together.	Dairy farmers owners would love to keep farming because they love the lifestyle but feel that it is threatened by the government and "them"	• The innovation needs to protect farmer's lifestyles.
Farmers are working hard and spending on reducing nutrient pollution	• New feed pad with a flood wash, $150,000 each. • Up-front costs of the combined waste systems were around $1,000,000 on top of the costs of the original system. • He would like more of his farm on the daily effluent irrigation system to balance out the fertility over a wider area	Dairy farmers are working hard to reduce nutrient pollution because they want to carry on farming, but they feel that their efforts are not recognised	• Need to publicise those farmers who trial BSFL based waste systems and tell the positive story
There is a willingness to embrace circular economy	• Collected manure solids go onto the maize in spring which is grown as supplementary feed. • He as proud that in the paddocks that get the effluent, he hasn't needed to use phosphate or potassium for 20 years and only a little urea. • He would like more of his farm on the daily effluent irrigation system to balance out the fertility over a wider area.	Farmers are willing to embrace the circular economy if they see the sense in it.	• Create a logical argument for BSFL farming. • Show the financial benefits.
Farm needs to be financially viable	• We are a commercial enterprise and need to make money.		

Waste systems are expensive	• Up-front costs of the waste system, which combined was around $1000,000 on top of the costs of the original system. • Feed pad with a flood wash cost about $150,000 each • Lined effluent pod cost approx. $150,000.		• BSFL system needs to reduce costs and/or generate income.
Waste system costs come from farm income, i.e., from sale of milk	• Waste system costs paid from cash flow. • We cover the cost of the waste system by increasing the size of the herd. • Waste system costs come from farm income.	For the expensive waste systems to be paid for, farmers will need to put more cows onto the farm.	• Need to emphasize the importance of using any income from BSFL farming to reduce stocking rates.
Farmer's feel their lifestyle is under threat	• Government wants us to have all cows on hard stands so the manure and urine can all be collected which is not the style of farming we are used to. • They have an agenda of trees. They want to replace all the cows with trees. • They want to get rid of all dairy farms.	Dairy farmer's lifestyles are under threat from multiple sources and it is easier to blame others than work together on a total rethink of the system.	• Frame my innovation to maintain farmer lifestyles whilst improving the nutrient retention.
The government is not listening to us.	• If they were genuinely wanting dairy farming to continue, they would be more responsive to solutions that farmers create. • I'm not sure if the government understands what happens on farms. • He tried to import a methane reducing feed additive and the government wouldn't allow him to.		• Try to include MPI in discussions about BSFL farming to overcome the legislative barriers to BSFL farming.
Loss of trust in the government	• They don't see the bigger picture. They are surrounded by people who think like them.	The government is taking more than its fair share of the blame for threats to farmer's lifestyle	• Trust is important, which reflects the insight that Miquel

	• Government wants us to have all cows on hard stands so the manure and urine can all be collected which is not the style of farming we are used to. • They want to get rid of all dairy farms	because the regulation causes a lot of stress and because it is easier to blame people not in your peer group. e.g. Fonterra; the rise of milk alternatives; damage to soils from the overuse of fertiliser.	from Veta la Palma fish farm gave me about the importance of relationships. • Work on creating good relationships
Government is destroying dairy farming	• Government wants us to have all cows on hard stands so the manure and urine can all be collected, which is not the style of farming we are used to. • They have an agenda of trees. They want to replace all the cows with trees. • They want to get rid of all dairy farms.	Dairy farmers conflict with the government because they want to keep their lifestyle but feel it is under threat from legislation.	
Them and us	• They have an agenda of trees. They want to replace all the cows with trees. • They want to get rid of all dairy farms. • They don't see the bigger picture. They are surrounded by people who think like them.	Farmers feel that a sector of society is against them, and they are under threat from 'them'.	• Try to stay out of the them and us narrative. Stay in the positive. • Try to stay out of the blame game.
The nutrient pollution and climate emissions regulations are not fit for purpose	• Input based nitrogen use regulation may have unforeseen consequences of having the maximum used as a target. • I think they are using the inputs because they are easy to measure, but the measurements are not very useful. Measuring outputs is much more useful but harder. • I don't feel the government knows how to get the results it wants.	Dairy farmers work hard to comply with regulations to reduce nutrient pollution but feel the regulations are not fit for purpose	Not an area I can influence beyond passing on my findings, which I have been and will continue to do

Frequently changing rules are a source of stress	• Frustration with the rules changing frequently and not knowing what legislation they would have to meet next. • There are so many rules, and they create more work		The enterprise needs to deal with the regulation implications of BSFL farming so the stress is not passed on to the farmers
Regulation should be context based	• Input based regulations about how much fertiliser can be put on don't reflect the context. • They seem arbitrary i.e. they are applied even where there isn't a problem. • Overseer is complicated but at least it measured results.	Farmers don't like being told what to do by people who don't understand their context.	Involve the farmers in designing the enterprise and the biodigester
Farmers feel the regulation is unfair to farmers	• They are attacking the good guys. • He liked the outputs based rules which was what Overseer was for. He liked it even though it was complex as it reflected more of what happened on the farm.		
Farmers feel their efforts at reducing nutrient pollution are not being recognised	• They are attacking the good guys. • There is no-one taking into account the carbon that is taken from the atmosphere by the photosynthesis of pasture.		
Farmers are the bad guys now	• We're the bad guys. • Dairy farmers are really unpopular now. • Farmers are defensive about how they are perceived.		• Tell the positive story of the BSFL farming
Researchers are not to be trusted	• He is suspicious of the motives of people who come to talk to him because he is worried about what their agenda is and what they will do with what he tells them.		• Act in a trustworthy and ethical manner

The thematic analysis generated these main insights:

Dairy farmers love their lifestyle but feel it is under threat – The data from these interviews, and my look at the cost, revenue, and profit functions for a dairy farm, along with data from the literature review and previous conversations with an ex-dairy farmer, all suggest that dairy farming is marginal even with the current high price of milk solids. There are multiple threats to the viability of dairy farms, from market changes such as the rise of milk substitutes, climate change, the rising demand for and costs of water for irrigation, inflation, loss of soil through overuse of fertilizer, and the rising costs of waste systems. Dairy farmers are also aware that they will gradually become expected to carry more of the costs of the externalities such as GHG emissions. All these factors will be adding to the farmers' perceptions of threat. I think the rise of the Groundswell movement illustrates the psycho-social impact this is having on the dairy farmers.

Dairy farmers are working hard to reduce nutrient pollution because they want to carry on farming, but they feel that their efforts are not recognised – The dairy farmers I have spoken to have all worked hard and spent considerable money on waste systems and other methods to reduce nutrient pollution and loss, and were also investigating innovative ways of reducing GHG emissions. Regardless of this effort, the pollution has been increasing. This high effort with little result reflects the "shifting the burden" architype I discussed in Chapter 4.1.2.2.

Farmers are willing to embrace the circular economy if they see the sense in it – The farmers I spoke to were all making the most of the nutrients in the DM and effluent by returning them to the paddocks and were keen to make more use of this and the water cycled through waste systems because it saved them money. I think they would adopt a system that saved more of the nutrients, for both financial reasons and for the positive feelings and personal satisfaction of doing things that benefit the environment and the soils.

farmers will need to put more cows onto the farms to pay for the expensive waste systems – This also backs up the insight from Chapter 4.1.2.2, that there are unintended consequences to expensive solutions that limit their effectiveness.

The government is taking more than its fair share of the blame for threats to farmers' lifestyle because the regulation causes a lot of stress and because it is easier to blame people not in your peer group – Like the dairy farmers, the government is also working hard to reduce nutrient pollution. However, my insights from chapter 4.1.2.2

suggest that some of the regulation is not working as anticipated. This reflects the complexity of this wicked problem and is also a symptom of the "shifting the Burden" architype. The situation where the different groups begin to blame each other is also a clue to the "shifting the burden" architype that seems to be playing out in the media now. I think it is easier for farmers to blame the government for the perception of threat to their lifestyle than the groups that they associate with such as Fonterra or the fertiliser companies. From my perspective, after a big picture investigation of the problem, the different groups need to find ways to work together if the dairy farming lifestyle is to continue with improved outcomes for the environment. The above insight will not directly help with my innovation as I'm not in a position to have much influence over government regulation. However, it does suggest that forging and maintaining strong relationships is essential, as stated to me by Miguel Medialdea, manager of the fish farm at Veta la Palma in Spain. This also encourages me to try to get the people interested in BSFL farming to work collectively to involve MPI, in creating suitable legislation for a new BSFL industry.

Farmers feel that a sector of society is against them, and they are under threat from 'them'. This insight highlights how essential it is to build good trust relationships with the farmers by acting in a trustworthy way, and setting up ways of working that avoid the blame game, such as Ken Wilber's Integral Theory approach of trying "to combine and synthesize the various viewpoints instead of wasting energy arguing whose is the more true" (Hartmann, n.d.).

Farmers do not like being told what to do by people who do not understand their context. This mirrors the insight I got from my early conversations with dairy farmers. What I will take from this is that it is important to Involve the farmers in designing the enterprise and the biodigester.

I have included the full list of insights and implications in Table 7.

4.6 Scientific experiments on growing BSFL and breeding BSF outside of a laboratory

I recognized the need for scientific research into the practicalities of growing BSFL in New Zealand using feed substrates containing DM and food waste, as part of the wider investigation into the possibilities of farming BSFL on New Zealand dairy farms. Initially, I enquired with the Wintec science department about laboratory facilities. However, as a distance student located two hours away from Hamilton, it would have been challenging to conduct the experiments myself at the Wintec facility. Consequently, I approached the Head of Science to explore the possibility of finding an undergraduate science student who might undertake the project. Although I was initially unsuccessful in finding a science student, I persisted with my enquiries and eventually found one. Due to the difficulty of obtaining BSFL in New Zealand, we decided to investigate the reported antimicrobial properties of the oil extracted from BSFL, given the student's interest in microbiology. This student's research will be completed around the same time as this thesis.

I also consulted my mentor at AgResearch about their facilities, and was referred to the Bioresource Processing Alliance, who provide funding and sponsor students to conduct research into bioresource processing. After contacting them, I discovered that they had already provided funding for two studies into aspects of BSFL farming, and would, consequently, not provide further funding.

I planned to conduct some basic experiments to gather quantitative data that would help answer questions such as:

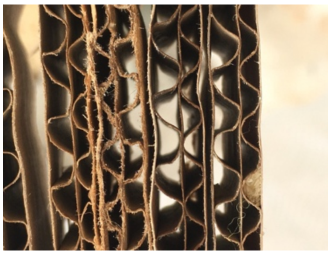
1. How long it takes BSFL to reach the prepupae stage (indicated by self-harvesting from the feed substrate) when fed on different feeds.
2. The increase in BSFL biomass over the feeding period from eggs to prepupae, on different feeds.

I aimed to use the data gained to compare the results with those of other studies that have investigated similar feed substrates and investigate what environmental conditions would need to be maintained in any BSFL-based adaptation to the dairy farm waste system. However, I encountered several barriers to scientific study (see Table 3).

Despite these obstacles, I decided to set up a small colony on my farm. Unfortunately, due to the lack of a controlled environment to conduct controlled scientific experiments, I had to curtail my ambitions and instead focus on observing how successfully I could grow and breed BSFL on my farm. BSF are naturalized on the Coromandel Peninsula, so I knew they could grow here, albeit with a short season. They often appear in my compost cage from around late January to between April and early June. I set up a semi-controlled environment by building a greenhouse to extend the growing and breeding seasons, and assembled the following equipment:

- Greenhouse - to extend the growing and breeding seasons.
- Growing tub - half mussel float with a ramp for prepupae self-harvesting. I part filled this with drainage medium, then a fine screen, topped with the feed substate. Aimed at growing larger numbers of BSFL to use as breeding stock to build up numbers so that we can get eggs to start trial colonies as prototypes on dairy farms.

- Ice cream containers - for testing different feed substrates with smaller numbers of larvae.
- Min/max thermometer - to measure temperature
- Humidity gauge - to measure humidity.
- Breeding cage - to contain adult black soldier flies to encourage mating.
- Eggies - for flies to lay eggs in. *Note*. You can see the eggs in the bottom right of the corrugated cardboard eggie.



- Sugar water and sponge for flies to drink so that they live longer and have more chance of mating.

Note. Photographs of the BSFL equipment taken by the author.

I used a process of trial and error to see if I could grow the BSFL and what I could learn within the constraints of a semi-controlled environment. The environment and issues with getting a supply of the BSFL in time to make the most of their short season created many barriers to getting meaningful scientific results. However, I kept observations and recorded them in a blog so that I could easily reflect on my observations, and share them with farmers when finally able to get sufficient BSFL to set up small colonies for farmers to trial (see Ch. 4.9.2).

I drew Table 8 to help me consider the barriers I had experience with getting a colony established and how to overcome them, as this would be useful to inform the conclusions and scenario 2.

Table 8

Barriers to my planned scientific experiments and adaptations

Planned method	Barrier to the planned method	Alternative idea/potential solution
To conduct some controlled experiments (as mentioned above).	Being located a long way from Wintec meant I was unable to use the science laboratories there	With assistance from Wintec, we attempted to find a science student to take on this aspect of the study. We found one who's research will be completed about the same time as this thesis. I also asked about getting some research done at AgResearch and investigated funding from the Bioresource Processing Alliance however they are already funding two studies into BSFL and were unable to fund another.
To buy in BSF eggs to make it easier to run experiments. This would give me a colony all the same age.	It was not possible as they are not sold in NZ.	Breed my own. I was eventually able to get mixed age BSFL however these were delayed by three weeks due to a mite infection in the colony I purchased them from. This limited the length of the season in which they would grow.
Use the initial purchased BSFL to grow the colony and collect the prepupae then allow them to hatch and collect the eggs.	Although there were signs of egg laying in my BSFL tub from BSF from outside my colony, and I now have adult flies emerged from the prepupae that self-harvested from the tub. There were no eggs laid in the	Follow suggestions from YouTube channel "Black Soldier Fly Colony" episode "how to attract black soldier fly from wild population" to attract BSF to lay eggs on the eggies (device with holes suitable for BSF females to lay eggs in). Suggest corrugated cardboard or bio balls, which are pool filter balls made of plastic, these are of a consistent size and mass which will make it easier to measure the mass of an egg cluster. I later heard that the company I

	breeding cage until quite late in the season.	bought the larvae from went out of business due to problems with their flies emerging from pupae. I would like to interview the company owners to find out more about their experiences. I wonder if genetics played any part in their problems as the colony had been going for ten years and possibly had been inbreeding since then.
See If BSFL prefer laying eggs in the corrugated cardboard eggies or the bio balls.	Since I put the bio balls into the breeding cage above the attractant along with a corrugated cardboard eggie, there have been no eggs laid in either eggie type.	I will have to wait for next season or try to get access to a controlled environment such as a lab.

I did manage to conduct one experiment into how many eggs are laid in a cluster (see Table 9). This has implications for estimating the size of the breeding colony needed to provide eggs for the BSFL farms.

Table 9

Experiment to find out how many eggs are laid in each cluster

Experiment/observation	Result	Analysis
To find out approximately how many eggs are laid per cluster by spreading out a cluster on dark coloured paper, using a pencil to draw round different sections to make it easier to keep count, and counting the eggs under magnification.	386 eggs counted, although there may be some error due to stacking of eggs and some due to squashing.	This was one test. I would need to repeat it to get an average. Other estimates are 500-800 eggs/cluster. I do not know how these estimates came about. I did not repeat it as I only found a few egg clusters and needed them to hatch.

4.6.1 Sub-conclusions

Although my efforts to grow a colony were only partially successful, I think the process illuminated some of the barriers to establishing BSFL farming in a field-based setting in New Zealand. These insights and the blog have informed my second scenario and recommendations.

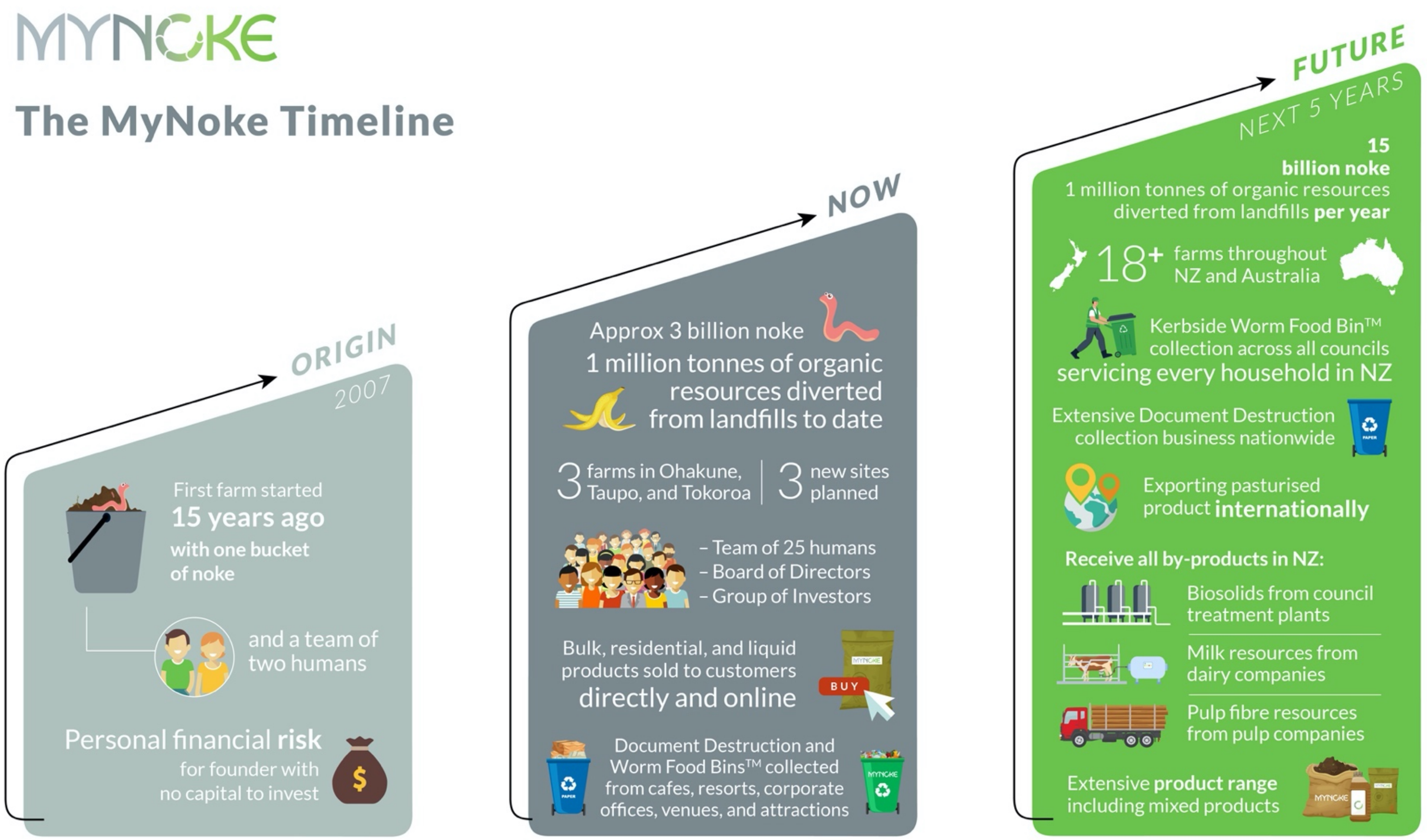
4.7 Case study of My Noke worm farm

I thought it might be useful to look at other insect farming/insect waste processing industries in New Zealand to see what I could learn from their experience. Having heard of My Noke through a Zero Waste Network webinar, I decided to seek more information from them about their operation as it would inform both the Thames Food Waste Resource Group and this research. I organized to have an online conversation with the General Manager and later arranged to join a tour of one of their sites. Other information in this case study has come from their website and a couple of webinars they were involved in (MyNoke, 2022; Circular Economy Agriculture and Food Network, 2022). I am including my information about this business because it provides a case study of a successful business that is creating a circular economy based on using invertebrates to process a variety of biological waste streams.

My Noke was started in 2007 by Dr Michael Quintern, A soil scientist who was working for Crown Research, to find a solution for getting more out of waste paper-pulp from the paper industry. Previously, it had been burned or sent to landfill. He considered it might be a useful resource to make worm farming scalable, and wanted to integrate the worm farming with other farming. Since then, the company has grown to being the largest worm farm in the world, with a one million tonnes of organic waste processed since it started and the aim of expanding to one million tonnes per year in the next five years (see Figure 30).

Figure 30

The MyNoke story



Note. From MyNoke ,2022. Reprinted with permission.

There are a lot of parallels and a few differences between this business and a potential BSFL business (see Table 10).

Table 10

Parallels between MyNoke and my proposed BSFL enterprise

Parallels between MyNoke and my proposed BSFL enterprise	Useful information about these parallels
Processing a variety of biological waste streams including manures and food wastes.	The worms can process a wide range of biowaste including food and agricultural waste; sewage sludge; DAF. In addition worms can process lots of paper pulp that BSFL probably cannot.
Using invertebrates to process the waste.	Worms and BSFL are natural detritivores and have enzymes and microbes in their guts that reduce pathogens in waste as they biodegrade it and reduce its volume by approximately 80%, whilst retaining most of the nutrients.
Producing fertilizer/soil improver.	Vermicast and BSFL frass both contain nutrients from the 'waste' and have high organic matter and microbes that improve soil.
Working with farmers as sources of waste; customers for the fertiliser and as landlords, with some of their worm farms located on farms.	MyNoke sells vermicast to farmers as fertiliser or soil improver and runs its worm farms on other farms, a similar model to my proposed enterprise. The worm farm adds fertility to the host farm, and the host farm provides the space to process the waste.
Having to seek resource consent for their facilities for discharge to air and to ground.	MyNoke have faced difficulties with getting resource consents and inconsistencies between councils on their interpretations of the rules.
Logistics of where to site their farms in relation to waste sources, to minimize transport while finding suitable conditions.	They have had to balance minimising the number of sites to reduce labour and infrastructure costs with being as close as possible to waste streams.

Working with councils to manage various waste streams including domestic food waste and sewage sludge.	MyNoke works with a variety of customers including councils and, consequently must negotiate contracts to council specifications and timescales.
Conducting experiments to find suitable waste streams and waste mixes that work as feed substrates for the worms.	MyNoke conducts small scale field trials using worms to process different wastes in varying combinations. They use a combination of site observation and laboratory testing to see how well the waste is processed and whether the worms are happy to stay in the substrate.

The main differences are that the worms can process more fibrous waste and they are purely the processors of the waste and are not yet sold as animal feed. The potential to sell BSFL for animal feed adds an extra layer of complexity as this requires legislation, which is currently not in place in New Zealand (Mason, 2021, In conversation) and extra management to ensure the safety of the animal feed produced. Selling the BSFL would also provide additional income.

4.7.1 Analysis of the case study with reference to BSFL farming

MyNoke plans to have 18 sites around New Zealand in the next five years, based near their largest waste streams to reduce transport, considering the availability of suitable inexpensive sites. This approach works well for waste sources that are near the site but will leave some waste with a considerable distance to travel. For instance, if the food waste were to be taken from Thames to the proposed site at Hampton Downs, it would be a round trip of approximately 130km. That will add a considerable amount of transport cost and emissions compared to if it were to be processed nearer to Thames. With rubbish trucks being reported to have a fuel economy of 0.94l/km, that makes an additional 122l of diesel per trip. If we assume an extra 10 trips to the site per week, this would cost $1220/ week for fuel, plus additional time, labour, and wear on trucks which would increase the costs. Using the MFE method for calculating the GHG emissions (Ministry for the Environment, 2022a), transporting 50 tonnes of food waste to Hampton Downs would produce 877 kgCO2-e, whereas transporting the food waste to the Tirohia landfill, as currently happens, would produce 540 kgCO2-e, and processing it 10 km from Thames in a BSFL biodigester on a dairy farm, as in scenario 1, would produce 270 kgCO2-e.

I think that BSFL farming could complement worm farming by processing some of the higher nutrient waste. The higher nutrient waste would grow better BSFL which could be sold for income. It would also be beneficial where there is a long distance to travel to the worm farm. BSFL farming requires less land for processing due to its quicker turnover of waste. As a result, it may prove useful in areas with high land costs, such as urban centers.

4.8 Anylogic computer simulation of a BSFL unit on a dairy farm

I programmed a computer simulation model of the systems dynamics of the proposed BSFL biodigester on a dairy farm to see how the results changed as parameters were adjusted. This initial model is basic and linear however it has the benefit of generating results when multiple parameters are changed simultaneously. The model is a series of interconnected stock and flow diagrams (see Figure 31). The model operator can change some parameters, allowing the model to respond to external data such as changes in price or a dairy farm with more cows. Experiments can then be run on the model for a selected period of time, and results generated. Figure 33 shows the results of a yearlong simulation experiment for an average dairy farm, with 444 cows and 18% manure collection. The price of prepupae is based on the equivalent price for fishmeal of $400/tonne dry weight (May, 2022) and the frass price is based on the price of vermicast in New Zealand, $25/tonne. I have estimated $100/tonne to take food waste, which is less than the current price to dump it in landfill.

As I gain more skill in using the Anylogic modelling software, I will make it more sophisticated and circular. I will also programme in the costs as I get an idea of what they will be. At present, the model is useful for giving an idea of the amount of waste processed, which is useful for working out the system's capacity. It also generates the potential income generated from the different products and services, which will help with working out what price range to aim for, for the infrastructure. I hope to get more data about potential costs by researching what other BSFL farming systems have cost for infrastructure and running, and by interviewing some BSFL farmers. So far this information has been difficult to obtain, however some research has come out very recently. In Scenario 2 (5.2.2) you will see that I recommend that the model continue to be used. I will continue to update the model as I get more information.

Figure 31

Anylogic simulation model diagram of BSFL unit

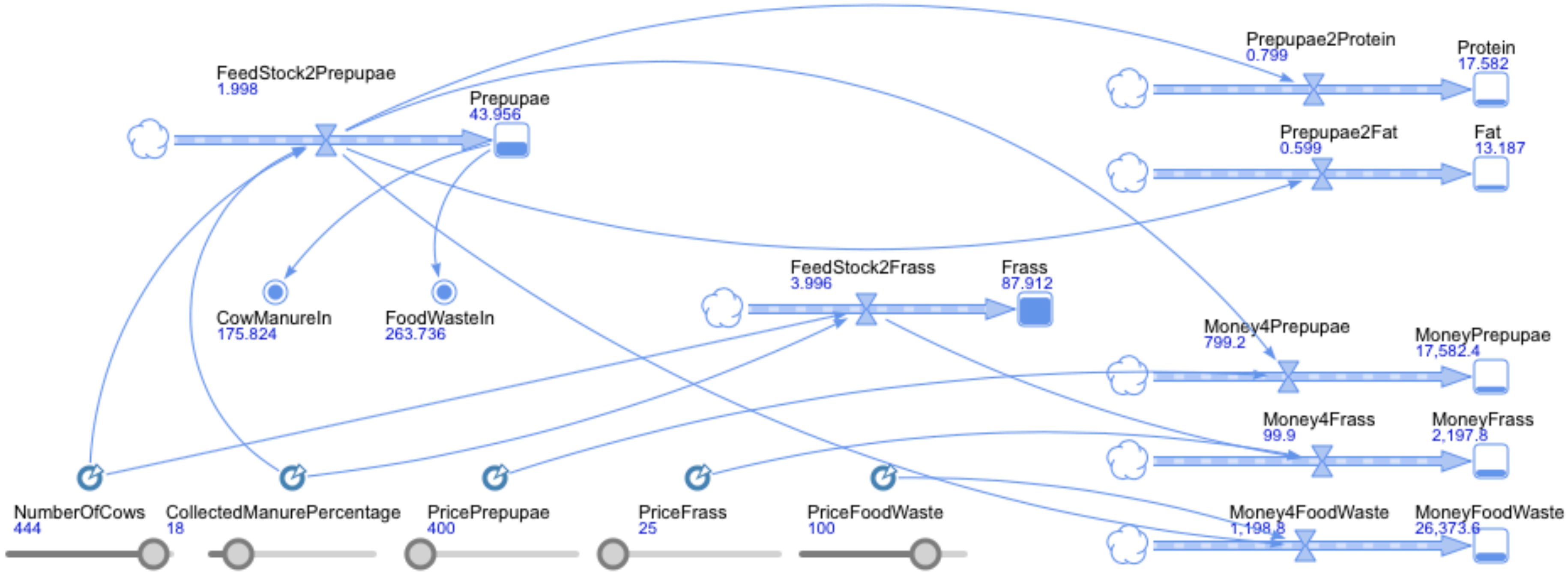
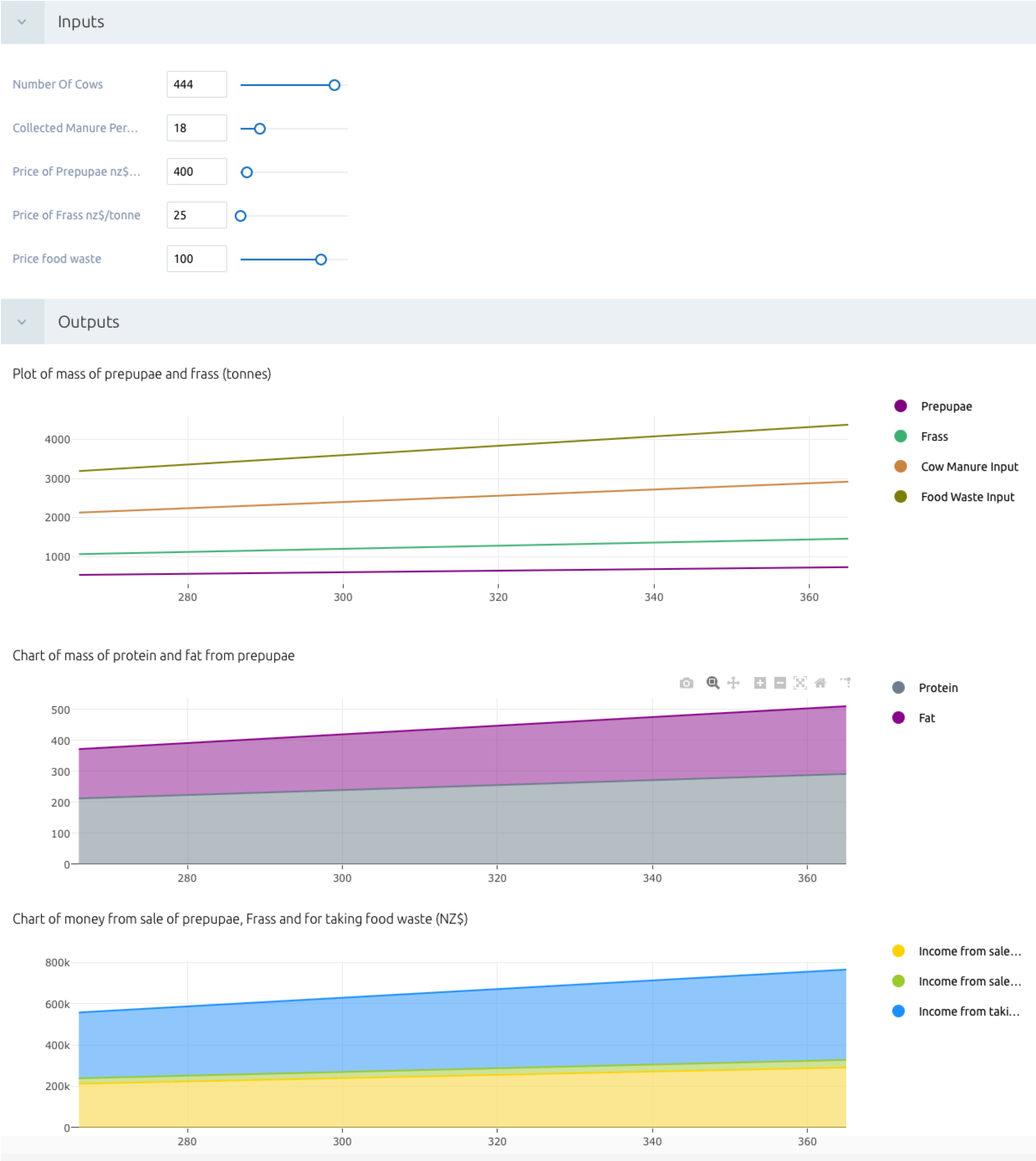


Figure 32

Inputs and results of the Anylogic simulation experiment on the BSFL Unit model



Note. The units on the x axis of the second chart are Tonnes. In the third chart, yellow = income from sale of prepupae, green = income from sale of frass and blue = income from taking food waste. Extract from my model BSFL Unit 2, Version 13, Experiment 2, https://cloud.anylogic.com/model/e5a2ed9c-cf0f-4dd4-bc4b-51f09ca8510b?mode=DASHBOARD&experiment=b892de40-0466-4216-b501-f4c0ab68e7f1

4.9 Pulling it all together

In this chapter, I have explained what I did to collect the data and the results obtained. I discussed the data and insights from the pilot visits and interviews and how they suggested that there is already a circular economy on the dairy farm, with nutrients being cycled back to the pasture and feed crops. I also discussed how waste systems might be retrofitted with a system that makes more of the nutrients in the DM, and how the current waste systems might not be having their intended results due to the high costs. Figure 33 shows a summary of some of the key data from the pilot interviews and how it relates to data from the literature review.

When analysing the surveys, I showed that waste systems vary in type and cost, and that the dairy farmers are generally satisfied with their waste systems on the level of compliance and ease of use. With the follow up interviews, I found out more about what farmers value about their lifestyle and investigated satisfaction at the system level. After a thematic analysis of the data, I found that they are less satisfied at the bigger picture level and feel particularly strongly that the legislation concerning nutrient loss to land and water, as well as to the air as GHGs, is ineffective and unfair to farmers. Figure 34 shows interesting data from the survey and follow up interviews.

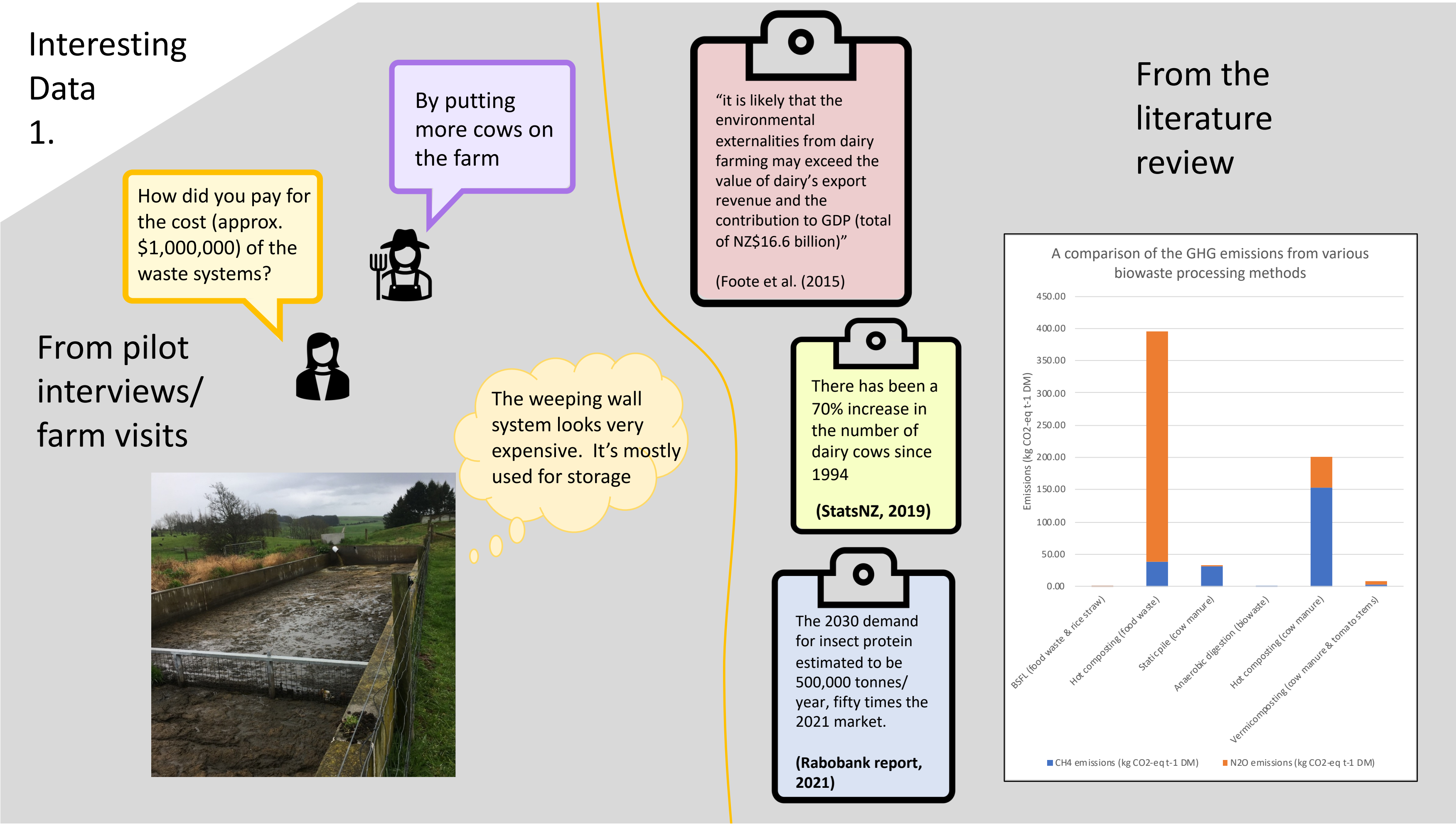
I shared my attempts to establish a BSFL colony on my small farm and the challenges faced, as well as how and why I chose to model the BSFL biodigester idea. I also explored the parallels between a successful worm farming business and my proposed enterprise.

Although I had many informal conversations, presentations, meetings, and interactions with stakeholders other than dairy farmers throughout the duration of this thesis, and in the work I did on this topic prior to this thesis, I have not included the analysis of them here as it will make the document too large and unwieldy. I analysed all these interactions with other voices at the time and reflected on them as part of my recursive process, to consider how they could feed into the design of the innovation, and to ensure it was acceptable to these other groups. The notes of these interactions are stored in my learning portfolio on Mahara or on my Miro board, and some of them are in my head. These other groups included Callahan Innovation, for a business and innovation perspective, BSFL farmers and scientists, Environmental groups such as T^3 and TFWRG for an environmental perspective, scientists from AgResearch for a government scientist perspective and staff members and councilors from TCDC and HDC for their perspectives. Some of the insights are included in Table 6.

In the next chapter, I will draw conclusions from the insights above and illustrate how they feed into the design of the BSFL innovation, as well as my recommendations for how to go about putting this idea into action.

Figure 33

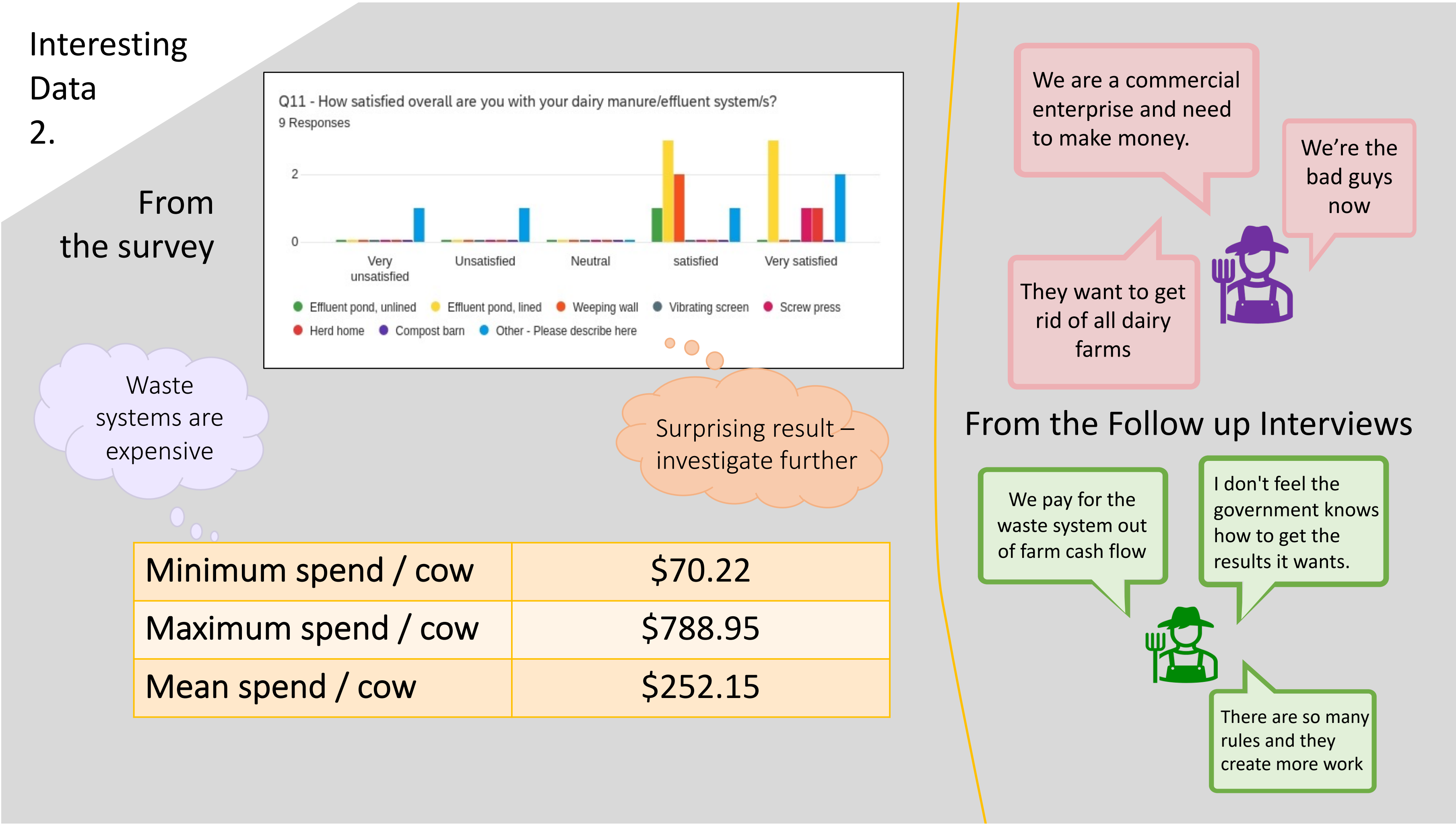
Key data from pilot interviews and literature reviews



Note. Slide 6 from a presentation for the Wintec Te Pukenga Sustainable Futures Symposium, created by the author.

Figure 34

Key data from the survey and the pilot interviews



Note: Slide 7 from a presentation for the Wintec Te Pukenga Sustainable Futures Symposium, created by the author.

Chapter 5 Conclusion and way forward

In this chapter, I revisit my research questions and goals, and draw the key findings together to create a future scenario for a BSFL biodigester that can be fitted to a dairy farm waste system. This system aims to work in Nicolescu's (2010) "included middle," where the different points of view can be reconciled, and the various needs of the different groups can be met. I then consider the next steps that will need to be in place to develop the technology, processes, and practice that will enable the BSFL industry to grow in New Zealand, and develop the circular economy around the inputs and products of BSFL farming.

5.1 Summary of findings and discussion

The research question for this thesis was:

> How might we work with dairy farmers to manage the impacts of surplus nutrients on the environment in such a way as to benefit the dairy farmers and the environment?

During this research, I have investigated whether a BSFL-based biodigester could improve the current dairy farm waste systems whilst fulfilling the following goals:

1. To answer the question in such a way as to convert biological waste products into resources that can be used to feed animals and/or plants, i.e., to create a circular economy.
2. To maximise the environmental benefits from the solution.
3. To build a viable enterprise around the research question.

To do this, I have conducted a transdisciplinary, mixed methods enquiry into current waste systems and why they do not appear to be working as they are intended to reduce the problem of nutrient pollution. From this process, I gained the following key insights:

- There is already a circular economy of nutrients within the dairy farms, with effluent and DM being returned to pasture and feed crops.
- The current legislation is encouraging more complicated and expensive waste systems on dairy farms. These systems work at the process level, but unfortunately, have the unintended consequence of increasing the number of cows on the farms as farmers increase their herd to increase productivity to pay for the increased costs (See Ch. 4.1.2.2). As the waste systems only collect a relatively small proportion of

the dairy manure and urine, the majority falls in the paddocks, and is not treated through the waste system. The increased loading on the pasture creates more potential for runoff with a compounding effect of more cows requiring more feed, consequently feed is imported, and more fertiliser is put on the paddocks to try to grow more grass, etc.

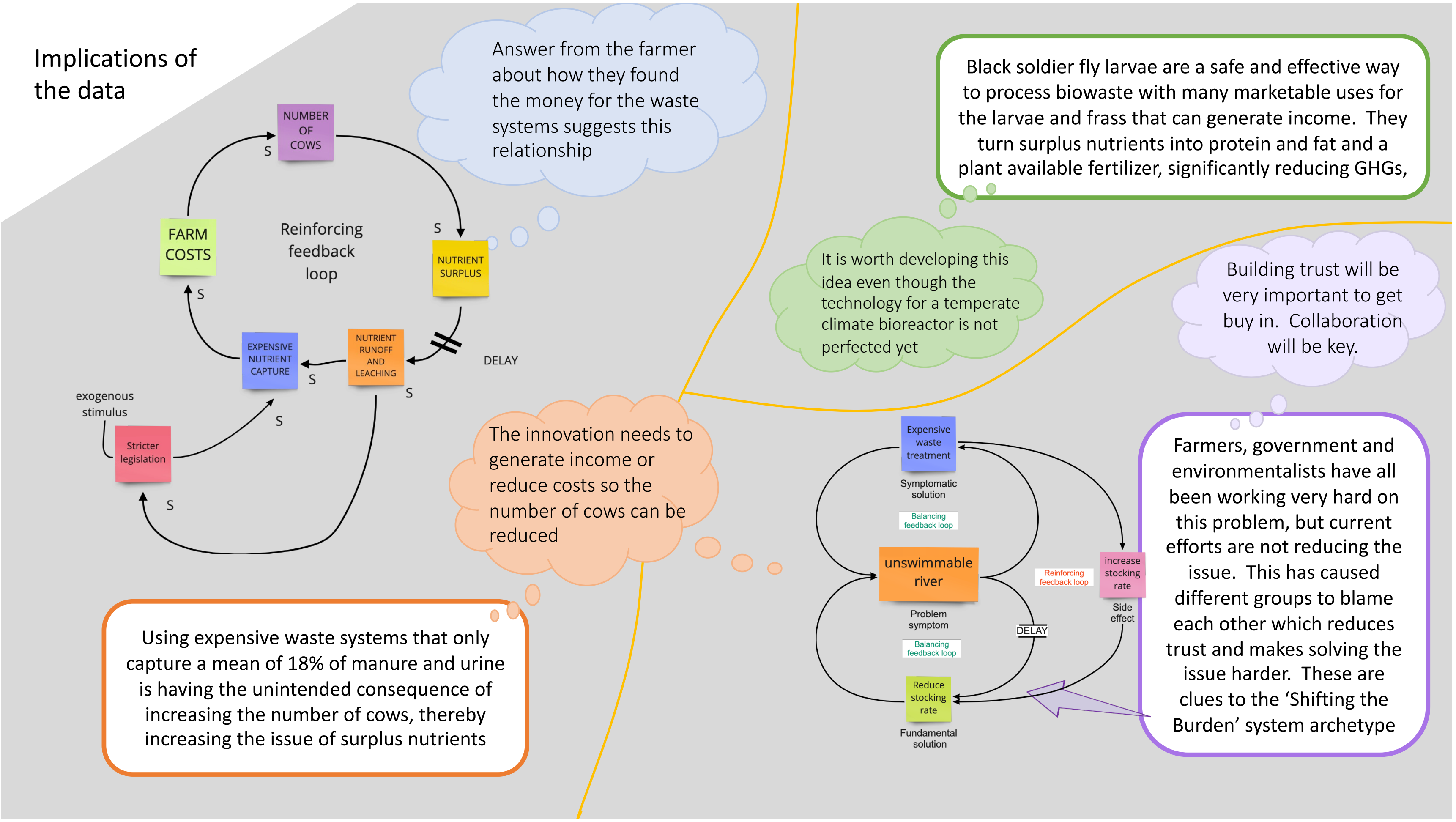
I also explored my proposed resolution in greater detail in the literature review and using the computer model, to see if it could meet the above goals and consider how best to go about establishing the enterprise. This research highlighted these key insights:

- Businesses working on how to farm BSFL in temperate climates have been struggling for a few reasons:
  - The technology is not quite there yet.
  - It is early in the uptake of the industry, and attitudes to feeding insects to animals are changing slowly.
  - The regulations are being changed slowly, and in NZ, there is not yet appropriate legislation and there is confusion in MPI about which regulations to apply.
- There is great economic potential in growing BSFL on a wide variety of biological waste streams if costs can be managed, with Rabobank predicting a 50-fold increase in insect protein demand by 2030 (de Jong, 2021).
- There is great environmental potential to growing BSFL on DM and food waste, also on other biological waste streams such as other animal manures and humanure, because more of the nutrients will be retained for reuse rather than being converted to GHGs or leached into water.

I conclude that the technology is not yet quite consistent enough to reliably grow BSFL in NZ, although it is getting very close. At this stage it may be more effective to bring in the technology from companies that are further ahead in trialling. A summary of the data analysis and their implications for my proposed innovation is illustrated in Figure 35.

Figure 35

Analysis and implications of key data



Note: Slide 8 from a presentation for the Wintec Te Pukenga Sustainable Futures Symposium, created by the author.

5.2 Scenarios

"We need to imagine as well as measure." (Pullman, 2019. Ch.23)

To create these scenarios, I have synthesised the data I have gathered about dairy farm waste and waste systems, as well as how farmers feel about their waste systems, with data about BSFL farming. I have then used this information to feed into value propositions, and an initial business model. I have fed quantitative data into my, at this stage, basic Anylogic system dynamic, computer simulation model, to estimate potential income to see if the idea is financially viable. I have also considered how best to meet farmer needs as well as maximise environmental benefits of the idea. The scenarios are a way to present the idea to farmers and other stakeholders.

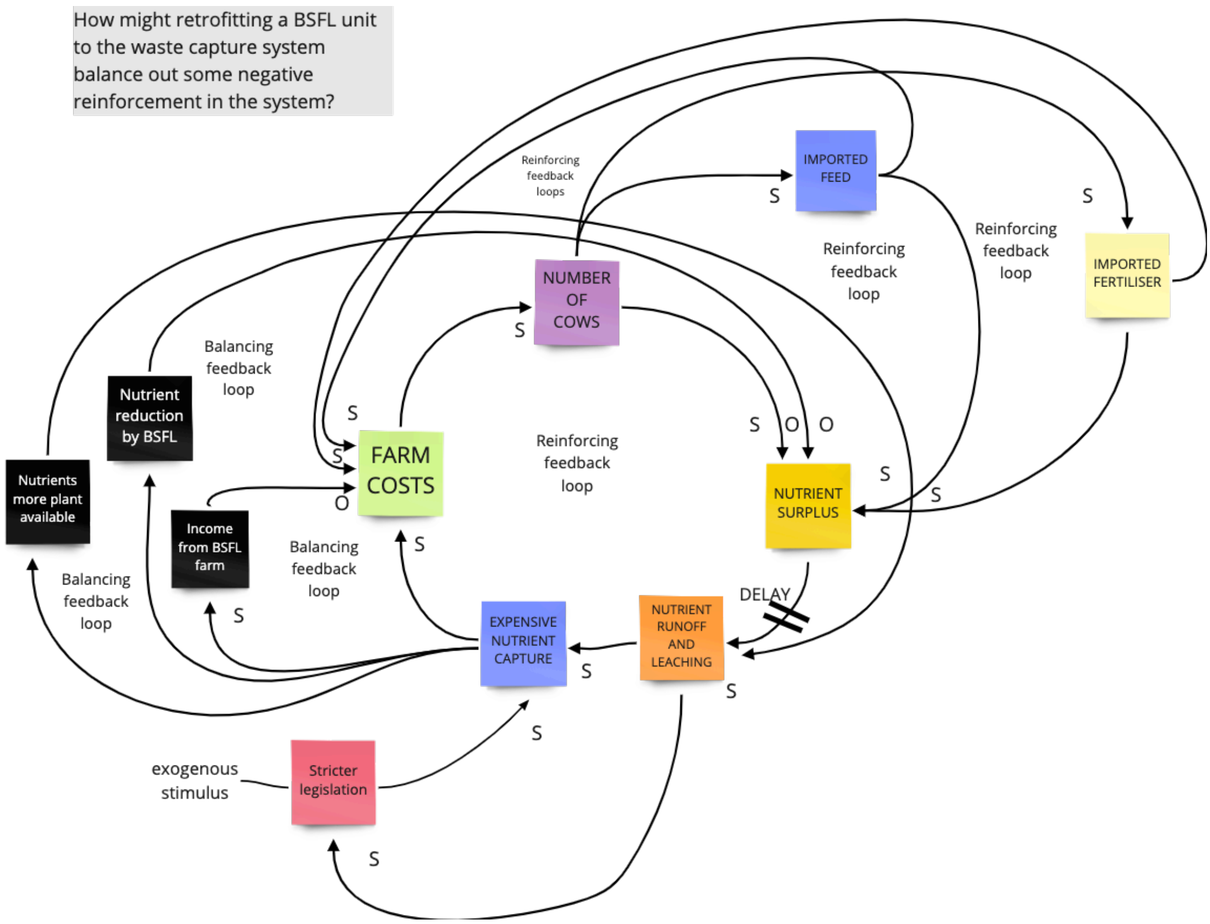
5.2.1 Scenario 1

My first scenario is a longer-term scenario showing how BSFL can fit into a dairy farm, using DM and food waste. This illustrates how a BSFL biodigester might benefit the dairy farm by providing an income to counteract the unforeseen consequence of the high cost of effluent and DM waste systems, which has led to farmers putting more cows on the farm. However, this is not a complete scenario yet, as more work needs to be done to design the appropriate infrastructure. Collaboration will be needed to develop a business model that works for all stakeholders (see Ch. 4.9.2).

Figure 36 shows how a BSFL unit on a dairy farm might alter the system dynamics to break the vicious cycle identified in Figure 22. The BSFL grow on the nutrients in the food waste and DM, reducing the surplus and producing a sellable product. The BSFL turn some of the volatile and soluble nitrogen (N) into plant-available forms of N which are excreted in their frass, which can be harvested. This reduces the nutrient volatilization as NO2 and leaching into runoff water. The frass can be used as a fertilizer on the farm, and any surplus sold, reducing the need for imported fertilizer. The income from BSFL, frass and taking food waste offsets farm costs, which means farmers can afford to reduce the number of cows to levels where the urine and DM they excrete in the pasture can be taken up by the plants on the farm. Figure 37 shows the technology that will be needed in the business and how it fits in the business ecosystem. Figure 38 shows how this idea can be used to create a circular economy which could either cycle within the farm if the farm diversified into poultry farming or market gardening or encompass a wider area outside the farm.

Figure 36

How a BSFL biodigester might break the vicious cycle

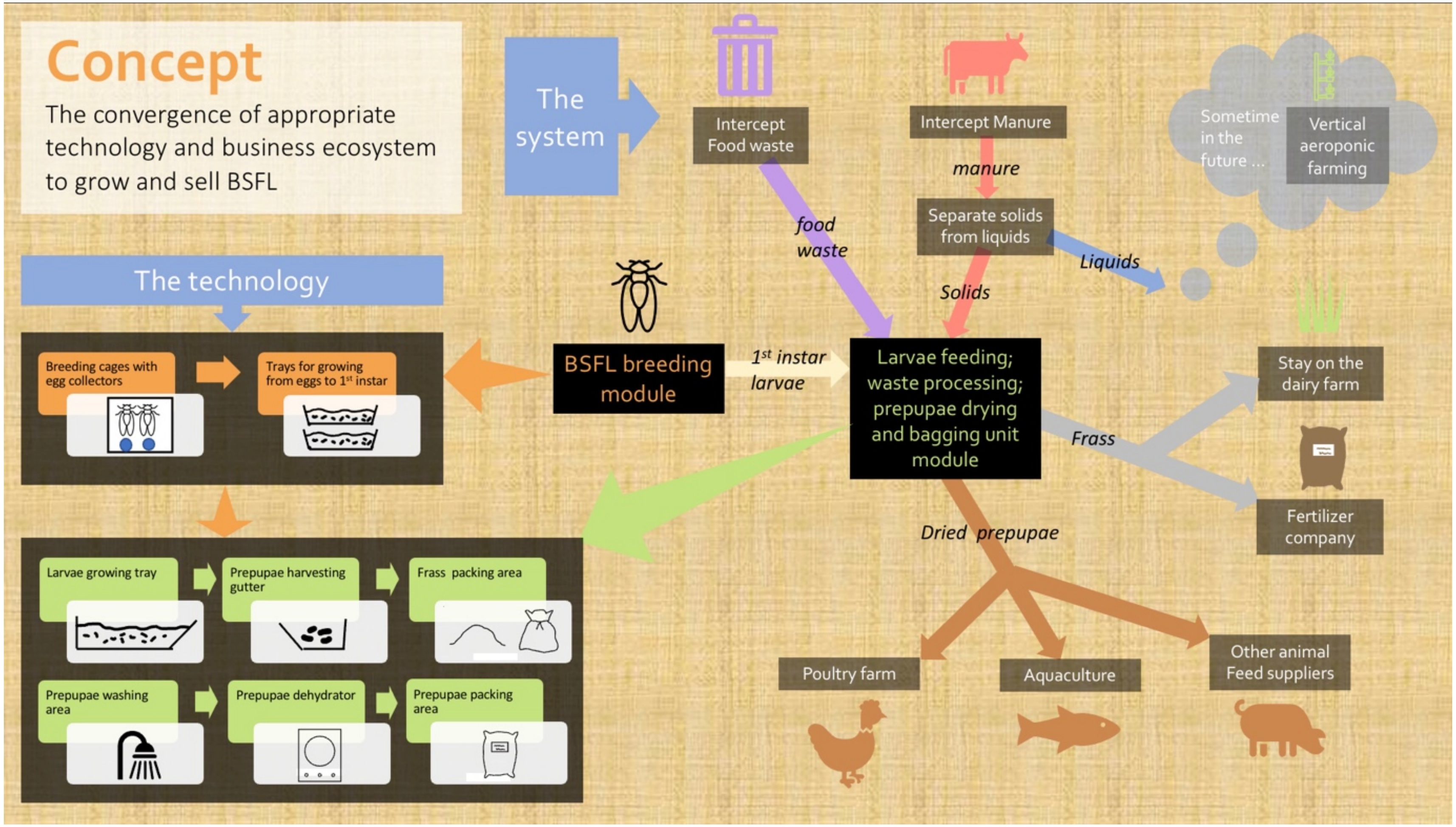


Note. Adapted from Figure 22. S = same direction relationship and O = opposite direction relationship.

I drew Figure 38 as part of the next phase of the BSFL farm simulation model, which would be the more sophisticated computer simulation model for scenario 1. I am in the process of collating the information needed to feed into the model, and working out how to set up the model using the Anylogic software. I hope to work with Dr Henk Roodt and Clemens Dempers on combining my model with their "Farm Model" (https://cloud.anylogic.com/model/bb5ce616-61f0-4503-adaa-d6d751595cf7?mode=SETTING), which simulates a diversified dairy farm with an anaerobic digester, a fish farm, and crops. We considered that the BSFL unit could be an alternative to their anaerobic digester in the model. The Poultry farm and market garden could either be part of the diversity of income streams on the dairy farm or could be other businesses external to the farm.

Figure 37

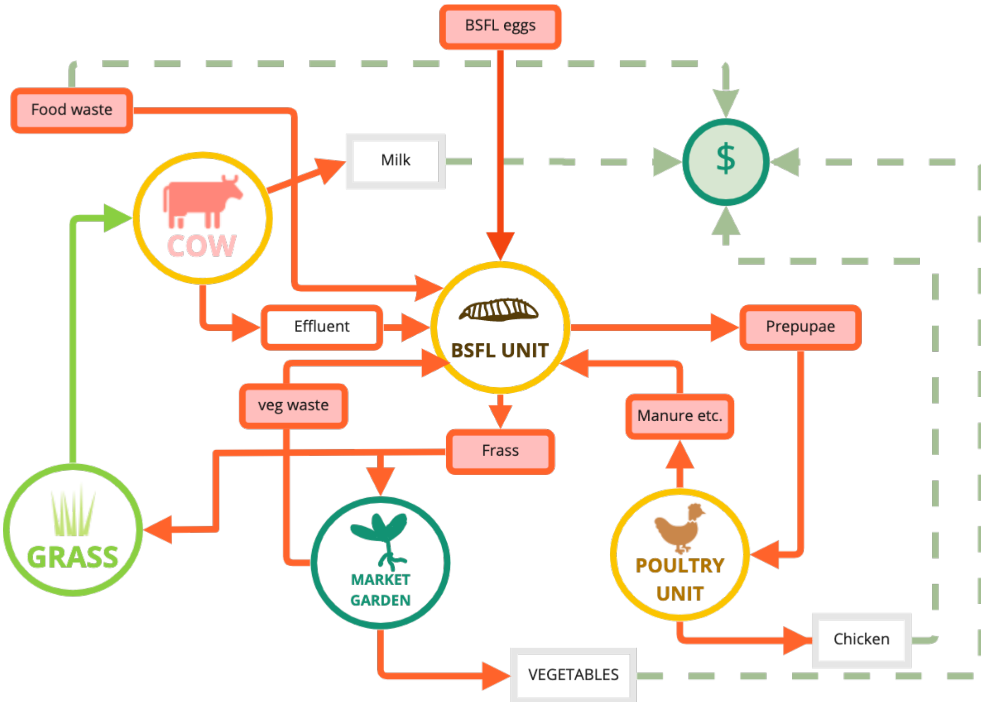
Pictorial diagram of how the technology fits into the business ecosystem



Note. Figure 2 from my 804 paper; adapted from a diagram I drew as part of the entry presentation for Callaghan Innovation's C-Prize (2021) which I entered as a way of seeking feedback to validate the idea.

Figure 38

System diagram of BSFL unit on a dairy farm

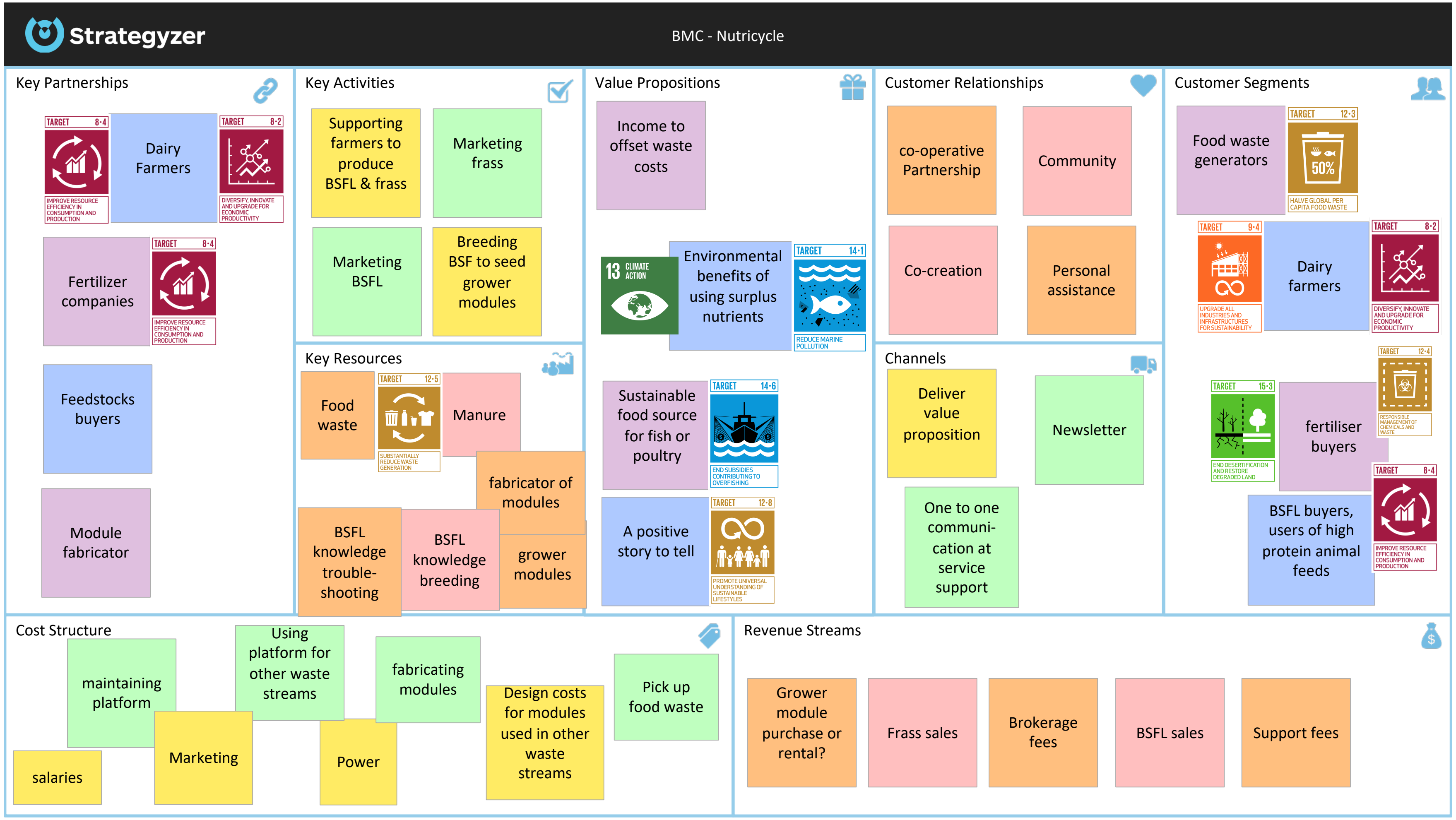


Note. Adapted from Roodt & Dempers (2019) Farm Model: A sustainable diversified farm simulation, Anylogic, https://cloud.anylogic.com/model/bb5ce616-61f0-4503-adaa-d6d751595cf7?mode=SETTING

Figure 39 shows the Business Model Canvas (BMC), and Figure 40 shows the Value Proposition Canvas (VPC) I drew for my 804 paper. Having re-examined them considering the research completed for this thesis, I have decided that they are still fit for purpose as a start point for the enterprise. These would be working documents that would be updated in collaboration with the stakeholders, as I recommend in scenario 2. The notes that accompany these and other recommendations for establishing the enterprise are in Appendix B.

Figure 39

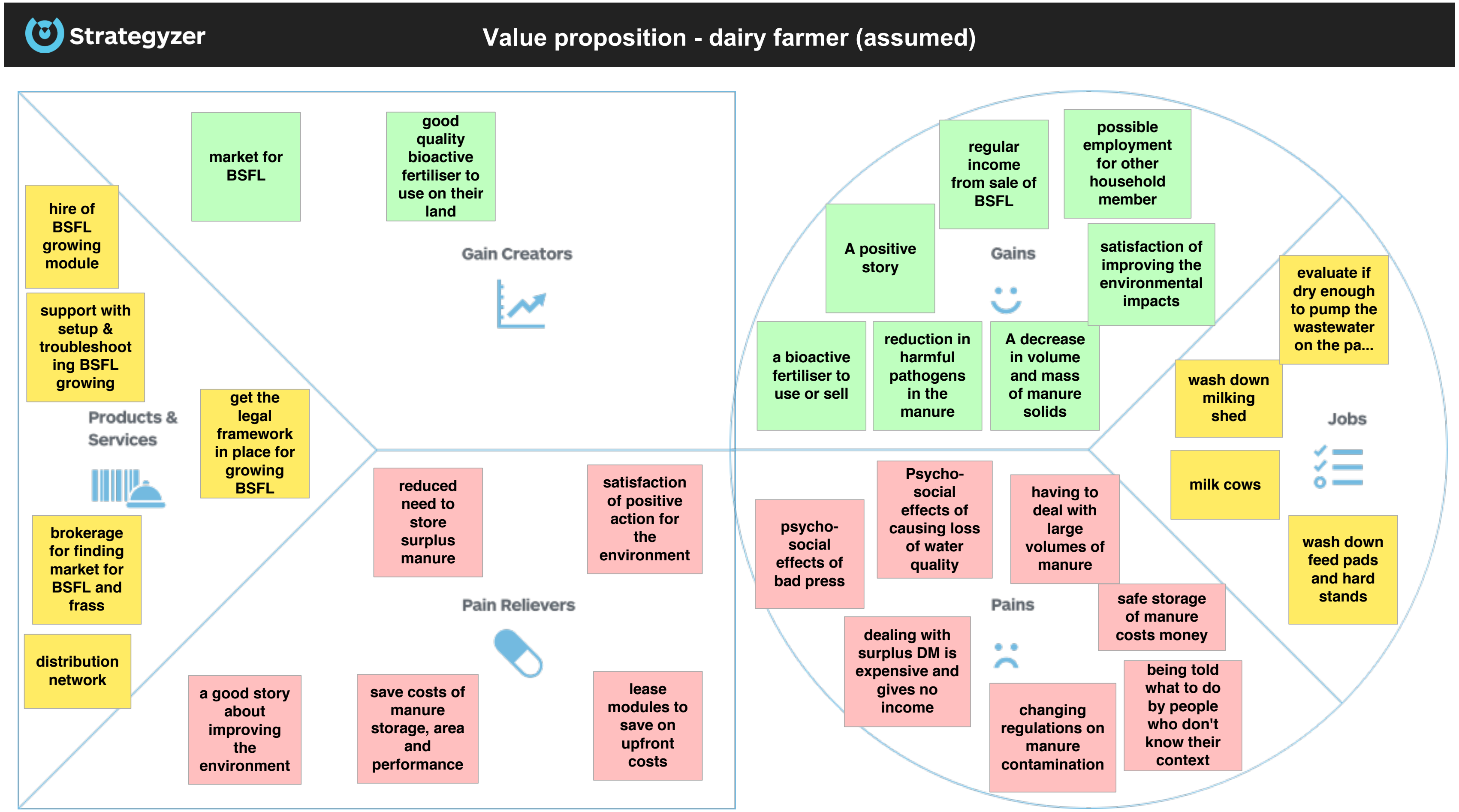
Business model canvas for scenario 1



Note. Taken from my 804 paper (figure 9, p. 38).

Figure 40

Value proposition for scenario 1



Note. Taken from my 804 paper (figure 10, p. 39).

5.2.2 Scenario 2

The aim of scenario 2 is to be a transitional phase to establish BSFL farming in New Zealand. I chose this scenario because my research, work with my own BSFL colony, and conversations with BSFL farmers and other interested parties suggested a few barriers were slowing progress for this business opportunity. Despite these barriers, the accelerating global interest in insect protein and the potential environmental benefits (see Ch. 2.5.6) make it worth continuing to develop and promote the idea. This is a multi-strand scenario, with each strand focussed on an identified barrier.

One major barrier I experienced was the difficulty in getting BSF eggs or young larvae, which I needed to start a colony for research purposes. Although some small scale, lab-based experimentation has been carried out in New Zealand, there seem to be insufficient supplies to allow larger scale field trials. Scenario 2 proposes the importation of the small-scale, high-tech system built by Entoprot, a start-up enterprise based in Finland. I would aim for their medium BSFL bioreactor at $1.9m^3$ which they estimate will provide approximately 760Kg per cycle (Vasala, 2022). They have been running it with their proprietary feed substrate on an 11 day cycle. The breeding system would also need to be imported.

Although the Entoprot bioreactor is a small-scale system that could be scaled up to some extent, it would not be suitable for the scale that would be needed to process the DM on a dairy farm. However, it could be suitable for on-site processing of a smaller scale waste stream, such as a supermarket or an onsite facility where the BSFL will be fed to animals, such as a poultry or fish farm. I suggest basing it near the main waste source to reduce GHG emissions and transport costs. The products of the bioreactor would be much lighter than the waste input, approximately one fifth (Rehman et al., 2017), therefore, it makes more sense to transport the products than the inputs.

The breeding unit would provide eggs and young larvae, initially for use in trials in the bioreactor, and later for other trials in other systems that might be developed. It could also provide young larvae to sell with the home scale BSFL tub (see Ch. 3.6.2) as a starter kit.

The home scale BSFL kit would be used to demonstrate the concept with potential customers, initially dairy farmers, so they could reassure themselves that BSF would not cause a problem. I explored this idea in 804 and had intended to give these kits to dairy farmers to trial during the period of the Master study but was unable to get my colony established sufficiently in the timescale (see Ch. 4.6). The home scale tubs could also be sold to generate funds to run the rest of the system.

The bioreactor could be run with different combinations of biowaste as feedstock. The BSFL grown on each combination could be tested for size, mass, and the nutrient components of the larvae. This would involve collaboration with a laboratory. As part of my recommendations, I suggest getting links to a university or polytechnic to work with students on testing the BSFL. We are currently trialling this idea with a Wintec science student who is investigating the anti-microbial properties of the BSFL fat on pathogens associated with DM such as E. coli and Salmonella. Their research will be completed about the same time as this thesis.

The BSFL grown in the bioreactor could be used to trial feeding to animals and fish, and the frass could tested as a fertiliser/soil improver. The quantities provided should be sufficient to supply larvae for lab work and to run field trials at a larger scale. I've included a few trials I would like to run in appendix L. Results of these trials could be used to provide data to feed into the Any logic model. The anylogic model would be used to generate data for the scenarios, and when scenario two is enacted, it would be used to feed data back into the Anylogic model, which would be used to run model experiments into scenario 1.

5.3 Recommendations

I recommend that we continue investigating ways to get the BSFL processing of biological waste to happen in New Zealand. To do this, I would:

1. Use the Anylogic simulation model of the BSFL biodigester to generate interest in the idea, continually evolving the model towards greater accuracy based on new data and knowledge.
2. Research in more depth the voices of the other customer segments, such as fish or poultry farmers, who could buy the BSFL for feed. Market gardeners, who are potential customers for the frass, which they would use as a soil conditioner, and other stakeholders, such as Māori and environmetalists, to find out their thoughts and feelings about the idea. Going in-depth on so many different aspects was beyond the scope and capacity of this study.
3. Create a collaborative community of scientists, engineers, dairy farmers, BSFL farmers, students, and other interested parties to:

- Advance the knowledge and experience of BSFL farming in NZ.
- Create/assemble the technology to do it in our climate.
- Work on the circular business environment around the inputs and products of BSFL farming using biological waste.
- Work on removing the barriers to, and mitigating the risks of, the farming of BSFL and the use of BSFL products.

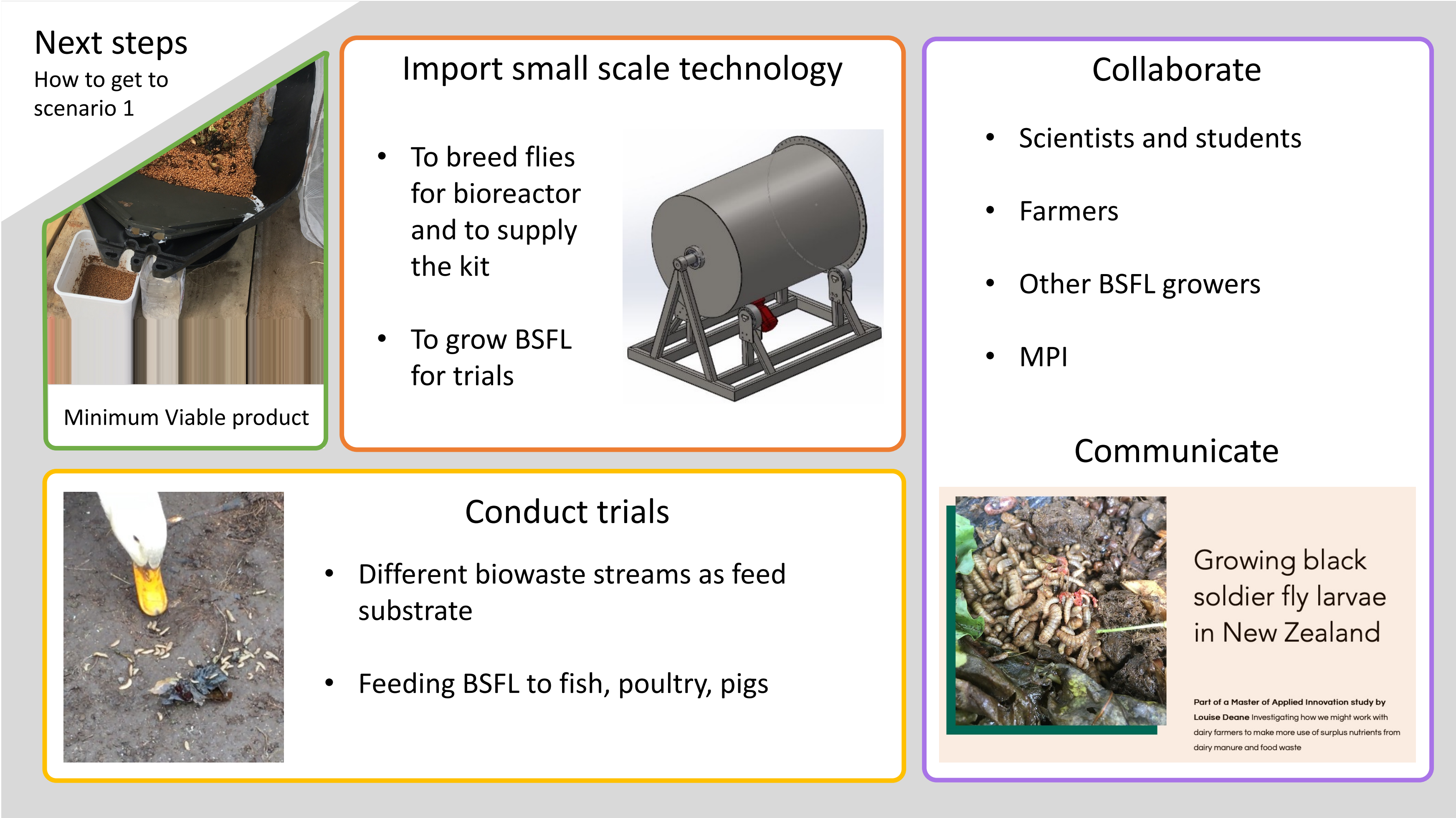
4. Develop an online platform for the above collective, with a private area to communicate and collate knowledge and a public area for sharing information in a clear and easy to understand format, with a positive narrative around the financial and environmental benefits of BSFL farming and education about the value of the circular economy. To encourage a fundamental solution to the problems associated with too many cows, I would ensure the message is about diversifying income streams as a way of maintaining income whilst meeting the need to reduce the number of cows.
5. Conduct field trials of a BSFL Bioreactor, using cow manure and food waste as the feed substrate.

Figure 41 summarises scenario 2 and my recommendations.

In this chapter I have drawn together my findings to inform my fantasy future BSFL biodigester based on a dairy farm, and suggested a pathway to reach this scenario whilst working on getting BSFL farming established in New Zealand. In the next chapter I reflect on my learning journey through this study, and evaluate my progress with the research.

Figure 41

Summary of Scenario 2 and recommendations



Note. Taken from a presentation for the Wintec Te Pukenga Sustainable Futures Symposium (slide 10), created by the author.

Chapter 6 Critical reflection on the learning Journey

In this chapter, I reflect on what I have learned through the course of this research, and where I have got to in relation to my goals and personal practice. I discuss how I have shared this inquiry knowledge and why I think dyslexia might be an advantage in transdisciplinary research.

6.1 Progress made with this research

I experienced many limitations with completing this thesis and consequently making progress with getting the enterprise established. These have included COVID lockdowns, bereavements, delays in completing my building projects which meant they impinged on this thesis, and problems with sourcing BSFL and getting my colony established. In adapting to these situations, I have adjusted my goals. For instance, on discovering that the insect farming businesses in the developed world, that I investigated, have all taken over 10 years to get established, I created more realistic expectations of how far I could get with preparation for the enterprise, and gained an understanding of some of the barriers they experienced, which has fed into scenario 2 and my recommendations.

With transdisciplinary pragmatic action research as my approach, it has been possible to adapt to the limitations experienced and reflexively adjust methods in response to findings and insights. This has led to learning several new skills such as system dynamics and computer simulation modelling. In the COVID lockdowns, I pivoted from face-to-face interactions with farmers to focus on these new skills. By having the freedom to adapt my methods, I managed to gain a much greater understanding of why the issues of surplus nutrients from dairy farming are so difficult to solve using the current approaches, which will improve my innovation. I have also been passing on the learnings from this segment of my research to parties for whom it is relevant and will continue to do so.

Overall, this journey has taught me the importance of being flexible, persistent and determined in the face of challenges. Despite the setbacks, I have gained valuable knowledge, skills and insights that will enable me to contribute to the field of sustainable farming and waste management.

6.2 How my practice has changed with this research

My previous main practice in sustainability has been in my own lifestyle, for example, building eco-buildings and other permaculture practices or voluntaring in community organizations such as T^3, to educate people about environmentally friendly actions. I have had limited paid work in this area. My practice has changed because of my experience in this thesis and the Master of Applied Innovation course tutors and supervisors. When I first had a public meeting with dairy farmers, I managed to offend some by referring to a waste problem. Since then, I have learned to choose my words more carefully and focus on the positive aspects of changes. Learning the skills and theory of TDR has also improved my ability to really listen to what people have to say even when I have a very different point of view. Consequently, I have found it easier to develop a trusting relationship with participants, which in turn has given me access to their genuine feelings and helped me understand their position. I think these skills will be useful preparation for the collaborative process I plan to follow to develop the enterprise. These skills will also be transferable to working with other groups of people and on other wicked problems. In addition, I have learned from the participants about their practice, and this has given me insights for my own.

In the future I would like to find employment in this sector, either in working to get BSFL farming established in New Zealand or in looking at other areas where regenerative change is needed.

By using many different methods and tools in this research, I have gained experience that will improve my practice.

6.3 How I have, and will, share this inquiry knowledge

From the early stages of this research, I have spoken to people at public meetings, and groups such as T^3 about my ideas, to gauge peoples' interest. I fed back my findings as I went along. When I was looking at the fish farming idea, I sent out regular newsletters, to everyone who was interested or had shared their knowledge. For both the fish farming and insect farming ideas, I have had meetings with and presented to Hauraki District Council staff and elected members and met with Economic Development staff at Thames Coromandel District Council and shared my proposal with potential sponsors such as Sanford's and Agrisea.

I made a presentation to enter the Callaghan Innovation C-Prise competition as a way of testing interest in the BSFL farming idea and recieved feedback from the judges. I have also presented to academic audiences at the DFNZ galas and the Wintec Sustainable Futures Symposium, Oct 2022. I networked with the other attendees and presenters and been involved with Ag Research's Circular Economy group run by my Industry Mentor, Dr Gina Lucci.

Currently, I am acting as a client for a Wintec Science student who is analysing anti-microbial properties of BSFL oil against pathogens found in food waste & cow manure. I am about to follow up leads directing me to other people and groups with an interest in BSFL farming in New Zealand. I plan to invite them to collaborate on overcoming the barriers that are slowing down the uptake of this idea. This will be dependant on getting buy-in. I aim to work with the DFNZ to develop a collaborative process for the group.

I started writing a blog about my soldier fly colony experiences to share information. I will put it online when I start the collaboration phase to encourage others to share their experiences. There is also a possibility of me collaborating with my supervisor, Dr. Celine Kearney, to explore and write about my experience as a neurodiverse thinker in relation to transdisciplinary research. We will look at making the most of different ways of working and exploring a problem.

6.4 How my dyslexia has affected this research

In my experience dyslexia has both disadvantages and advantages for studying. I have problems with short-term memory and sequences, which makes it hard to follow sequential processes such as formalized interviews and thematic analysis (TA) and deal with some of the systems in place at higher education establishments, including passwords, technology and parking. I think the advantages are around ability to see the bigger picture and with the analytical, recursive processes of TDR.

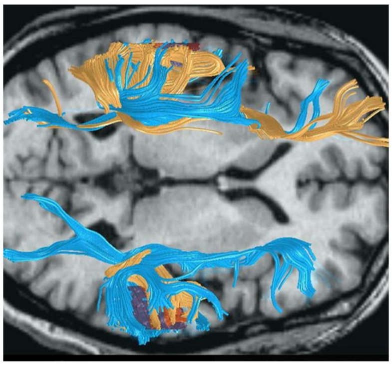
When I first learned about TDR at the start of this course, it was like getting recognition for the way my brain works naturally. In my B. Ed Hon's thesis, completed in 1995, I had combined qualitative and quantitative research even though I was advised against it. I had felt that I wouldn't get enough information from either approach alone. In this research, I have found that the pragmatic TDR suits my intuitive and discursive process.

Both Nicolescu (2010) and Heisenberg (1942, as cited in Nicolescu, 2010) recognize the value of intuition.

Throughout this thesis I have found that the most useful information has come from insight, often after informal conversations when participants are less on their guard, and when I am more relaxed and not focussing on specific questions. I am aware that there may be ethical issues with getting information in this way. However, I sought consent where possible and preserved participants' anonymity. I find I get an intuition to ask a particular question, and that will give me some knowledge. The insight from that answer will come to me later, very strongly. I also find I pick up a lot of peripheral information, from body language, patterns I've seen before, connections my brain makes to other situations, emotions, and instant insights. This method of gaining knowledge is reportedly common to dyslexics (Davis, 2010). Brain scans of people with dyslexic traits show different brain patterns to non-dyslexics, when doing the same activity. Figure 41 shows the wide area of the brain that dyslexic people use to solve problems and gain knowledge. In my experience this allows for multiple perspectives on an issue including that of emotions, which gives a useful skill I call 'reading between the lines'. The flip side of this is that I find difficulty 'knowing things' without lots of information.

Figure 42

Brain patterns in a dyslexic man compared to a neurotypical man



Note. This MRI image shows fibre tracings from diffusion tensor imaging of a dyslexic man as compared with a man with ordinary reading ability. The blue areas show the pattern in the dyslexic man and the buff areas those in the neurotypical man. From "Brain Imaging findings in dyslexia" by Y. Sun, J. Lee and R. Kirby, 2010 *Pediatrics & Neonatology* 51(2), p. 91, (https://www.sciencedirect.com/science/article/pii/S1875957210600174). Reprinted with permission.

Throughout this enquiry, I kept in mind that trusting to insight alone could lead me open to bias. To mitigate this, I used multiple methods to add rigour to the academic process and used the TA to triangulate the data from various sources and collection methods.

From my personal experience, I would argue that intuition and insights are legitimate ways of gaining knowledge, although they do not fit with the academic norm of provability which has come from the classical science framework of Galileo. They do not respond to universal laws and are not necessarily replicable. However, their non provability and the difficulty in tracing the source of insight, as it is drawn from multiple sources often put together in the subconscious mind, should not preclude this knowledge from being legitimate. In my experience, knowledge that arrives in this way often provides the missing pieces that explain why things do not work as we think they should. I think this corresponds with Nicolescu's (2010) concept of the 'Hidden Third', with insight giving clues to the knowledge we cannot know from our own perspective. My experience with this study has given me confidence in the validity of my insights.

Another advantage for dyslexic people in dealing with wicked problems is the ability to see the big picture and to imagine alternatives. Personally, I find that I have a feeling for systems, with a visceral sense for problems in the system.

6.5 A critical reflection on reflexivity in relation to this research

Looking at Popa et al. (2015), in their discussion of reflexivity, I wonder if the challenges of COVID; my operating from outside the industry I am trying to change, and slow progress with getting the BSFL colony established have delayed me getting to that part of the project where the process could be truly considered reflexive. My intentions were to reach a stage where there was more equal collaboration with scientists in the science of BSFL and with farmers in a citizen science exploration of the possibilities of farming BSFL on dairy farms. The individual nature of the Master of Applied Innovation programme may create a power dynamic between the researcher and the participants. At present, I have not set up the Community of Practice where the "mutual learning and co-production of knowledge" suggested by Popa et al. (2015) might address this issue, as I'm not where I hoped to be at this time. I feel that the time to set this up is after the scenarios are shared as these may generate the interest that will find the community.

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Appendix A

Executive summary of my 804 paper

This study explores the potential for using an enterprise to solve the research question *How might we assist dairy farmers to manage the impacts of surplus nutrients on the environment in such a way as to benefit the dairy farmers and the environment?* The complexity and impacts of the issues involved make this a Wicked Problem[2].

Chapter 2 looks at the environmental impacts of surplus nutrients from dairy manure (DM) and chemical fertilisers, such as eutrophication and climate change, the psycho-social effects on stakeholders and the interrelationships within ecosystems.

Chapter 3 follows the journey taken to come up with and refine the above research question; moving from ecosystem-based fish farming that uses surplus nutrients to grow algae for fish feed, to dairy farms as a source of many surplus nutrients. It adds the goals of: creating a circular economy; maximising environmental benefits and developing a viable enterprise. A variety of possible ways to use the nutrients are considered including growing algae in containers; using effluent as water and nutrient source for vertical farming and using DM to grow insects.

Chapter 4 introduces the chosen idea of creating an enterprise to sell farmers the means to use collected DM, with food waste, to grow black soldier fly larvae (BSFL) to sell as animal feed with the added product of the frass, insect manure and exoskeletons, available to use on the farm or sell. The additional benefits of this idea, such as reducing food waste and providing an alternative to unsustainable fish feeds, are considered because of the transdisciplinary nature of this research.

Chapter 5 is a review of the literature about how and why to farm BSFL at a variety of scales and levels, including some factors and suggestions to evaluate. Business tools and

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[2] Wicked Problem: a social or cultural problem that is difficult or impossible to solve for as many as four reasons: incomplete or contradictory knowledge; the number of people and opinions involved; the large economic burden; and the interconnected nature of these problems with other problems Kolko, J. (2012). *Wicked problems: Problems worth solving: a handbook and call to action*. Austen Centre for Design. https://www.wickedproblems.com

canvases such as the business model canvas, SWOT analysis and Value Proposition Canvas are also appraised along with the transdisciplinary tools: Soft Systems Methodologies and Integral Analysis.

In chapter 6 the multiple opportunities are evaluated and the above business tools and canvases used to create an initial business model; plan of how to test it, using design thinking and transdisciplinary methodologies; get funding and start marketing.

I conclude that the research suggests that the idea is worth pursuing in terms of business opportunity, feasibility and potential benefits to people and the environment and that the business model will be refined iteratively as the assumptions are tested.

Appendix B

Building the enterprise (extract from 804)

Methodology

The proposed methodology is to develop a business model for a financially viable enterprise. The reason for choosing an enterprise instead of a charitable organization is that this idea has the potential to generate the income to cover its costs and it is difficult to find ongoing funding for environmental projects aimed at making businesses more sustainable. The business model has been designed, initially, based on a literature review and the insights that were gained from the preliminary public meetings and conversations with farmers and other stakeholders. Further input has come from an investigation into "Bringing regenerative diversification to the Hauraki Plains" conducted by a group of undergraduate students from Design Factory NZ for the Hauraki District Council. As a part of their research, they conducted interviews with stakeholders. At this early stage the business model is also partly based on assumptions.

B.1 Building a business around this idea

The initial literature review (section 5) suggests a range of opportunities exist for creating a business around this idea; some are opportunities to make a business viable and others are opportunities to make the enterprise meet social and environmental needs that have often been seen as externalities to business. With a rise in more conscious consumption there is a growing demand for businesses to meet a triple bottom line[3]. There will potentially be financial benefits in making the social and environmental credentials clear to customers.

B.1.1 The business opportunity

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[3] "The triple bottom line (TBL) is a framework or theory that recommends that companies commit to focus on social and environmental concerns just as they do on profits. The TBL posits that instead of one bottom line, there should be three: profit, people, and the planet" Kenton, W. (2020). *Triple bottom line (TBL)*. Investopedia. https://www.investopedia.com/terms/t/triple-bottom-line.asp

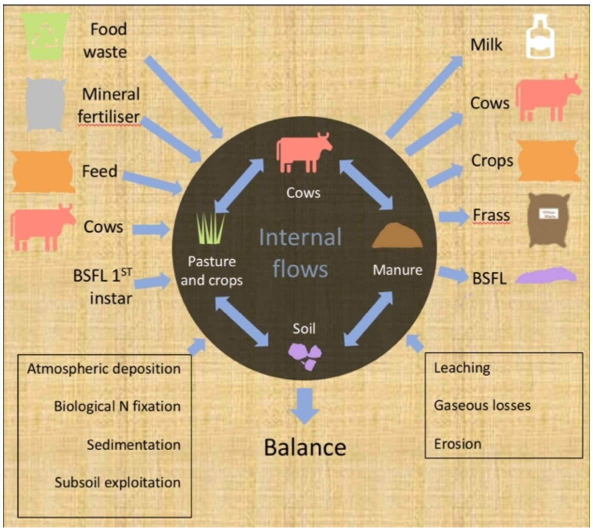
The need to find solutions for the issues mentioned in sections 2 and 4, creates justification for this idea although, by itself, it does not provide a business case, especially as many of these impacts and costs are treated as externalities, i.e. they are not paid for by the industries that cause them. In the case of nutrients from dairy farming, Foote et al. (2015) estimate it is between 2 and 600 times cheaper to reduce nutrients at source than clean them up when they have been leached, a cost that will eventually have to be paid by someone. The business opportunity however comes from the financial, or other, costs to the customers of either solving or not solving these issues and in the case of the dairy farmers, the potential to generate income.

B.1.1.1 The opportunity for the dairy farmer

For the dairy farmer the idea offers a way to help balance farm nutrient budgets. Farm nutrient budgets are now used in many New Zealand dairy farms, with approximately 200 certified Nutrient Management Advisors having been trained by 2017 (Power, 2017).

Figure 43

Nutrient budget diagram for a dairy farm with a BSFL grower module operating



Note. Adapted from "What is the nutrient balance of your dairy farm?" by Q. Ketterings, 2016 (https://blogs.cornell.edu/whatscroppingup/2016/04/20/what-is-the-nutrient-balance-of-your-dairy-farm/). Adapted with pemission.

The BSFL grower module could provide an alternative to larger, expensive, waste storage solutions with the potential for the farmer to generate income by selling the BSFL grown on the DM and brought-in food waste.

The frass could be used on the farm, potentially saving money that would be spent on buying in fertiliser. This would also help with balancing the nutrient budget. Data collated by Foote et al. (2015) suggests that the potential of this enterprise to produce an alternative to chemical based fertilisers, for use on the dairy farm or to sell to other growers, may have a greater environmental benefit than that from reducing the nutrients in the collected DM.

Farmers do use the nutrients in DM to put back on the farm however the processing of the DM and/or food waste by BSFL adds many additional benefits to its value as a fertiliser.

- Reduction of pathogens such as salmonella, campylobacter spp. and clostridial spp.
- Changing the form of the nutrients to make them more bioavailable to plants thereby promoting pasture growth, reducing leaching and runoff, and absorbing more CO^2 from the atmosphere.
- Introducing beneficial microbes that help generate healthy soils.
- Reducing methane emissions from the decaying DM

(Beskin et al., 2018; Green & Popa, 2012; Liu et al., 2019).

Because the frass is a more effective fertiliser than DM, less may be needed and any surplus could also be sold, generating more income.

B.1.1.2 For the food waste generator

This idea uses food waste as a proportion of the feed substrate for the BSFL as research has found that BSFL grow faster if a suitable food waste is combined with the DM as a food source for the larvae. Rehman et al. (2017) found, in their experiments feeding BSFL on a 2:3 mix of DM and soy curd residue, that it "… demonstrated that a balanced nutrition and buffering capacity enhances the total waste conversion efficiency and helps with the digestion of material which cannot be well utilized by BSF". This enterprise would provide a viable alternative to dumping food waste in landfill or composting it. Perednia et al. (2017) found a significant reduction in greenhouse gas emissions when processing food waste with BSFL compared with aerobically composting it.

The benefits for the food waste generator would be to reduce the considerable costs of dumping food waste. As a resource the food waste would acquire value. At the least this should reduce costs for the food waste generator and has the potential to generate income if the type of food waste, perhaps due to high protein content, makes it a particularly nutritious feed for the BSFL.

B.1.1.3 For the fish farmer

This idea has the potential to provide a sustainable, high protein, nutritious feed source for the aquaculture industry. Tschimer and Kloas (2017) state “Insect meal as an alternative protein source in aquafeeds is a promising candidate both to meet the growing demand for animal protein and to greatly increase the sustainability of aquaculture production systems in the long run”. The growing size of the aquaculture industry is increasing demand for suitable fish feeds. Overfishing, and public concern about it, is leading to increasing pressure on aquaculturalists to find alternatives to wild caught fish and their products. The demand for fishmeal has increased due to the growth of the aquaculture industry and this has led to the price of fishmeal tripling between 2000 and 2015 (Lalander et al., 2019). For farmers of Marine and carnivorous species, these alternatives need to contain certain polyunsaturated fatty acids and amino acids that are not found in plant-based alternatives but are found in insect meal and oil (Tschimer & Kloas, 2017). In trials using BSFL as feed for farmed barramundi, Katya et al. (2017) concluded that “Observations from the fish feeding trial, augment well for the use of black soldier fly larval meal as the dietary protein source in fish feeds”.

B.1.2 Reflection on COVID 19 as it may impact on the business opportunity

One of the effects of Covid 19 has been an increased trust in science and scientists. During this event New Zealanders are generally following the advice of scientists. This may have positive implications in the area of regenerative farming. Regenerative farming is gaining interest, for example, most of the current series of country calendar has been around this topic and there have been many articles on Radio New Zealand. I think that this may provide an opportunity. Getting farmers, scientists and other stakeholders working together to make informed changes is part of a just, informed and empowered transition that this enterprise aims to be part of.

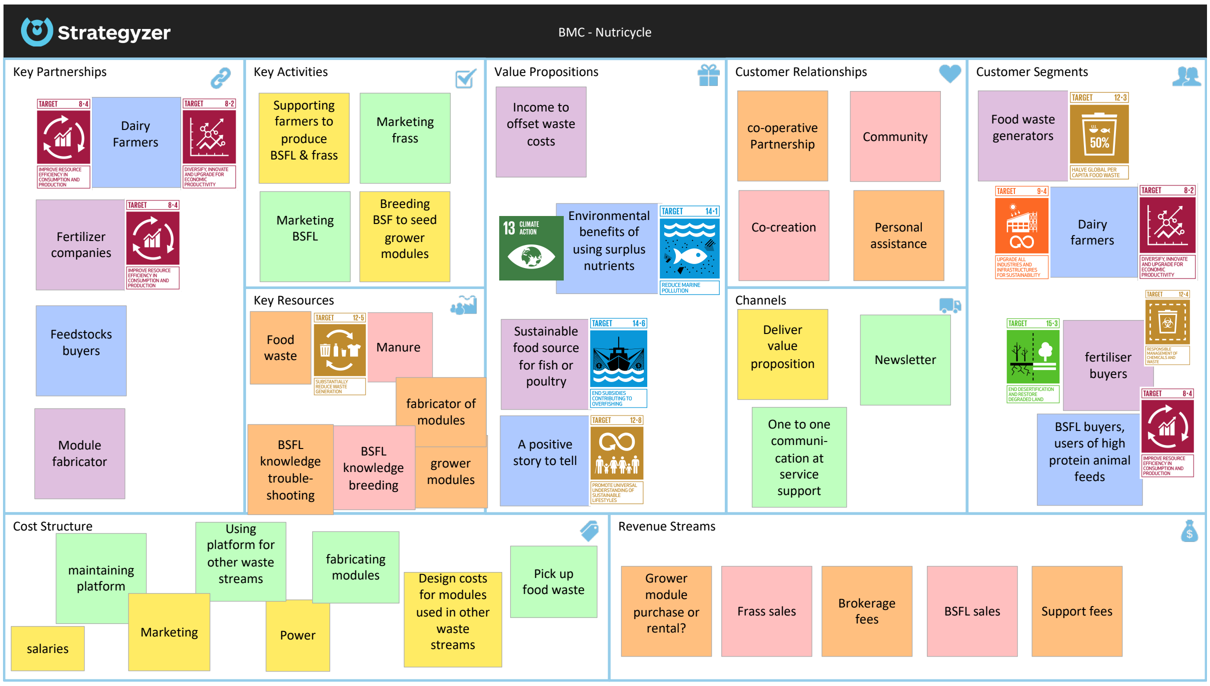
B.2 Discussion of initial business models and validation exercises for the proposed enterprise

The following BMC is aimed at the business when it is past the start-up stage. It will be updated as the ideas within it are tested. In order to include the environmental and social goals of the enterprise, I've added the UN Sustainable Development Targets that each factor most closely works towards. These targets are aimed at governments not business so I've used some licence when choosing them.

I've also used the BMC as a basis for a spreadsheet on which to add more detail and keep track of the tools I use to test the assumptions and the insights gained from these tests (see section 6.5).

Figure 44

Business Model Canvas for the business when up and running



Note. I included the relevant UN Sustainable development goals and targets so that it gives a more complete picture of the triple bottom line nature of the enterprise.

B.2.1 Additional thoughts around customer segments

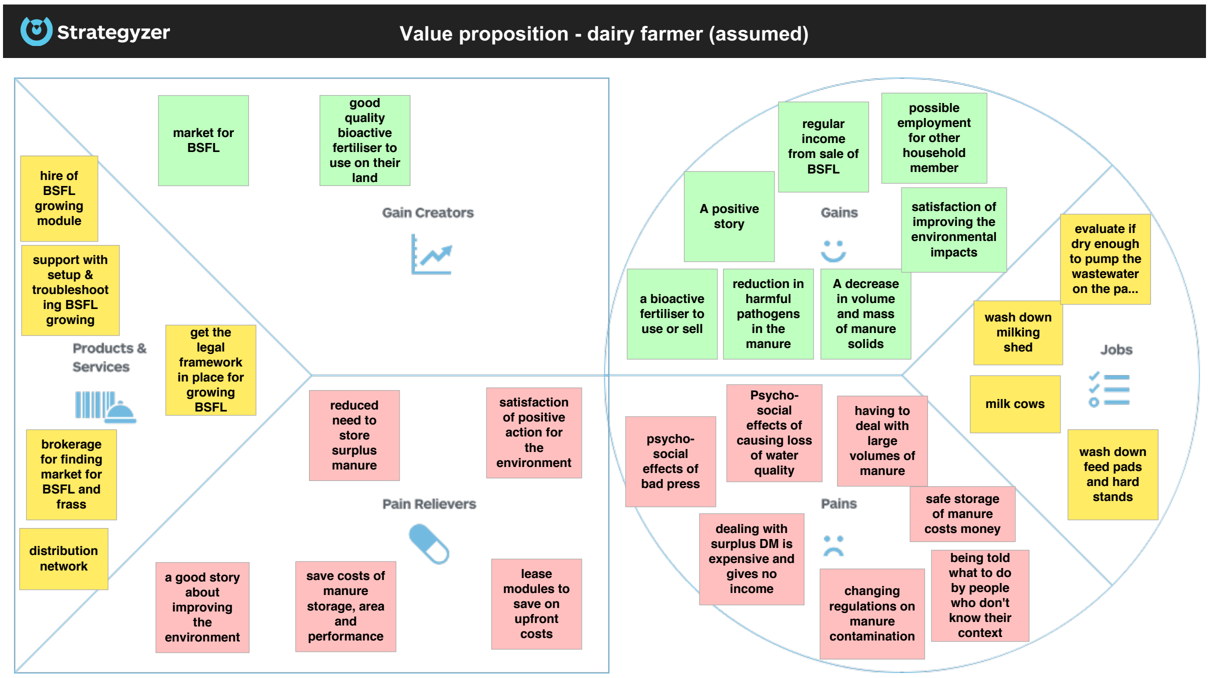
This enterprise will use a multisided platform as dairy farmers will be one just one segment. They will purchase the BSFL grower modules and the success of these modules will be dependent of finding customers for the BSFL and frass. The market is niche and different buyers of the BSFL may be segmented as they will be buying the same product for slightly different reasons. The food waste brought in to feed the BSFL, may need to vary depending on the specific nutritional needs that the BSFL buyer has to meet for their livestock. This could involve customisation of the product for different BSFL customers.

B.2.1.1 The value propositions

Using research into the opportunities, I have created a Value Proposition Canvas for each customer segment. I have included the VPC for dairy farmers here and attached the others in appendix C in the full 804 document.

Figure 45

Value proposition canvas for dairy farmers.



As with the BMC I've created a spreadsheet for each VPC, following the same format, to give a structure for taking the next steps in getting prepared to start the enterprise (see appendix C, Paper 801).

This enterprise is based around an innovation; a different way of meeting the dairy farmer's need to balance nutrient budgets. It should provide potential for cost reduction, in the area of DM management, and the potential to create income from the waste stream. It could create value by diversifying the income stream for the farmer thereby reducing the risk of relying on existing income streams which are at risk from changes in markets and increasing costs due to legislation changes and climate change impacts. The BSFL grower module will need to be designed in a way to be easy to use. It could be a way to improve farmer status by reducing their environmental impacts.

B.2.1.2 More thoughts on the Key Partners

The business model I would like to go for would be an open business model as at this early stage of the 'use of insects as feedstock' industry it might be more cost effective to collaborate with stakeholders and competitors. With competitors it could be useful to get together to look at the different aspects of the idea and decide on a part each could investigate; for example, others may have the more technical information on growing BSFL and we might look into the barriers to doing this in NZ such as temperatures; the legal situation and possible markets for the larvae and frass. I think there is big enough potential in this idea to give room for a few players.

B.2.1.3 Customer relationships – a place for the community in the structure of the enterprise

Relationships centred on co-creation and community would provide a way to run the enterprise with transdisciplinary values at the core. Collaboration within the community could involve working together with the dairy farmers and module designer to refine the best ways of growing the BSFL. In addition, the dairy farmer partners that grow the BSFL could work together on finding the best feed substrates to get the most appropriate nutrition into the BSFL for the market they will be aimed at. Setting up a community in such a way that encourages stakeholder science collaboration and makes it as easy as possible, could be a useful part of the key activities of the enterprise ensuring an informed, reflexive enterprise.

Keeping links with academia through organisations such as the New Zealand Institute for Rural Entrepreneurship would be useful as it aims to link rural enterprises with academic support.

B.2.1.4 Channels

The community will need an interface and this may be one of the channels. Depending on the technical skills of the stakeholders this could be a community website where farmers can share experiences and data and ask for help or advice. The exact form this takes could be co-created with the community. In the interest of keeping stakeholders informed it could also be a repository for research that the community has found. Farmers could interact with this if they wish to keep up to date with the science.

Another aspect of the community interface will be that of sharing good news. Having a space for good news stories will help with advocacy. One role of the enterprise will be to get this good news out into society.

B.2.1.5 Balancing cost structure and revenue stream

The spreadsheet, table 4, shows some of the main costs and possible revenue streams for the enterprise.

Table 11

Potential main costs and revenue streams.

Main costs	revenue streams
design of modules	grower module purchase or rental?
fabrication of modules	service fees
Sales and marketing	brokerage fees
salaries	income from sales of BSFL
collecting food waste?	income from sales of frass
	fee to collect food waste?

Some of the revenue streams will depend on how the business is structured, which will depend on the model favoured by the stakeholders. This is also likely to change between the business start-up phase and establishment phase, for example, at the start-up phase, the brokerage fee may be covered in the support fee. The income from sales of BSFL and frass will only come to the enterprise if the dairy farmers partner with the enterprise to sell the BSFL and frass, if not it will go directly to the dairy farmer. At this stage I'm not yet able to give an estimate of costs and income as more research is required. As part of the next steps, I aim to find out the following to inform the design and, as a result, the budget:

- Volume of DM collected per mean NZ dairy farm.
- Volume of food waste required to give a ratio of 2:3 DM to food waste.
- What are the costs to industries of disposing of food waste, i.e. could we charge to collect it? or will we need to pay for it?
- What are farmers spending on storage of DM? this will inform what they are prepared to pay for an alternative.
- What business structure is preferable to the dairy farmers?

- What is the legal situation in New Zealand about using insects, grown on manure, in animal feed?

These next steps will form part of the validation of the business idea.

B.3 SWOT analysis

Figure 46

SWOT analysis matrix for the proposed enterprise.

SWOT

Strengths

- Innovative.
- Big picture thinking skills.
- Skills in reimagining.
- Transdisciplinary approach to get big picture and help with buy in.
- Links to the Design Factory and Wintec supervisors for cooperation, prototyping expertise and business experience.

Weaknesses

- Not an established business.
- Profit has not been my motivation which may mean I need to upskill in this area.
- Lack of experience of accurate financial planning.
- Transdisciplinary approach can get confusing for self and to explain to others.

Opportunities

- Novel idea in NZ.
- Meets a need for using surplus nutrients.
- Uses waste as inputs to create useable product as outputs.
- Diversifies farm income streams.
- Upcoming changes in regulation re: managing nutrients.
- Positive environmental impacts for nutrient pollution and sustainable fish feed and fertiliser.
- Increasing interest in regenerative farming and circular economy.

Threats

- Lack of buy in from farmers.
- Potential reductions in numbers of cows on farms may reduce the amount of DM collected. (can be mitigated by using higher proportions of food waste).
- Other company, already established in BSFL farming abroad, deciding to do this in NZ.
- Legislation about the use of BSFL may not be up to date in NZ yet.

A next step with the SWOT analysis will be to consider how to capitalise on the strengths and opportunities and mitigate or eliminate the weaknesses and threats.

B.4 Lean start-up: Starting with the minimum viable product

One suggestion of the idea of lean start-ups is that of starting with the minimum viable product in order to minimise the financial risks and effort of trying out a new idea, just in case the idea does not work or needs refining. The BMC for this enterprise (figure 6) shows that there are many key activities listed. As part of the master's thesis I'll need to decide what can be cut out of the model and still have the enterprise work.

- Some infrastructure would still be needed to grow the BSFL. Perhaps it could be less automated though it would still need to provide a suitable environment for the BSFL to grow. It could initially be run just in the summer as a trial, with the modules being refined as the trial continues.

- Could the process be modelled at a much smaller scale using existing technology such as the Biopod or homemade equivalents, to demonstrate to farmers the process of growing BSFL?
- Could the idea be initially trialled with farmers who also grow chickens so the need to find a market can be delayed?
- Could the enterprise be run with a single employee? They would need to help set up the modules and train farmers in their use. The farmers could then find their own market for the BSFL and frass?
- Rather than the enterprise employee providing all the support, the farmers could use their community to help each other work out how best to grow the BSFL land what food waste to mix with the DM. This would require there to at least be an online community. A wiki-based website would work well for this. There are a range of existing applications that would work for this so there would be no need to build a bespoke one, at least until we know how farmers will use the forum.

B.5 Lean social canvas for the enterprise

Figure 47

A Lean Social Canvas for the enterprise in its early stages.

Purpose

To be part of the solution for the environmental issues caused by surplus nutrients by treating those nutrients as a resource for a circular economy

Impact

- To reduce surplus nutrients from DM and food waste, getting into the environment
- To showcase a circular economic model in farming
- To provide an alternative to fish meal or soymeal in feed for aquaculture or poultry farming

Problem

- Managing collected dairy manure (DM) is difficult, expensive and if not well managed it can cause environmental harm
- Chemical fertilisers are expensive and have environmental impacts
- Dairy farms are often dependent on a small number of income streams

Existing Alternatives

- Storage of DM, for later use on the farm, in lined ponds
- Storage in tanks or bladders
- Separation of DM solids with reuse of the liquid as washdown water.

Solution

A product that helps dairy farmers use the DM as a a feed to grow black soldier fly larvae. The larvae can be sold as a high protein feed for fish or poultry and the Frass (manure and cast-off exoskeletons) can be used on the farm and/or sold, to generate income for the farmer.
A service to support the use of the above product; breeding the flies and assisting with sales of the outputs.

Key Metrics

- 50% mass reduction in the combined food waste and DM after it has been processed by BSFL in the grower module
- Successfully grow BSFL in NZ on 2 organic waste streams including a manure and a food waste
- BSFL accepted as a food source for animals
- Net positive financial benefit for the dairy farmer
- Have the enterprise be financially viable and sustainable

Unique Value proposition

- Income to offset waste costs
- Environmental benefits of using surplus nutrients
- Sustainable food source for fish or poultry
- A positive story to tell

Unfair Advantage

- This is not being done in NZ yet
- We will design the infrastructure to fit the scale and methods used on NZ dairy farms
- The product meets needs both on and off the farm

Channels

- Deliver value proposition
- Newsletter
- One to one communication at service support

Customer segments

- Dairy farmers are the main customer

Customers that the dairy farmer will sell to assisted by this enterprise

- Food waste generators
- BSFL buyers, users of high protein animal feeds
- fertiliser buyers

Early Adopters

Dairy farmers who are into regenerative or organic methods

Cost structure

- Salaries
- Designing modules
- fabricating modules
- Marketing
- Sales

Revenue

- Grower module purchase or rental?
- Support fees
- Brokerage fees

B.6 Testing this business model

These assumptions will be tested using a variety of techniques including, but not limited to those used in Design Thinking, such as Empathy Mapping, ideating and getting feedback, interviews with stakeholders and customers and use of financial modeling tools. These tools will be used to verify that the idea and the business model will provide the value it aims to offer to the enterprise owner; the dairy farmer; customers of the BSFL and frass, and other stakeholders in both the business and the wider issue. I will keep track of the testing carried out and the insights gained, using the spreadsheets I designed to accompany the BMC and the VPC's (see table 5 and appendix C)

Table 12

Part of the spreadsheet, based on the BMC, that I will use to track testing of assumptions

Topic	Description	Hypotheses	Experiments	Evidence	Insight	Attachments
About this BMC system	This BMC is based on the Strategyzer system. See attachments for a link to their homepage.					https://www.strategyzer.com/
How to use this template	This template gives a structure for completing a business model canvas and recording any actions you take to test it. It works with the Business Model Canvas on PowerPoint.	What are you looking to validate?	What experiments would validate this sticky?	What did you learn from this sticky? This can include from experience, experiment or literature review	What insights did you gain about this sticky?	Attach links to any images, videos, documents or presentations that relate to this sticky.
Fill in each section of the VP with stickies from the VP canvas						
Attach link to matching VP PowerPoint presentation						
1. Customer Segments						
Dairy farmers	Dairy farmers with surplus dairy manure	Dairy farmers need a way to use up surplus dairy manure				
Food waste generators	Industries which create food waste such as: supermarkets; restaurants; markets; market gardeners; breweries; coffee shops; etc	Food waste causes significant costs to these industries				
fertiliser buyers	Farmers, gardeners or fertiliser suppliers that would buy a nutrient dense and bioactive fertiliser ingredient	Fertiliser buyers would be prepared to trial new fertiliser products/additives				
BSFL buyers, users of high protein animal feeds	Industries that need a high protein animal feed such as: aquaculture; poultry farming; pet food suppliers; pig farms					
2. Value Propositions						
Income to offset waste costs	Waste processing is a significant cost to farmers. Selling BSFL and frass could provide an income to offset costs	Waste processing on dairy farms is a significant cost to farmers				
Environmental benefits of using surplus nutrients	Surplus nutrients can get into waterways and harm ecosystems					
Sustainable food source for fish or poultry	Fish farms often use unsustainable sources of fish food such as wild caught fish	NZ aquaculture uses unsustainable fish food				

Insights gained by this testing will be used to iteratively update the business model. Prior to starting the business, research will be carried out into the legal, ethical and policy implications of the idea and how it is carried out. Prototyping will be used as a way of refining the design of the infrastructure needed to grow the BSFL.

All research will be carried out in an ethical way with the methods being approved by an ethics committee.

B.6.1 Using a transdisciplinary approach

Customers and key partners will be directly involved in the prototyping of infrastructure, the refining of the product and the development of the business model as these will need to work for customers. Buy in from customers and key partners will be especially necessary as this idea is new in New Zealand. Tools such as Peter Checklands's

Soft Systems Methodology and Ken Wilber's Integral Theory will be used to organize and analyse information as it is generated.

B.6.2 Validation exercises carried out so far

I have already conducted some initial exercises to start testing the validity of the idea.

B.6.2.1 Presentation for Callaghan Innovation's C-Prize competition

I entered the C-Prize competition as a way to practice the skills needed to promote business ideas and as a means of validating this enterprise idea. For the entry I had to complete a visual presentation and a 2 minute video of myself, describing the idea (see appendix B for the full presentation). Although it was not one of the 10 ideas chosen to go forward, out of the 140 entries, the feedback was positive about both the idea and the presentation.

B.6.2.2 Ground testing the use of BSFL to compost food waste and as a food for ducks

After discovering black soldier fly larvae in my compost cage (see figure 4), I decided to do a very basic test to see how popular they were as a feed for ducks. I fed some BSFL to my ducks for 2 days and videoed their response. On day 1, it took the ducks almost a minute to start eating the larvae, which I had placed among some of their usual feed. Once they realised that the larvae were edible it took them about another 40 seconds to eat them all. On the second day the ducks ate all the larvae within 40 seconds. Although this was not a very scientific test it did show BSFL to be a popular feed for muscovy ducks. I also observed that when the BSFL processed the food waste the pile was reduced much quicker than when there were compost worms but no BSFL present. The residual frass has a granular structure and is moist and less wet that the worm casts.

B.7 Responding to change

B.7.1 How the enterprise might respond to potential changes on dairy farms

One of the threats coming up for dairy farming, is the potential need to reduce dairy cow numbers due to climate change regulations or changes in demand for milk. With the potential to grow BSFL on a variety of biological waste streams, if the volume of DM is reduced, the proportion of food waste or other manures such as poultry or pig manure, could be increased in the substrate and the modules could still operate to capacity.

B.7.1.1 Changing scale and changing scope

One reason for considering a modular design is to allow the operation to be easily scaled up; the capacity could increase to a certain level by adding modules.

There seem to be many potential opportunities for growing the scope of the business which would allow for it to expand or respond to change in the future. The research so far suggests that the BSFL will grow on a wide range of biological waste streams in very similar environmental conditions. This would make the grower module suitable for use in a number of different settings including the following:

- At a supermarket for dealing with food waste.
- For a group of households for their food waste to reduce the need for transporting the waste.
- At a zoo to process manure and food waste and provide feed for animals such as reptiles.
- As a waste treatment plant for humanure.

B.8 The initial marketing

Initial marketing will be aimed at those dairy farmers identified, by the business idea testing that has and will occur, as being more open to innovation and receptive to regenerative farming ideas, as they are more likely to be early adopters. With this in mind, directing marketing at the recently formed regenerative and organic farming groups might be useful along with stands at agricultural field days. Partnering with organic farmers will have the advantage of minimising chemical contamination of the DM used as the substrate to feed the BSFL. I will also work on getting exposure in more mainstream dairy farming by approaching Dairy NZ to see if they would be willing to trial the idea on one of their research dairy farms.

B.9 Getting start-up funding

By entering the Callaghan Innovation C-Prize I gained experience of applying for funding in a competitive environment. After phase 1 of the competition, Callaghan Innovation suggested they may be able to help me find funding sources in the future. I will follow up this lead and re-approach Te Waka, the Waikato Economic Development Agency, whom I visited previously to discuss my initial, ecosystem based fish farming, idea. Wintec Design Factory also has contact with business funders and may be able to assist with this.

Appendix C

How BSF are being domesticated around the world at different scales and levels.

It has been showed that BSFL can be domesticated at a variety of different scales and levels of technology. I've included a few examples to illustrate this. Many of the earlier trials of using BSFL to process biological waste streams have taken place in developing countries where the legislative environment is less strict. In the past few years, trials have been being conducted in more developed countries and as thorough testing has taken place, the laws, that have previously restricted how BSFL can be farmed and how they can be used as feed for animals, are gradually being amended.

C.1 Home scale, medium technology

The Biopod, designed by Protaculture LLC (2007) in America, is an off the shelf, home scale BSF farm made of roto-moulded plastic. It is now sold in many countries around the world. There are many homemade variations with similar features to this design. These are aimed at using biological wastes and/or manures to grow BSFL for feeding to poultry, pets, or fish on a very small scale.

C.2 Medium scale, modular, very high technology

Entocycle is based indoors in London, UK and has developed fully automated breeding and growing modules that can grow BSF and process large quantities of food waste in a small space and clean environment, very quickly. They use very specific food waste streams and aim ultimately, to produce BSFL suitable for human food. The currently sell high technology BSF breeding and BSFL growing units.

C.3 Medium scale, low technology

A company in Kenya, called Bio Resource Based Sanitation, collects humanure from sources such as schools and slum areas. It uses simple dry toilets that separate the urine from the faeces. They collect the faeces daily and take it to a processing unit where it is fed to BSFL. These are harvested after 10 days and used to feed chickens or fish. (Ro, 2019)

C.4 Large scale, high technology

Hangzhou Tianyuan Agricultural Company rears black soldier fly larvae on an enormous scale on huge industrial pig farms in China. Many of the systems are automated.

Appendix D

Greenhouse gas emissions from different forms of composting

Method	conditions	CH4 emissions (kg CO2-eq t-1 DM)	N2O emissions (kg CO2-eq t-1 DM)	CO2 emissions	GHG emissions excluding biogenic carbon (kg CO2-eq t-1 DM)	GHG emissions including biogenic carbon (kg CO2-eq t-1 DM)	NH3 emissions (g/kg)	Notes	Reference	Implications for my study
BSFL	Variety of pHs tested. Substrate was Food waste and rice straw at 9:1. I have chosen to use the results for pH7 as dairy manure tends to make the substrate more alcali and food waste generally makes it more acidic so the combination balances the pH.	0.03	0.25	144.61	0.28	144.89	0.99	pH of feed substrate affects these significantly so I have chosen the range from pH3 to pH11. this C has a biogenic origin (IPCC, 2007). Hence, only CH4 and N2O were taken into consideration when calculating the total GHG emissions. Taking the global warming potential of CO2 as 1, that of CH4 and N2O was 25 and 298, respectively. high pH value of the substrate effectively enhanced BSFL in recy- cling C and N. BSFL can recycle 1.95–13.41% and 5.40–18.93% of the C and N in the substrate into stable and readily harvestable biomass such as fat and protein. Emissions based on dry weight.	(Pang et al, 2020).	This has implication for the benefit of using DManure in the feed substrate due to its tendency to increase the pH. Maintaining a slightly lower temperature keeps more of the nitrogen in the frass
Hot composting	Temperatures > 45oC	37.5	357.6		395.1		2.71		*GHGs, Yang et al., 2019. (Amonia, Komilis and Ham, 2006; Yang et al. 2013; Zhang et al. 2016 as cited in Pang et al, 2020)*	
Static pile	Substrate = dairy manure	31	2.5	141	33.5	174.5			Ahn, et al., 2011, cited in Naushin et al., 2022	
Anaerobic digestion		0.02			0.02				MFE, 2022	
Hot composting	Substrate = dairy manure	153	48	587	201	788			Mulbry & Ahn, 2014, in Naushin et al., 2022	
Vermicomposting	Substrate = dairy manure + tomato stems	2.28	5.76		8.04				Yang, et al. 2017 cited in Naushin et al., 2022	
Disposal in landfill with gas recovery	Food waste	0.602			0.602			CO2 and n20 emissions are not included in IPCC estimates as the co2 is assumed to be biogenic and the N2O is assumed to be insignificant	MFE, 2022	
Disposal in landfil without gas recovery	Foodwaste	1.881			1.881				MFE, 2022	

Note. This table contains data adapted from the following sources: (Ministry for the Environment, 2022a; Naushin et al., 2022; Pang et al., 2020)

Appendix E

Pilot interview survey questions

Questionnaire about dairy manure/effluent system

1. What is your role in the farm? ____
2. How many cows do you run on your farm? ________________
3. Which dairy manure effluent system/systems do you have on your farm? E.g. weeping wall, screw press, effluent pond, herd home, feed pad, other
   ____
4. What capacity do they have? i.e. What volume of dairy manure/effluent can they store?
   ____
5. What percentage of spare capacity would you estimate the system has for your farm?
   ____
6. What other equipment do you need to operate your system?
   ____
   ____
7. What did each system cost upfront?
   ____
   ____
8. What are the ongoing costs associated with your system/systems?
   ____
   ____
9. Approximately how many hours are spent interacting with the waste system/systems per week?
   ____
10. How often does the slurry/solids need to be removed from the system/systems?

____

11. How long does this take?

____

12. What happens to the slurry/solids when the system is emptied?

____

____

____

____

Thank you very much for answering this questionnaire. If you would be willing to consider being involved in the early prototyping stage of this research, please write your name below.

____

Please keep the copy of the participant information sheet and consent form for your information.

Appendix F

Ethics application

Wintec WAIKATO INSTITUTE OF TECHNOLOGY Te Kuratini o Waikato	**Research and Postgraduate Office (RPGO)** **Human Ethics in Research Group (HERG)**

LOW RISK HUMAN ETHICS IN RESEARCH APPLICATION FORM

Please refer to the Ethics Guidelines prior to completing this application.

The RPGO is located at the City Campus, D-Block (Offices D2.22 – D2.24), email research@wintec.ac.nz or phone Megan Allardice on Ext. 3582 for more information.

Please see the last page of this document for detailed instructions for completing this form.

1.0 PROJECT TITLE	
	From waste to resources: making the most of surplus nutrients from dairy manure and food waste

2.0 RESEARCHER(S)		
2.1	Primary researcher's name	Louise Deane
2.2	School//Centre/Unit	Design Factory
2.3	Contact Details (Telephone and E-mail)	Tel: 0223016797 Email: louise.earthcamp@gmail.com
2.4	Is this application a:	☒ Student Application ☐ Staff Application

2.5	If this is a student application, please provide the Module code here	908
2.6	Is this project a staff application that utilises work partially or wholly undertaken by students who are not participants (e.g. data collection undertaken by a researcher's class)?	No
2.7	If so, please clearly describe what the role of these students is to be in this research, what the work will be used for explicitly (including any issues regarding authorship of research outputs such as journal articles), and what steps have been taken to ensure students are aware of this.	N/A
2.8	Name of other Researcher(s) and positions. (If this is a student application please provide the name(s) of the project supervisor(s) and indicate that they are supervisors here.)	Supervisor: Dr Henk Roodt Dr Celine Kearney
2.9	Contact Details of other researchers and/or supervisors (Telephone and E-mail)	henkroodt@icloud.com Celine.Kearney@wintec.ac.nz Ext 3618
2.10	Is this application:	☒ A new application ☐ A subsequent approval request following a significant change to an already approved application

3.0 PROJECT TIMELINE	
	Projected start date for **data collection** *(once this ethics application is approved. Please note, projects can only begin once applications have been approved, regardless of the level of risk)*: This research is grounded in a two-paper Postgraduate Certificate in Innovation completed throughThe Design Factory NZ, at Wintec: TDRI 801 and TDRI 804. This masters' level paper TDRI

908 will develop the project explored in the two previous papers to a further stage of application and trialing. The project will take place over four phases:

1. As a first step, I will conduct an exploratory pilot project to gather information about how dairy farm waste systems operate. I have conducted a literature review of different types of dairy farm effluent system and aim to visit 3 dairy farms and ask farmers to walk me through their waste systems so I can more fully understand how they work. This will involve informal interviews with farmers and may involve observations. I will use the information to help finalise the interview questions for the second phase.

2. I aim to start to conduct surveys and interviews with dairy farmers about their waste systems, from August /September 2021.

3. In phase three, I aim to deliver prototypes of a small scale BSFL growing tub to farmers, from December 2021.

4. Following data collection and proptype trialing I will facilitate a collaborative process to upscale the prototype and develop a business model. This will take place from March 2022.

Projected end date: 1/11/2022

4.0 PROJECT SUMMARY (please include your research purpose and objectives, methodology will be dealt with in Section 6)

The purpose of this research is to investigate how we might work with dairy farmers to manage the impacts of surplus nutrients on the environment, in such a way as to benefit the dairy farmers and the environment. I aim to conduct the study in the Hauraki area.

This question could be answered in many possible ways. In order to narrow the range of possibilities I included the following goals:

1. To answer the question in such a way as to convert biological waste products into resources that can be used to feed animals and/or plants, i.e. to create a circular economy.
2. To maximise the environmental benefits from the solution.
3. To build a viable enterprise around the research question.

With these in mind and a review of the research into possible options, I chose to research the idea of creating an enterprise to sell farmers the means to use collected dairy manure (DM) combined with food waste, to grow black soldier fly larvae (BSFL). The BSFL will be:

1. sold as animal feed
2. with the added product of the frass, insect manure and exoskeletons, available to use as fertiliser on the farm or to sell.

I intend to look at a collaborative business model with dairy farmers as active participants in the research into both the growing of the BSFL and in the creation of the business model. Black soldier fly larvae are being used around the world to process biological wastes, from food waste to various manures and human sewage. The larvae are being used as feed for fish, poultry and pigs and are being investigated as a food for humans. The frass, manure and exoskeletons from the larvae are used as an ingredient in fertiliser as this combination provides nutrients in a form that are accessible to plants. This is being done at a variety of scales and levels of automation (Singh & Kumari, 2019).

Singh, A., & Kumari, K. (2019). An inclusive approach for organic waste treatment and valorisation using Black Soldier Fly larvae: A review [Review Article]. *journal of environmental management, 251*. https://doi.org/10.1016/j.jenvman.2019.109569

5.0 PROJECT METHODOLOGY (including methods for data collection)

Transdisciplinary frame

As this is a complex, real-world problem I am working within a transdisciplinary frame which requires using multiple disciplines working in a relational way with an attitude of openness and collaboration (Leavy, 2016). The predominant methodology will be pragmatic action research (Creswell & Creswell, 2018) and within that I will use mixed methods due to the complexity of the subject and the variety of things I need to find out to create the enterprise. I will draw on Design Thinking, particularly as used in the Strategyzer business book, Testing Business Ideas (Bland et al., 2020).

Quantitative Scientific Studies

I will need to conduct some quantitative scientific studies on the Black soldier flies, including:

- Optimum conditions for growth
- Impacts of different waste streams as feed substrate for BSFL
- Whether BSFL bioaccumulate cadmium at sufficient levels to cause harm if using dairy manure as a feed substrate

Animal Ethics

I have put in an Animal Research Ethics Application for this aspect of the research (13/5/21) and been informed that animal ethics is not required for working with insects though will be required later when testing the larvae as a feed for other animals or fish.

Human Ethics

Pilot study

A pilot study with 3 farmers will be used to get information about different dairy farm waste systems. This will involve informal interviews and a walk through of the system with the farmer. It may also involve some observation. I anticipate that this may help eliminate from the study those farms whose waste systems are least adaptable to the idea I am proposing.

Survey

A survey will be sent out to at least 30 dairy farmers about the jobs they complete and the needs they have around waste management. I aim to use survey monkey for this however I may have some paper copies in case computer use is an issue for some farmers. This will involve a range of questions including some about practical matters such as the the size of the dairy herd and the amount of dairy manure (DM) collected. They will also be asked about the steps they complete as part of processing and using the collected dairy manure/effluent and their level of satisfaction with each step.

Interviews

I aim to conduct at least 5 interviews with dairy farmers. Open questions will be used to drill down into the specific jobs and needs identified in the survey.

Mixed methods

The combination of pilot study, survey and interviews will be used to:

- triangulate the results to see how well they match (Creswell & Creswell, 2018).
- help ensure that researcher and participants have a shared understanding of the meanings of vocabulary.
- explore the context.

Data gathered from the survey and interviews will be used to gain insights into:

1. Where the waste system could be adapted to use natural processes to convert the nutrients into forms that are more readily available to plants and/or animals, and are less likely to be leached.
2. How an altered system could fit into farmers' workflow.
3. Whether and how it might reduce the size of effluent storage facilities.
4. How much manure the BSFL growing module would need to accommodate.
5. Whether and how it might create income to offset the costs of waste processing.

Initial prototype testing

In addition to the interviews I plan to find up to 10 farmers to trial a basic prototype black foldier fly larvae (BSFL) growing farm to see their response to the concept. I will give the farmer participants a briefing on how to use the prototype and any health and safety considerations they need to take into account and will also leave a paper copy of this information. I'll leave the prototype with them for at least 2 cycles of growing BSFL then interview them about their experience. Cycles are approximately 16 days though will be dependent on the feedstuff and environmental conditions. The length of time taken for the BSFL to grow to prepupae will be recorded. I will allow 2 months for 2 cycles, to take into account variability in the growth speed.

Scaling up and creating the business model

I then aim to involve farmers more in the development of the scaled up prototype and the creation of a business model that will work for them. This may involve a focus group. The focus group will meet at least once and there will be a means for the group to share observations, insights and ideas. The communication method will be decided by the group.

Potential for changes due to using Pragmatic Action Research

As pragmatic action research involves a collaborative process with participants having input into how the research develops, and methods being adapted based on continual evaluation of if and how they are working (Creswell & Creswell, 2018), there may be some changes to the methods throughout the study. Gibb's Reflective Learning Cycle will be used to continuously evaluate and iteratively update the research methods. These methods fit well into the transdisciplinary framework. If this process suggests a significant alteration to the research methods, an updated ethics approval will be sought.

Bland, D. J., Osterwalder, A., Smith, A., & Papadakos, T. (2020). *Testing business ideas*. Wiley.

Cresswell, J. W. C. J. D. (2018). *Research Design: Qualitative,quantitative & mixed methods approaches* (5th ed.). Sage edge.

Leavy, P. (2016). *Essentials of Transdisciplinary Research: Using problem-centered methodologies.* Routledge.

6.0 CONSIDERATON OF ETHICAL ISSUES AND PROCESSES

Please describe below the process that you have undergone in order to discuss and analyse the ethical issues present in this project. (For example, who have you consulted in regards to ethical issues or in completing the screening questionnaire and this Low Risk application)

I have consulted my supervisors, Dr. Henk Roodt and Dr. Celine Kearney about ethical issues with working with farmers and and attended a sessions on ethics by Dr Jonathon Ryan and Dr. Celine Kearney.

I have consulted with Jeff Wilson, Head of Applied Science, regarding animal ethics and was informed that Animal Ethics approval was not needed for working with insect larvae. It will be sought when research extends to using the BSFL to feed fish or animals.

In order to be sure that this topic is worth investigating further I have conducted a thorough literature review of research into growing BSFL both as a means of processing waste and as a feed and fertiliser source. There are a rapidly growing number of examples of this idea being used at a variety of scales and levels of technology yet there appears to be a gap in the market for a medium scale, medium technology BSFL growing module that would work on NZ dairy farms. I am satisfied that there is sufficient evidence to suggest that exploring this idea will provide enough potential benefits. For me there is the potential of future paid employment. For the participating farmers there is a possibility of a future income stream that could offset the costs of waste treatment. For the environment there are the potential benefits of:

- Creating an environmentally friendly high protein animal and fish feed from a waste product
- Processing the nutrients in collected dairy manure and food waste into a form more available to plants and less likely to be leached
- Making use of food waste that might otherwise go to landfill and create methane

Pilot Study

For the pilot study I will follow up on leads I have been given. I will be be visiting AgResearch to meet with Gina Lucci on the 13th July and will ask there if they have suggestions for farmers who may be willing to show me their waste systems. This will require up to an hour of the farmer's time. Participants will be asked to sign a consent form and given an information sheet (see appendices)

Surveys and interviews

I will approach participants about the surveys and interviews through existing farmer groups and give an information sheet and ask for expressions of interest in being involved.

Inclusion in the study is on a voluntary basis. If my pilot study suggest that some waste systems are unsuitable I will make this clear when asking for expressions of interest.

Participants will receive a Participant Information Form, and a Participant Consent Form, so they will be well informed about the purpose and processes of the study. (Both forms are attached as appendices to this application, as is the list of question topics for interviews).

Participants will be able to choose the time and place of their interview which will be audio recorded and sent back to each participant after transcription so they can be comfortable with the accuracy of the interview narrative. Interviews will require up to an hour of the farmer's time.

Since stress levels and suicide rates are currently high among farmers I will bring contact information for Farmstrong NZ to the interviews in case a farmer shows signs of stress (Farmstrong NZ is an organisation that provides mental health support for farmers).

Participants will be able to withdraw from the study with no consequences up until the data is analysed. If they wish to withdraw they can let me know by emailing me and receiving a confirmation email back from me. The process for withdrawing is given on the consent form.

Data and transcriptscollected in surveys and interviews will be kept in password protected online storage, in ZIP format, that only I and my supervisors will have access to. Interview recordings will be transcribed using an artificial intelligence engine and any printed copies of transcripts will be kept in a locked file in the researcher's office. Participants' identity will be kept private at all times. Psuedonyms will be used in the writing up of data and analysis to protect participants' anonymity. Participants can choose to be acknowledged by name if they consent. Transcripts and surveys will be kept for 7 years for research purposes.

Initial Prototype testing

Participants will be given a small scale BSFL growing tub to use. They will be given instructions on how to set it up and any health and safety considerations they need to take into account. They will also be given a record sheet to complete. The time commitment will be approximately an hour to set up the tub and note down the mass and texture of DM also the type, mass and description of food waste. For most of the cycle they will require few minutes each day to check on the tub and take a photograph and note what is happening. They will require a few more minutes at the end of each cycle to measure the mass of BSFL prepupae that self-harvest and the mass of frass. After the 2 cycles they will be interviewed about their observations and ideas and asked if they are willing to be involved in the focus group.

If after the interviews and prototyping it is decided that the idea of growing BSFL is unfeasible, undesirable or unviable, the data collected from the interviews will be used to look at other ways the DM waste system could be adapted.

Focus Group

The focus group will be made up of participants who are interested in taking the idea further. They may self-select from the interview or prototyping group or express interest at a public meeting. Participants will be asked to sign an agreement to behave in a way that is respectful to all participants. The time and effort commitment will be decided by the group.

If any participant experiences any difficulty with any aspect of their participation, there are contact names and email addresses available on the Participant Information Form – including that of the Masters in Innovation Academic Co-ordinator and Research Leader, Dr Anthea Fester.

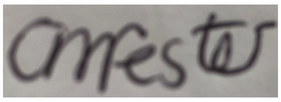
Treaty of Waitangi

I will be attending a Te Tiriti workshop on the 11th of July to find out how to go about ensuring my idea is acceptable to Iwi. I will then follow the suggested protocol.

Researcher(s) signature(s) (the <u>name and signature</u> of all researcher(s) are to be included):

Name	Signature	Date

Supervisors' signature (if this is a student application):		
Name	**Signature**	**Date**
Dr Jan Hendrik Roodt		25/08/2021
Dr Celine Kearney		01/07 2021

Research Leader's signature:		
Name	**Signature**	**Date**
Anthea Fester		03/08/21

HERG Chairperson or delegated representative's signature (RPGO use only):		
Name	**Signature**	**Date**

HUMAN ETHICS IN RESEARCH LOW RISK APPLICATION FORM - CHECK LIST	
Research project title:	From waste to resources: making the most of surplus nutrients from dairy manure and food waste
Name of primary researcher:	Louise Deane

Attached please find (as applicable) in the order listed below	
Completed HERG Low Risk Application Form	☒ Yes ☐ No
Consent Form for participants	☒ Yes ☐ No
Information Sheet for participants	☒ Yes ☐ No
Copy of Focus Group Questions, Interview Schedule, or similar	☒ Yes ☐ No

Appendix G

Appendices to the Ethics Application

G.1 Participant consent form

From waste to resources: making the most of surplus nutrients from dairy manure and food waste

(one copy to be retained by the Research Participant and one copy to be retained by Researcher)

I…………………………… (participant's name) consent to being a participant in the above-named research project, and I attest to the following:

1. I have been informed fully of the purpose and aims of this project
2. I understand the nature of my participation
3. I understand the benefits that may be derived from this project
4. I understand that I may review my contributions at any time without penalty
5. I understand that I will be treated respectfully, fairly and honestly by the researcher/s, and I agree to treat the other participants in the same way
6. I understand that I will be offered the opportunity to debrief during, or at the conclusion of this project
7. I have been informed of any potential harmful consequences to me of taking part in this project
8. I understand that I may withdraw from the project up to the data analysis stage (without any penalties) by emailing Louise Deane at: loudea03@student.wintec.ac.nz. Withdrawal will be confirmed by return email

9. I understand that my anonymity and privacy are guaranteed, except where I consent to waive them

10. I understand that information gathered from me will be treated confidentially, except where I consent to waive confidentiality

11. I agree to maintain the anonymity and privacy of other participants, and the confidentiality of the information they contribute

12. I understand that if I have any concerns I can contact the Academic Supervisors Dr Henk Roodt at: henkroodt@icloud.com, Dr Celine Kearney at Celine.Kearney@wintec.ac.nz or Dr Anthea Fester at: Anthea.Fester@wintec.ac.nz

Participant………………………………………………………Date……………

Principal Researcher: Louise Deane Date…………….

G.2 Participant information sheet

Dear farmer

My name is Louise Deane and I'm studying for a Master of Applied Innovation through Wintec, looking at how we can make more effective use of the nutrients in the collected dairy manure from milking sheds and hard stands. I have an idea for a solution to this and need to test if and how it could work. In order to do this I first need to understand how the various waste systems on dairy farms work and how farmers interact with these systems.

Data will be collected by visiting various dairy farm effluent systems to see the processes involved then surveying and interviewing farmers/farm workers who work with the systems. The purpose of the survey and interviews is to get information that will help us understand how working with the waste system effects farmers and how the system fits in the context of the farm. What works well about it and what you feel could be improved.

The data collected will be used to gain insights into:

1. Where the waste system could be adapted to use natural processes to convert the nutrients into forms that are more readily available to plants and less likely to be leached.
2. How an altered system could fit into farmers' workflow.

3. What size an alternative system would need to be.
4. Whether and how it might reduce the size of effluent storage facilities.
5. Whether and how it might create income to offset the costs of waste processing.

Would you be willing to be interviewed for approximately an hour to assist with this?

Participation is voluntary and you retain the right to withdraw up until the data is analysed, by contacting me on the email address below. To protect your privacy, data will be stored securely and any published data will be anonymous.

Your valuable contribution will be acknowledged in my thesis and in any publications, with your permission.

I will send you a summary of the research results.

If you have any concerns, queries or further discussion, please feel free to contact me via email on: loudea03@student.wintec.ac.nz. Or you could contact my academic supervisors: Dr Henk Roodt at: henkroodt@icloud.com, Dr Celine Kearney at Celine.Kearney@wintec.ac.nz or Dr Anthea Fester at: Anthea.Fester@wintec.ac.nz

Thank you for any help you can give me.

Louise Deane
loudea03@student.wintec.ac.nz

Date:

G.3 Draft questions for the farmer interviews/survey

1. How many cows do you run?
2. Approximately how much Dairy manure/effluent do you collect per day?
3. What type of dairy manure waste system do you have?
4. What steps does the effluent/collected manure go through in the system you have?
5. What storage capacity do you have for effluent/dairy manure?
6. How satisfied are you with the waste system you have on a scale of 1 to 5 with 1 being very unsatisfied and 5 very satisfied?
7. Please give reasons for your rating above.
8. List the jobs you do related to the effluent system.
9. How much time do you spend on each job per week?

10. Rate each job for your level of satisfaction.
11. Please give reasons for your rating above.
12. Would you be willing to be involved in further investigations of effluent/dairy manure waste system ideas?

Appendix H

Survey questions

dairy farm waste system

Start of Block: Default Question Block

Participant information

Dear farmer

My name is Louise Deane and I'm studying for a Master of Applied Innovation through Wintec, looking at how we can make more effective use of the nutrients in the collected dairy manure from milking sheds and hard stands. I have an idea for a solution to this and need to test if and how it could work. In order to do this I first need to understand how the various waste systems on dairy farms work and how farmers interact with these systems. Data will be collected by visiting various dairy farm effluent systems to see the processes involved then surveying and interviewing farmers/farm workers who work with the systems.

The purpose of the survey and interviews is to get information that will help us understand how working with the waste system effects farmers and how the system fits in the context of the farm. What works well about it and what you feel could be improved. The data collected will be used to gain insights into:

1. Where the waste system could be adapted to use natural processes to convert the nutrients into forms that are more readily available to plants and less likely to be leached.
2. How an altered system could fit into farmers' workflow.
3. What size an alternative system would need to be.
4. Whether and how it might reduce the size of effluent storage facilities.
5. Whether and how it might create income to offset the costs of waste processing.

Participation is voluntary and you retain the right to withdraw up until the data is analysed, by contacting me on the email address below. To protect your privacy, data will be stored securely and any published data will be anonymous. Your valuable contribution will be acknowledged in my thesis and in any publications, with your permission. I will send you a summary of the research results. If you have any concerns, queries or further discussion, please feel free to contact me via email on: loudea03@student.wintec.ac.nz.

Consent

1. I have been informed fully of the purpose and aims of this project
2. I understand the nature of my participation
3. I understand the benefits that may be derived from this project
4. I understand that I may review my contributions at any time
5. I understand that I will be treated respectfully, fairly and honestly by the researcher/s, and I agree to treat the other participants in the same way
6. I understand that I will be offered the opportunity to debrief during, or at the conclusion of this project
7. I understand that this research has Wintec Ethics Committee approval
8. I understand that I may withdraw from the project up to the data analysis stage, by emailing Louise Deane at: loudea03@student.wintec.ac.nz. Withdrawal will be confirmed by return email
9. I understand that my anonymity and privacy are guaranteed, except where I consent to waive them
10. I understand that information gathered from me will be treated confidentially, except where I consent to waive confidentiality
11. I agree to maintain the anonymity and privacy of other participants, and the confidentiality of the information they contribute
12. I understand that if I have any concerns I can contact the Academic Supervisors: Dr Henk Roodt at: henkroodt@icloud.com, Dr Celine Kearney at celine.kearney@wintec.ac.nz or

Aidan Bigham at aidan.bigham@wintec.ac.nz

- I give my consent (1)
- I do not give my consent (2)

Q1 Personal details - *optional*

- Name (1) ____
- Email address (2) ____
- Phone number (3) ____
- Gender (4) ____
- Ethnicity (5) ____

Q2 What is your role on the farm?

- Owner (1)
- Manager (2)
- Farm worker (3)
- Other - please describe your role here (4)
____

End of Block: Default Question Block

Start of Block: Block 2. Some details about your dairy manure/effluent system

Q3 How many cows are run on your farm?

0 200 400 600 800 1000 1200 1400 1600 1800 2000

Milking ()	
Other ()	

Q4 What are the dairy manure/effluent system/s you have on your farm? - please click on each system

- Effluent pond, unlined (1)
- Effluent pond, lined (2)
- Weeping wall (3)
- Vibrating screen (4)
- Screw press (5)
- Herd home (6)
- Compost barn (7)
- Other - Please describe here (8) ____________________

Q5 Approximately what percentage of dairy manure produced on your farm is collected in your dairy manure/effluent system

	0 10 20 30 40 50 60 70 80 90 100
Percentage ()	

Q6 What is the approximate capacity of your dairy manure/effluent systems in cubic metres?

- Effluent (1) ____
- Separated solids if applicable (2)

  ____

Q18 What happens to the dairy manure solids on your farm?

- Shipped off the farm - If so, where to? (1)

  ____
- Spread back on the pasture (2)
- Composted - If so, how are they composted (3)

  ____
- Other - please describe (4)

  ____

Q7 What other equipment do you use as part of your waste system?

- Pump and hoses (1)
- Loader (2)
- Muck spreader (3)
- Other - Please describe here (4)

  ____

Q8 In an average week, how many hours are spent interacting with your waste system?

▼ 0 - 3 (4) ... more than 11 (7)

Carry Forward Selected Choices from "What are the dairy manure/effluent system/s you have on your farm? - please click on each system "

X→

Q9 What upfront costs are associated with your system, in $1,000s?

- Effluent pond, unlined (1) ____
- Effluent pond, lined (2) ____
- Weeping wall (3) ____
- Vibrating screen (4) ____
- Screw press (5) ____
- Herd home (6) ____
- Compost barn (7) ____
- Other - Please describe here (8) ____

Q10 What are the ongoing costs associated with your system in $1,000s per year?

- Labour (1) ____
- Power (2) ____
- External contractors (3) ____
- Other - please describe & state costs (4) ____

End of Block: Block 2. Some details about your dairy manure/effluent system

Start of Block: Block 3 - level of satisfaction with your dairy manure/effluent system

Carry Forward Selected Choices from "What are the dairy manure/effluent system/s you have on your farm? - please click on each system "

X→

Q11 How satisfied overall are you with your dairy manure/effluent system/s?

	Very unsatisfied (1)	Unsatisfied (2)	Neutral (3)	satisfied (4)	Very satisfied (5)
Effluent pond, unlined (x1)	•	•	•	•	•
Effluent pond, lined (x2)	•	•	•	•	•
Weeping wall (x3)	•	•	•	•	•
Vibrating screen (x4)	•	•	•	•	•
Screw press (x5)	•	•	•	•	•
Herd home (x6)	•	•	•	•	•
Compost barn (x7)	•	•	•	•	•
Other - Please describe here (x8)	•	•	•	•	•

Carry Forward Selected Choices from "How satisfied overall are you with your dairy manure/effluent system/s?"

X→

Q12 Please give reasons for your satisfaction levels in question 11; include specific aspects or jobs that you feel strongly about.

- Effluent pond, unlined (1) ____
- Effluent pond, lined (2) ____
- Weeping wall (3) ____
- Vibrating screen (4) ____
- Screw press (5) ____
- Herd home (6) ____
- Compost barn (7) ____
- Other - Please describe here (8) ____

Q19 What factors would influence you to change your dairy farm waste system? Please rank from 1-6 with 1 being the most influential and 6 being the least. Click on and drag each factor into rank order.

______ Cost (1)

______ Time it takes to operate (2)

______ Improved environmental performance (3)

______ Able to be retrofitted onto your existing system (4)

______ Simple to operate (5)

______ Potential to generate income (6)

Q16 If time and budget were not a factor, what changes would you make to your dairy manure/effluent system? and why?

____

____

____

____

____

End of Block: Block 3 - level of satisfaction with your dairy manure/effluent system

Start of Block: Block 4 - Attitudes and values

Q13 Attitudes and values - Please click all the statements that apply to you or that you most agree with

- Animal wellbeing is my top priority (1)
- I work hard to improve the environmental performance of the farm (2)
- Profitability is the most important indicator of a good farm (3)
- I consider myself to be a regenerative farmer (4)
- When choosing farm infrastructure I take ongoing costs into account (5)
- I like to continue farming the way I always have (6)
- I like to keep up with new ideas and research (7)
- I prefer to create my own solutions to problems on the farm (8)
- I take advice on what I need to do from knowledgeable sources (9)
- I like to try new ideas (10)
- I like to balance profitability, environmental care, animal wellbeing and life/work balance (11)

End of Block: Block 4 - Attitudes and values

Start of Block: Block 5 - further participation in the study

Q14 Please indicate if you are willing to be contacted for further participation in this study

- I am willing to be contacted to be interviewed in order to provide more detailed information about the subjects of this questionnaire. Please add your email address or phone number here if you didn't above (1)

____

- I might be interested in testing a prototype (2)
- I am not willing to participate further (3)

Q18 Please can you give the names and contact details for any other dairy farmers you think may be willing to fill out this survey.

____

____

____

____

____

End of Block: Block 5 - further participation in the study

Appendix I

Survey report

Q1 - Participant Demographics

Gender

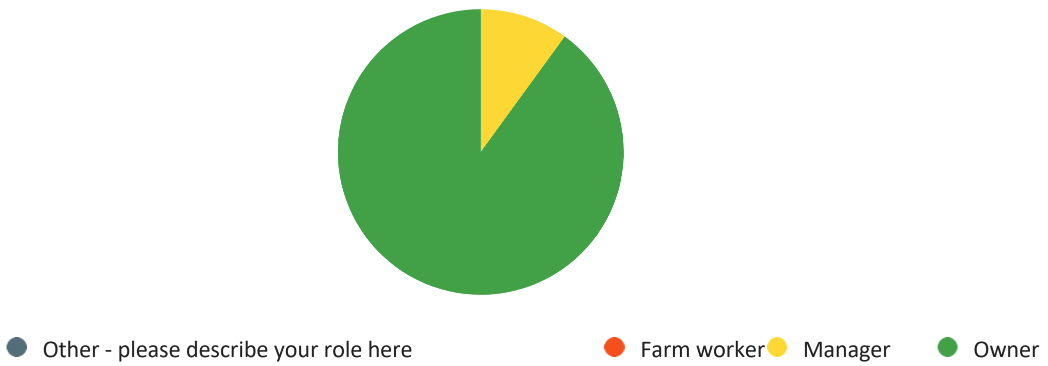
Male = 9
Female = 1

Ethnicity

European/
Pākehā = 5
New
Zealander/
Kiwi = 2

Q2 - What is your role on the farm? - Selected Choice

10 Responses

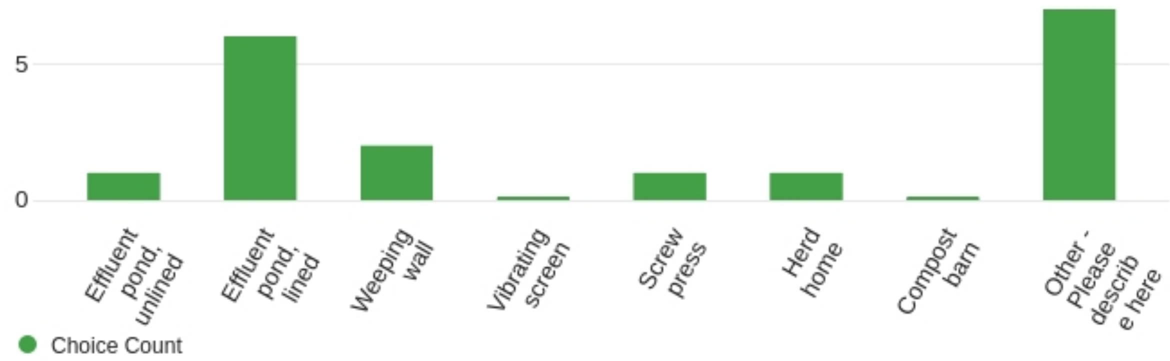


Q3 - How many cows are run on your farm?
9 Responses

Field	Min	Max	Mean	Standard Deviation	Variance	Responses	Sum
Milking	252	1300	609	303	91754	9	5477
Other	0	1726	575	814	662017	3	1726

Q4 - What are the dairy manure/effluent system/s you have on your farm? - please click on each system - Selected Choice

9 Responses



Q4_Other - Please describe here

7 Responses

Other - Please describe here - Text

Stonetrap
Saucer

off yard to stone trap to saucer and then goes into clay lined storage pond which holds 3.6 million litres or 90 days storage

travelling irrigator that can bypass pond if conditions are appropriate for spreading. The effluent goes into a concrete bunker for air travelling irrigator

Covered wintering pad, effluent scraped into pond. Cows calve on woodchip which is then spread on paddocks. 172000cu (approximately)

chanel

Seperating screen

Feed pad uncovered with flood wash into a settling pond through a weeping wall.
The feed pad is 60% finished

Q5 - What percentage of cow manure is collected on your farm?

8 Responses

Field	Min	Max	Mean	Standard Deviation	Variance	Responses	Sum
Percentage	7	100	36	28	768	8	284

Q6 - What is the capacity of the dairy manure and effluent storage on your farm in cubic metres?

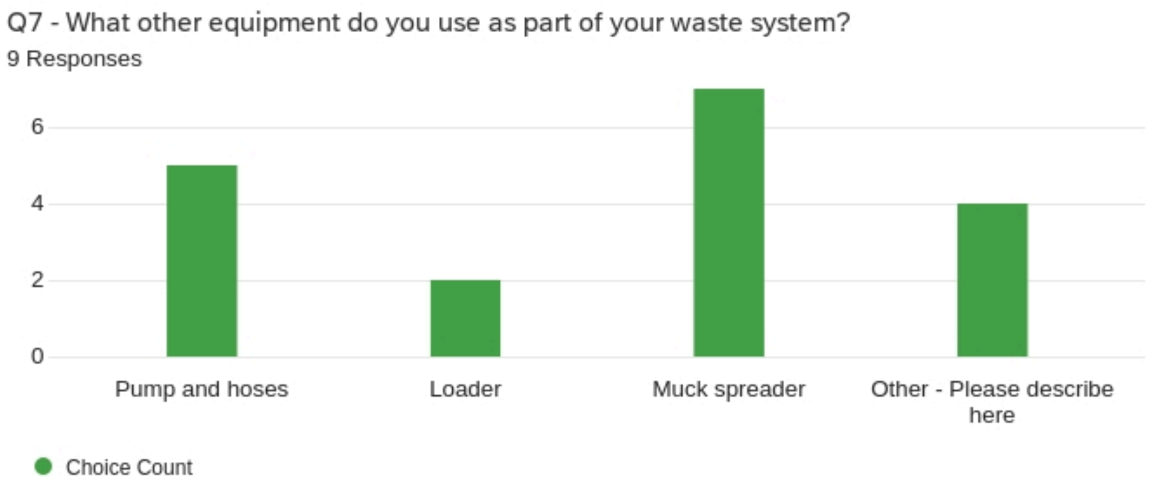
9 Responses

Effluent	Separated solids if applicable
N/A	N/A
4000	30
3600 m3	no - stir and pumped out
1500	N/A
688	960
172000	N/A
8000	300
2000000	N/A
200	50
Guess 80 m long 50 m wide 3,5 deep	50m long 12 m wide and 2 m deep

Storage capacity of the dairy farm waste system surveyed

	Effluent	Separated solids
	0	0
	4000	30
	3600	0
	1500	0
	688	960
	172000	0
	8000	300
	2000000	0
	200	50
	14000	1200
mean storage	220398.8	254

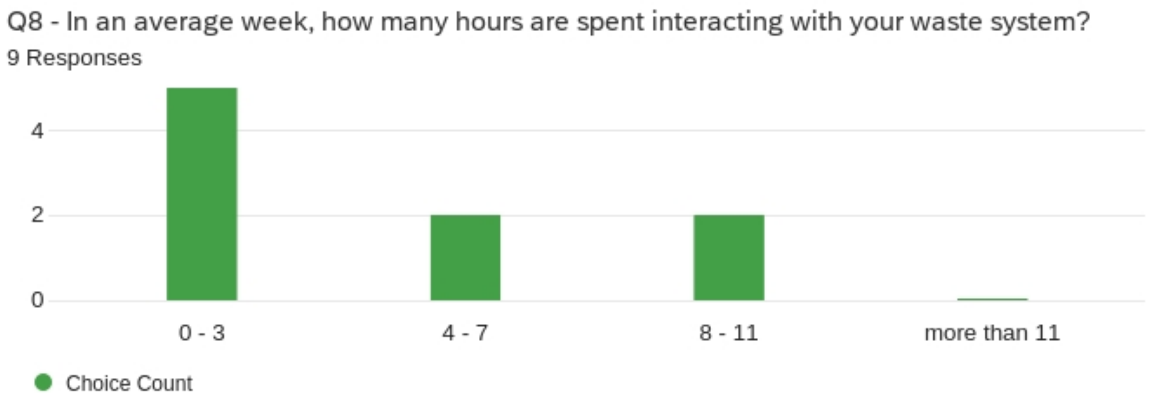
Note. I cleaned up the data from Q6 so I could get the mean storage capacity.



Q7 - Other

4 Responses

Pivots, silage wagon, slurry tanker, tractor
vacuum tanker - 12,000 litres at a time to spread on paddock
Pump the liquids and muck spread the solids
Cobra travelling irrigator

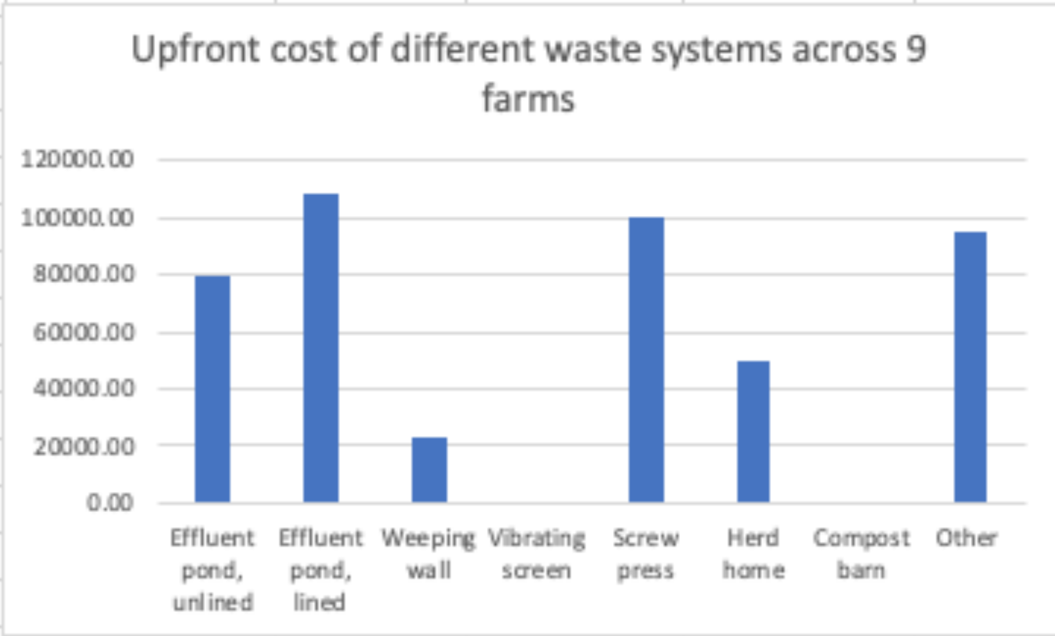


Q9 - What upfront costs are associated with your system?

9 Responses

Effluent pond, unlined	Effluent pond, lined	Weeping wall	Vibrating screen	Screw press	Herd home	Compost barn	Other - Please describe here
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N/A	60	N/A	N/A	100	N/A	N/A	50
N/A	N/A	N/A	N/A	N/A	N/A	N/A	$45,000 to build. Total costs $65k60
N/A	48,000	N/A	N/A	N/A	N/A	N/A	10,000
N/A	$65,000	$23,000	N/A	N/A	N/A	N/A	N/A
N/A	200000	N/A	N/A	N/A	N/A	N/A	200000, covered the wintering pad to minimize fluid from rain events
N/A	220	N/A	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A	N/A	5000000	N/A	N/A
N/A	60000	N/A	N/A	N/A	N/A	N/A	N/A
Been there along time. To line the pond-$80k	N/A	N/A	N/A	N/A	N/A	N/A	Settling pond inc pumps-$150k

Note. I cleaned up the data from the results entered above because some respondents had just put in the thousands, and another appeared to have forgotten the decimal point. I needed to remove the text to work with the data. I exported this *table from Qualtrics to Excel then found the mean cost of each waste system and created the chart below.*



Note. I calculated upfront spend/milking cow for each farm and created a distribution curve of the results as this gives me a useful figure to work with when considering cost to aim for with a BSFL based system.

Q10 - What are the ongoing costs associated with your system?

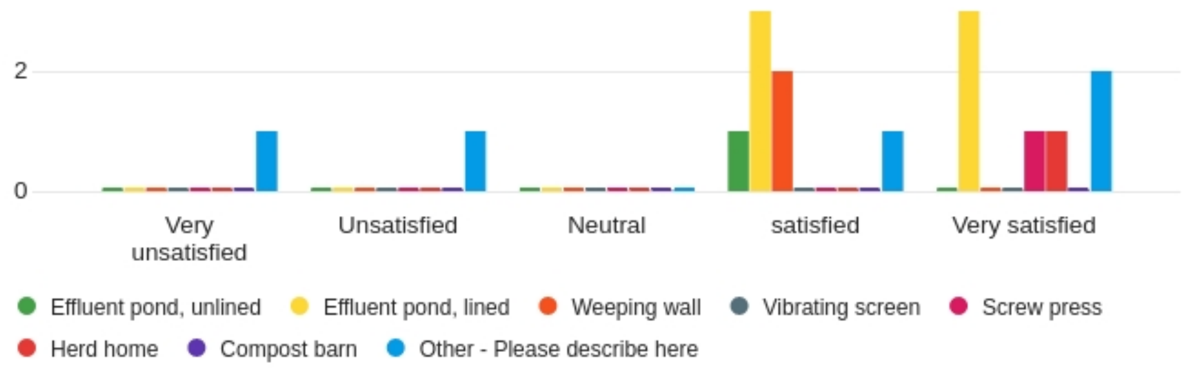
9 Responses

Labour	Power	External contractors	Other - please describe & state costs
N/A	N/A	N/A	N/A
1	3	4	N/A
$5k	$2k	no	stirrers and general maintenance $500/yr
13,500	11,000	1,000	maintenance on irrigator $1000 year
$5,500	$2,000	NIL	Tractor costs spreading - $4,500
N/A	N/A	6000	N/A
5	5	N/A	N/A
250 hr	N/A	N/A	N/A
1000	4000	1000	N/A
3 to 5 hours a week plus week to spread solids	Guess- $5k	Pump service irrigator service	Usually spend $7k a year on upgrading the system. Also

Note. I exported this table from Qualtrics to Excel, cleaned up the data to make its format consistent, remove text and perform the calculations where the costs were reported as hours of labour. As I do not know the hourly rate, I used the current living wage.

Q11 - How satisfied overall are you with your dairy manure/effluent system/s?

9 Responses



Q12 – What are the reasons for your satisfaction level?

Effluent pond, unlined

1 Responses

Effluent pond, unlined

Could be improved but not this year spent enough

Effluent pond, lined

6 Responses

Effluent pond, lined

Zero maintenance, zero risk and makes compliance easy

plenty of storage - about 55 days storage

liners - no testing for leaks required which is good, as it is above ground

Future proofing for the environment/climate change.

very simple, gravity filled, fail safe

Virtually maintenance free easy to deal with

Weeping wall

2 Responses

Weeping wall

low maintenance is good, no moving parts

Haven't used it yet. Another job to do on the farm

Screw press

1 Responses

Screw press
Makes clean green water suitable for pivot discharge, heaps of uses for solids around farm and easy to feed out with silage wagon, automatic

Q11- Other

3 Responses

Other - Please describe here - Text
Bullet proof
irrigation system
Yet to use it.

Q19 - What factors would influence you to change your dairy farm waste system? On a scale of 1-6, 1 having the most influence

8 Responses

Field	1	2	3	4	5	6	Total
Cost	3	1	1	1	1	1	8
Time it takes to operate	0	3	1	3	1	0	8
Improved environmental performance	3	0	2	1	1	1	8
Able to be retrofitted onto your existing system	0	2	0	2	2	2	8
Simple to operate	1	1	3	1	2	0	8
Potential to generate income	1	1	1	0	1	4	8

Q16 - If time and budget were not a factor, what changes would you make to your dairy manure/effluent system? and why?

8 Responses

If time and budget were not a factor, what changes would you make to your dairy manure/effluent system? and why?

More effluent coverage over farm, better spread of nutrients
Water saving changes (being able to wash down with less or using green water)

WOuld change to either a weeping wall or add in a separator so have another option of spreading on farm

put in 2 pond system and inject into centre pivot. This will happen.

Increase storage for more efficiency which would decrease number of times necc to empty. The generation of income ie power would be ideal, or any other source of income.

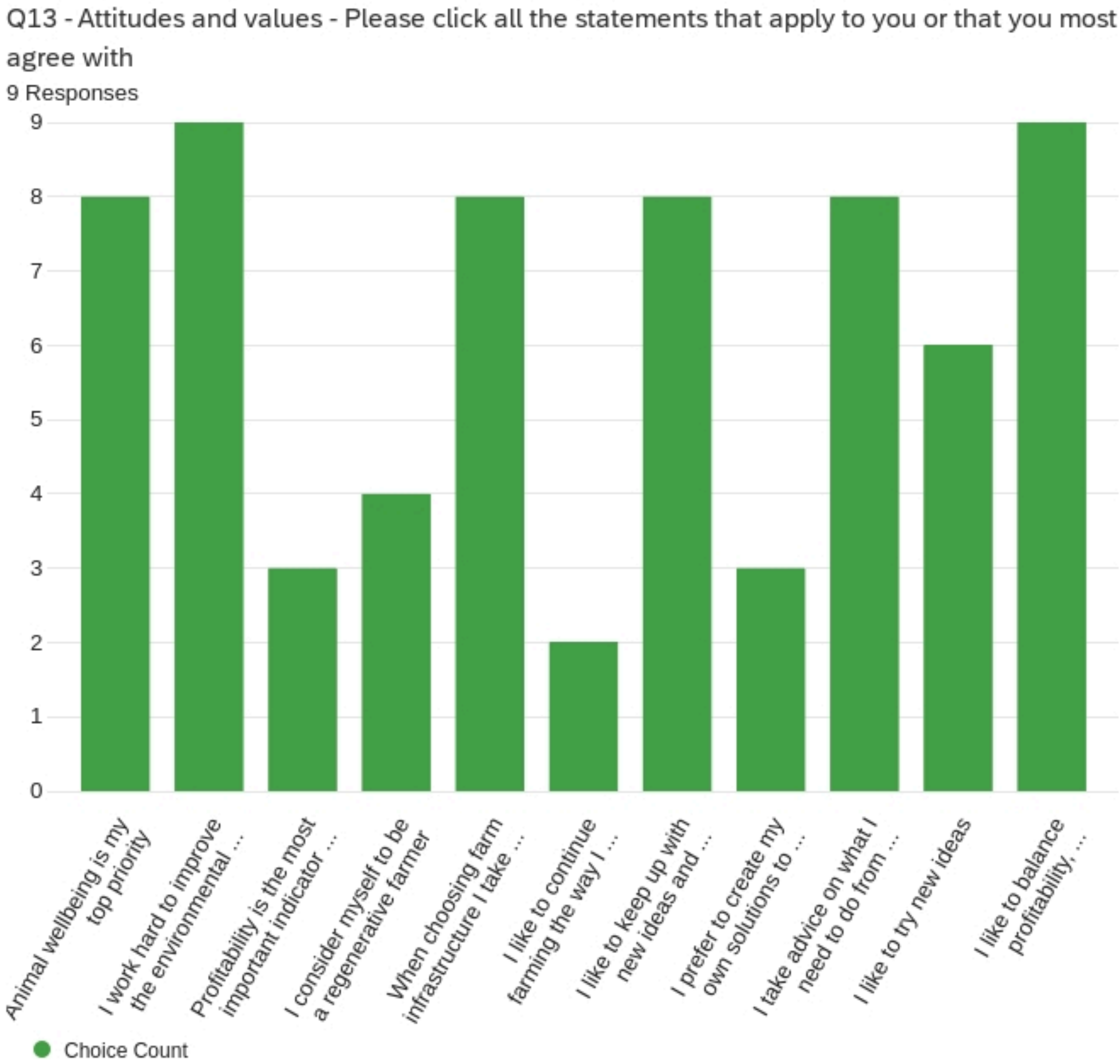
I would like to compost the woidchip on the pad better

more mainline, travelling cannon for wider spread and less turn around

Secondary solids trap before slope screen to catch more sediments

The above statements are all factored in when upgrading.

In the middle of a huge upgrade.



Q13 - Attitudes and values - Please click all the statements that apply to you or that you most agree with
9 Responses
9
8
7
6
5
4
3
2
1
0
Animal wellbeing is my top priority
I work hard to improve the environmental ...
Profitability is the most important indicator ...
I consider myself to be a regenerative farmer
When choosing farm infrastructure I take ...
I like to continue farming the way I ...
I like to keep up with new ideas and ...
I prefer to create my own solutions to ...
I take advice on what I need to do from ...
I like to try new ideas
I like to balance profitability, ...
Choice Count

Appendix J

Understanding the survey and what I could do with it

Q. no.	Question	Type of data	What I want to learn from it	What I could do to make more of the data	critique of question	What I learned from this
1	Personal details	Demographic	Who is answering the survey	See if different demographics answer differently. NB// They all seem to be the same demographic	I could have made this multi-choice so they had less options. They used different words for the same thing. I can't be sure of ethnicity	I think they are all European but can't be sure
2	Role on the farm	Demographic	As above	As above		If the survey reflects the reality of dairy farming, I will mostly be needing to convince white men
3	No. of cows on farm	Quantitative	likely capacity needed by a system that processes the DM	Get an average (mean)	Don't really have a big enough sample size. Not from lack of trying	Mean number of cows from the survey participants was higher than the published statistics at
4	What waste systems are on the farm?	Quantitative	What systems are used, variety, technology	Find prevalence of different systems	Limitations of small sample size	There are a wide variety of waste systems & multiple systems/farm
5	Percentage of DM & urine collected	Quantitative	Likely capacity needed by a system that processes the DM. To help with scenario	Multiply the number of cows by the manure produced/cow/day x the mean percentage collected to get an estimate of the volume	I suspect the farmers are estimating higher than reality as, in a follow up interview, a farmer estimated much higher than estimate from literature review	Farms are tending towards collecting more of the DM and urine
6	Capacity of the DM and effluent systems in M3	Quantitative	Find out what storage capacity the farm has as this may have implications for their use to store product of the BSFL farm or ingredients such as the food waste and DM	Use it to consider whether the existing system can be repurposed as part of the new system	There were variations in how the capacity was recorded and I suspect some errors as one system was unfeasibly large	There will be sufficient storage for brought in bio-waste between batches in the BSFL biodigester.
18	What happens to the collected DM solids?	Quantitative descriptive	To help understand the system	Find the variety of processes and the mean use of each		DM solids are spread back on the farms
7	Other equipment used as part of waste system	Quantitative/ desciptive	To help understand the system, possible costs. /equipment available to use in the new system	Consider if any of the equipment can be reused in the BSFL system. e.g. loaders		

8	Time spent on the waste system	Quantitative	How much time they currently devote to the waste system so I can consider whether an alternative system would need to use more or less , which has implications in the business model i.e. farmer operated/ external operator	Look at mean time spent. time spent in relation to satisfaction level or number of cows		Different systems have different amounts of time spent on them.
9	What upfront costs of the different systems	Quantitative	What they currently spend to ensure an alternative will be more cost effective	Find average costs. Graph costs for different systems	Farmers may have included or excluded different components of their systems	Variable costs but systems are expensive
10	Ongoing costs	Quantitative	Current ongoing costs as this gives a price point I want to improve upon	Find average costs. Graph costs	There seem to be discrepancies in what is recorded i.e. labour costs	
11	Satisfaction level with the different systems	Quantitative	General level of satisfaction with different systems as it has implications for willingness to change	graph satisfaction with different systems	I suspect that the respondents are less satisfied than they say, at different levels. Explore further	Most farmers are reasonably satisfied with most of their systems at the performance level
12	Reasons for different satisfaction levels	Qualitative	What are the pains? Helps with finding the value proposition.	Thematic analysis		ease of use, reliability and whether the system was compliant with the regulations.
19	factors that would influence a change of system	Quantitative, ranked	Helps with value proposition. Creating a product that works with farmer priorities	Find out a suitable way of expressing this; perhaps as an overall rank		Innovation that reduced costs and improved environmental performance
16	What changes would the farmer make?	Qualitative	Gain ideas	Thematic analysis?		They like to make use of the circular economy within their farm.
13	Attitudes and values	Does this count as qualitative or quantitative?	How the farmer sees themselves. Could be useful in framing a product to fit their values	Frequency of each option?	It gave some idea of attitudes and values within the limitation of whether farmers were wanting to give a certain impression	They value the environment, their animals, profitability and lifestyle and are open to new ideas and following advice
14	willingness to participate further		Useful fo finding out who to go back to			
18	provide links to other participants				Not answered. Not willing to do this?	

Appendix K

Thematic Analysis

Figure 48

Initial sorting of data by topic

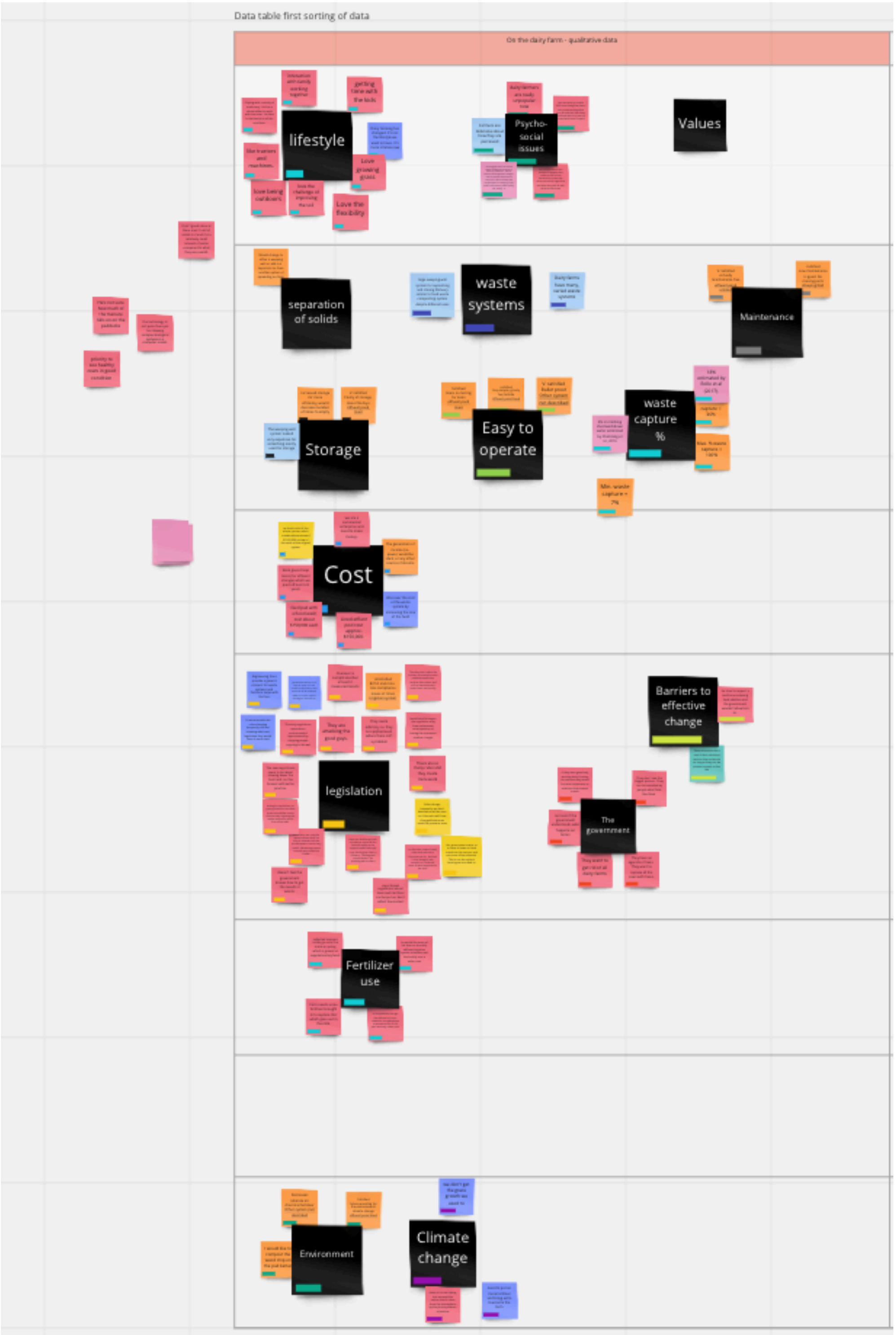
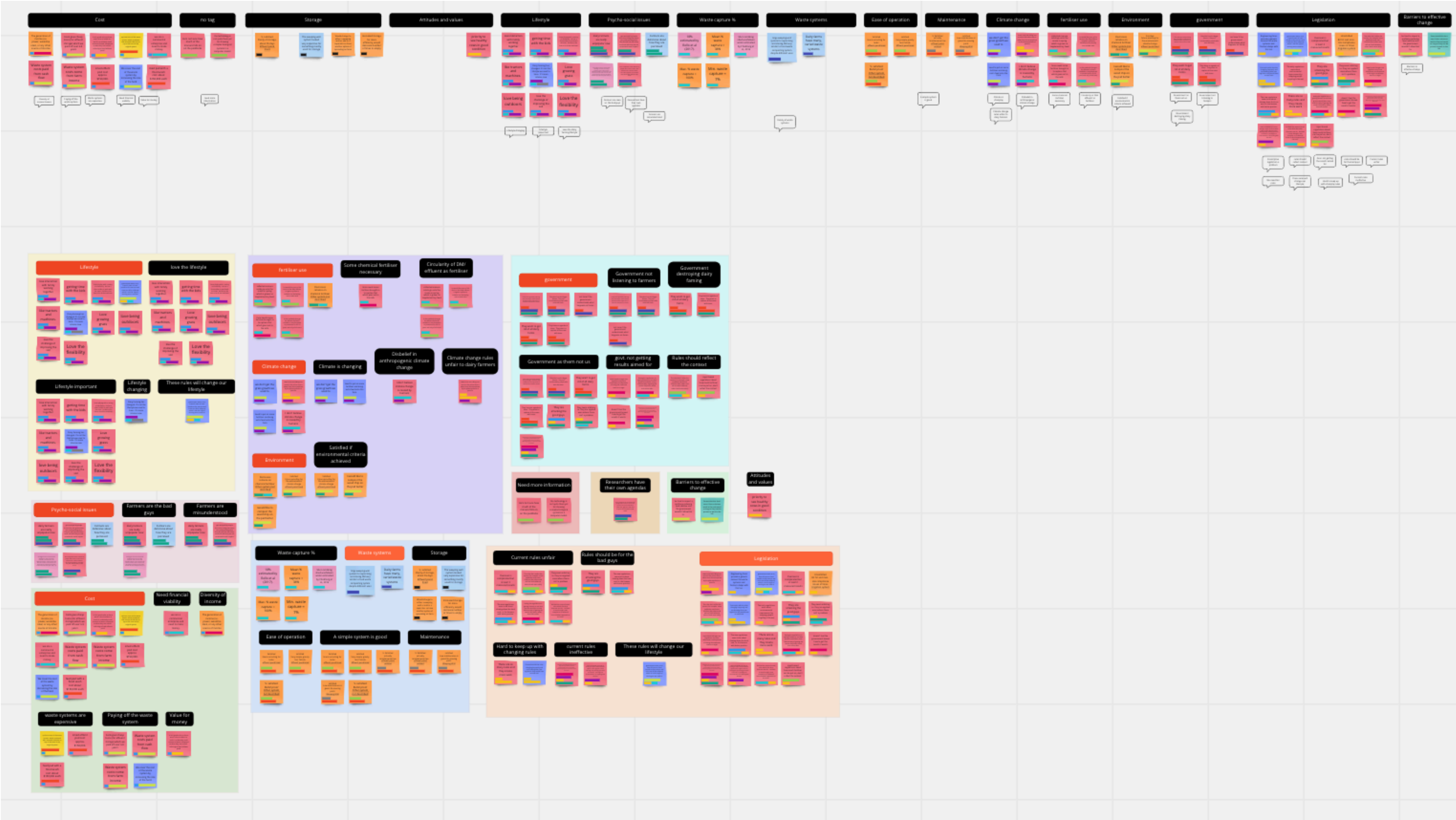


Figure 49

Coding and re-sorting data



Appendix L

Trials I would like to run in scenario 2

L.1 Trials on different biowaste streams

- DM and slaughterhouse waste
- DM and brewery waste
- DAF (Dairy factory waste)
- Sewage sludge
- Anaerobic digester sludge
- Chicken manure and other animal manures
- Seaweed
- Aquaculture industry waste

L.2 Trials on feeding BSFL to different animals

- Combinations of BSFL and other ingredients as a fish feed
- Combinations of BSFL and other ingredients as a poultry feed
- Combinations of BSFL and other ingredients as pig feed

L.3 Trials on frass

- Feeding frass as part of fish feed
- The best ways to use frass as a fertiliser/soil improver
- The long term efficacy of frass as a soil improver