MULTI-CRITERIA DECISION ANALYSIS COMPARING AGRICULTURAL PRODUCTION METHODS: PROTOCOL FOR ANALYZING BRITISH COLUMBIA BLUEBERRIES

by

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Abstract

INTRODUCTION: Methods such as Multi-criteria decision analysis (MCDA) are often applied to assess how preferences to make rational choices are applied. This thesis aims to examine how farmers balance environmental and social factors of sustainability and health with economic factors (e.g. costs) by assessing their preference for applying alternative agricultural approaches (e.g. conventional, agro-ecological/organic, and integrated farming/mixed-methods).

METHODS: First, a systematic bibliometric review of studies that used MCDA techniques for agricultural purposes was conducted to consider the ways that the analytical approach was being applied in this area. The review was restricted to all English language studies of farm-based agricultural studies that considered cost in their analysis. Studies from the Web of Science, CAB Direct, and Agriculture & Environmental Science databases were reviewed to identify publication trends that helped situate the objectives the thesis' own MCDA feasibility study. Second, a small group (9) of BC Blueberry farmers were interviewed using an Analytic Hierarchy Process (AHP) MCDA technique to elicit their preferred production system while considering potential constraints. The costs of agricultural production systems were divided by the aggregate value scores of the AHP, and systems ranked on their cost-benefit ratio.

RESULTS: MCDAs in agriculture have become increasingly popular over time, particularly AHPs in Europe and Asia, and in fruit, vegetable, and nuts farming sectors. Most studies considered costs as one of the criteria in the analysis, most often as a production/operating cost. Health was not mentioned extensively in these studies. The MCDA study showed that organic farming is the most preferred method without the consideration of costs, but conventional farming was the most preferred in the cost-benefit ratio.

CONCLUSION: Farmers prefer to be more mixed-methods or ecological (without the consideration of costs), constraints (specifically costs) prevent them from practicing their preferences. As a novel approach in agriculture, the MCDA-CBA is a feasible tool to understand farmer preferences and how they can be advocated for to achieve more sustainable and healthy processes in policy. MCDA-CBA has potential for understanding health and sustainability as connected with similar, if not the same, goals and criteria.

Lay Summary

British Columbia blueberry farmers make decisions that require consideration for many criteria. These decisions balance environmental, social, and economic concerns that have consequences on the sustainability and health of agricultural systems. This thesis explores how multi-criteria decision analysis can consider (determinants of) health relevant implications of farmer decisions.

This thesis assessed how farmers weigh criteria in their decision-making and their preferences for alternative agricultural production methods. Farmers expressed a preference for mixed-methods or ecological farming without consideration of cost. With costs, conventional methods were preferred; suggesting that costs of production have a significant role in decision-making, causing farmers to lean towards conventional farming.

This methodology has never been applied to evaluate and understand farmer decisions through the scope of *both* the determinants of health *and* agricultural sustainability. MCDA has potential to better understand farmer preferences and aid policymakers to incorporate them to advocate for more sustainable *and* healthy agricultural production.

Preface

The initial version of this thesis was supposed to use Ecuador as a case study as part of a research program examining health equity relevant consequences associated with different ways of producing food. Due to unforeseen circumstances, this thesis had to be adapted to the British Columbia blueberry farmer population. The project allowed me to pursue my interest in economic evaluation methods.

The protocol and preliminary study for the MCDA study (Chapter 3.2 and Chapter 5) was presented at the 2017 EPICOH conference in Edinburgh, Scotland, UK.

Articles are planned for submission to academic journals for version of Chapters 1, 3, 4, 5, and 6.

This dissertation is an original intellectual product of the author, Rami El-Sayegh. The fieldwork reported in Chapters 3-5 was covered by UBC Ethics Certificate number H17-02527.

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List of Abbreviations

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BC	British Columbia
BCBC	British Columbia Blueberry Council
CBA	Cost-Benefit Analysis
CDC	Centre for Disease Control
CEA	Cost-effectiveness Analysis
CR	Consistency Ratio
cm	Centimeter
DEX	Decision Expert
ELECTRE	ELimination Et Choix Traduisant la REalité
ha	Hectare
HIA	Health Impact Assessment
HTA	Health Technology Assessment
LCC	Life Cycle Costing
LFV	Lower Fraser Valley
m	Meter
MAUT	Multi-attribute Utility Theory
MAVT	Multi-attribute Value Theory
MCDA	Multi-criteria Decision Analysis
MOP	Multi-objective Programming
NAFTA	North American Free Trade Agreement
NPV	Net Product Value
PMRA	Pest Management Regulatory Agency
PROMETHEE	Preference Ranking Organization METHod for Enrichment of Evaluations
SAW	Simple Additive Weighting
SWOT	Strengths Weaknesses Opportunities Threats

TEG3	Think, Eat and Grow Green Globally
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
US	United States
USMCA	United States-Mexico-Canada Agreement
WPM	Weighted Product Model

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I also would like to thank those who I have met in Vancouver, including those that I worked with at Indigenous and Northern Affairs Canada. Your friendship and support have been profound, and I cherish all of you deeply. I will treasure the memories forever

Lastly, the biggest thank you goes to my parents, my siblings, and the love of my life – the foundation of everything I do. Without each and every one of you I would not be here. I went to Vancouver not knowing anyone in the city, but you always kept me grounded, and I always felt close to you all. And although I lost my uncle and my Teta back home while I was away and before I could finish this degree, their strength and hope allowed me to get to the finish line. I share this accomplishment with all of you.

1 Introduction

The framing of population health draws attention to consider how the processes that generate broad ranges of health determinants can be modified.[1,2] This, in turn, challenges us to develop tools of analysis for considering healthier alternatives and the feasibility of achieving this. As agricultural production inevitably generates environmental, economic, and social effects as externalities, the societal impact of this on health and sustainability merits attention. Moreover, if we assume that the way that we produce and eat food has important implications for health, how can those whose decisions are producing negative impacts consider better options.

United Nations Sustainable Development Goal 2 aims to "end hunger, achieve food security, and improve nutrition, and promote sustainable agriculture".[3] In order to meet this challenge, it has been asserted that agricultural systems must produce affordable, appropriate, and accessible food[4] in a way that is sustainable and in line with social justice[5,6] and principles of food sovereignty.[7] Although the sustainability consequences of different approaches to producing food have been highlighted as of great importance by the United Nations Special Rapporteur on the right to food, there has been limited attention given to broader health determinants related to the costs and consequences of different agricultural production systems; these include agro-industrial/conventional, agro-ecological/organic, and integrated farming/mixed-methods.

Moreover, while methods for considering and evaluating the economic costs and consequences associated with different ways of delivering health services have received considerable attention by health economists in healthcare settings,[8–15] adopting a comparable population health approach can be similarly useful in broader decisions that affect health, such as in agricultural production. In this thesis, I set out to explore how this can be pursued.

1.1 Research Focus

1.1.1 Health and Agricultural Sustainability as Adaptive Processes

In applying a population health approach, health is defined with relevance, consequence, and association to a number of factors or *criteria* known as determinants. These determinants cover social, economic, and physical environments, as well as characteristics and behaviours of individuals (i.e. income and social status, education, social support networks, genetics, availability of health services, gender, etc.).[16] Agricultural sustainability is similarly defined, providing a holistic integration of environmental, economic, and social equity factors. Agricultural sustainability assumes a long-term stewardship of natural and human resources as an urgent set of criteria to consider as an alternative to focus on to short-term economic profits. Intrinsic in this is consideration for social responsibilities such as working and living conditions of farmers, needs of rural communities, and consumer health and safety. There is also a social responsibility for sustainable use of land and natural resources, and considerations for animal welfare.[17] Agricultural sustainability is further characterized by resilience and adaptability. Resilience refers to the ability of agricultural systems to absorb certain conditions, such as the climate, political contexts, and economic concepts that are often unpredictable and unstable. Adaptability, a component of resilience, is the ability to respond and/or change after conditions disturb the agricultural system.[17,18]

These considerations of agricultural sustainability are consistent with applications of public health and are not dissimilar to definitions of health. Huber et al defined health as “an ability to *adapt* and self-manage in the face of social, physical, and emotional challenge.”[19] This concept of adaptability as a response to challenges in health has been around for decades, such as Rene Dubos assertion in 1965 that “the states of health or disease are the expressions of the success or failure experienced by the organism in its efforts to respond adaptively to environmental challenges”[20]; and notably the Ottawa Charter for Health Promotion also considers health as the ability to satisfy your needs, and change or cope with your environment.[21]

1.1.2 Health and Food Production Relationships

Health and agriculture also have a more direct relationship. Agriculture produces food, medicine, and provides livelihoods to millions which all contribute to good health. Agriculture has a role in relation to malnutrition, chronic disease (i.e. cardiovascular, obesity), infectious disease, food safety, and occupational health of farmers (i.e. 85 agriculture related fatalities per year in Canada (2000-2012)[22] with higher rates in less developed countries[23]). Some physical occupational hazards include respiratory disorders, skin disorders, noise, and cancers. Particular attention has been given to negative health effects being associated with chemical hazards that have been increasingly incorporated in agricultural process, such as chemical hazards, such as pesticide use, which pollute and strain water resources, which further increases risk to certain diseases[24–28]

The reciprocal relationship is that health also affects agriculture. People's health status influences the demand for agricultural outputs, and among farmers, poor health reduces work capacity, reducing income and productivity, which further contributes to poor health.[28]

1.1.3 Health and the Process of Agricultural Production Interaction

To go one step further, the viewpoint described above, although crucial, focuses on food as a product, often in the shape of food supply. Some proponents for conventional agricultural systems argue that with a continuously growing population worldwide, the agricultural sector needs to keep pace; which, in part, has led the farming sector to focus more on revenues and yields in order to achieve "productive efficiency" (in purely commercial terms) and, in this view, produce sufficient quantities of food. The counter to this thought is that we do produce enough calories globally for a growing population, though there is insufficient production of fruits, vegetables, and protein and major over-production of energy-dense foods such as sugars, cereals, and oils. Often the issue is food waste and supply chain, distribution, and poverty issues.[29] Therefore, thought should be given towards the process of food production; in other words, *how* the food system organizes the production of food (over and above the nutritional content of the food itself) and generates health relevant consequences. From this perspective, agriculture and health can be seen as interconnected through three pathways: health effects directly flowing from human exposures encountered in production activities (e.g. toxic or bio-physical exposures); indirect effects related to impacts on the environment and sustainability (e.g. water contamination or enhancement); and indirect effects related to the social dynamics (e.g. positive or negative stresses) that flow from how production is organized.[5,30]

It can be suggested that a perspective on assessing "productive efficiency" that is purely restricted to commercial production unit-specific criteria (i.e. revenues and yields) in relation to expended *costs* of production should be critically reconsidered to take fuller account of effects of agricultural production on sustainability, social justice, and health equity. Under the narrow assumption of "productive efficiency" indicating superiority of conventional approaches , consideration of producer perspectives and preferences for alternative agricultural production methods has largely been ignored.[31,32] This thesis aims to examine how producers can and do take influences on agricultural sustainability and health into their decision making. This chapter explores parallels between these two concepts. Although sustainability can be seen as a proxy to evaluate the determinants of health as a result of the similarities, I admit this is not an exact evaluation. This thesis tries to address this limitation by exploring how an application of multi-criteria decision analysis (MCDA) in an economic evaluation perspective (via cost-benefit analysis (CBA)) can elicit the preferences of farmers with regards to agricultural production methods; and I will reflect upon how these preferences fit into concepts of population health. I conducted this thesis to contribute to the "Food systems and health equity in an era of globalization: Think, Eat and Grow Green Globally [TEG3])" research program that comprehensively examined consequences associated with different ways of producing bananas in Ecuador.[33] The specific context to be considered in this thesis will be the largest fruit agricultural exports in British Columbia – blueberries.[34]

1.1.4 Assessing Alternative Agricultural Methods

Consideration of productive efficiency that primarily draws on analysis of costs of production in relation to yields and revenues suggests that agro-industrial/conventional systems produce higher yields and revenues than alternative methods, such as agro-ecological/organic (which has been highly argued against) – and high yields have been widely accepted as central to sustainable food security to meet growing global demand for food.[35,36] However, although many studies have shown that yields and revenues are significantly lower in agro-ecological farming, even this assumption has been called into question by research that analyzes the specificity of different production contexts.[37,38] Moreover, such studies generally restrict their frame of analysis to narrowly framed costs, ignoring externalities such as effects on sustainability and health. A push towards agro-ecology may be a solution for sustainable food production, as other studies have shown that this method can provide adequate nourishment capable of delivering sufficient yields to feed the growing population.[31,39]

Expansion of industrial approaches to agriculture has stimulated calls for greater attention to concerns of the effects that may be generated,[40] for example from the use of agro-chemicals.[41] It is often argued that a reliance on pesticides is necessary to increase yields to meet demand from a growing global population, although concerns raised about implications for climate change associated with such processes have called this into question.[31] This is misleading, as a bigger issue may well be inequitable production and distribution systems preventing access to food.[31] Additionally, there are a number of environmental risks to wildlife, water supply, and soil associated with pesticide use.[42,43] There are also costs to remediating any type of damage in addition to the input costs required to protect crops through agrochemicals. This is not to mention the health effects to the communities.[44,45] As a potential alternative to agro-industrial/conventional systems, agro-ecological/organic farming is a system that aims to produce food with minimal harm to ecosystems, animals, or humans.[37] Agro-ecology replaces chemicals with biology (through natural pest control), and promotes practices that are suitable to local environments and conditions to stimulate long-term capacity of soil health and fertility.[31,46,47] These practices include biodiverse systems, crop rotation, and developing habitats around farms to support natural pest control animals.[31,48] Unfortunately, most seed companies are owned by agrochemical companies, and there is a limited amount of interest in developing diverse crop systems. Instead there is a focus on monocultures through high-yielding varieties that respond well to chemical inputs that actually end up more susceptible to pests and diseases due to a diminished ecosystem void of natural pest control.[31]

It is argued that agro-ecology may have lower yields (ranging between 13% to 34% lower than conventional) and would require more land to produce similar amount of crop as conventional farming practices, ironically undermining the benefits of agro-ecological/organic methods through deforestation and biodiversity loss.[49] These criticisms, however, vary depending on farm locations and are highly contextual.[37] For example, it has been argued that if done properly, biodiversity and efficient use of resources can enable farms to produce more per hectare than large industrial farms. This system can also help limit the financial stress on producers since they would not have to rely on expensive agro-chemicals.[31] Comparative studies show that diversified systems are even more profitable when looking beyond only crop yields. Agro-ecology is more likely to produce constant yields long-term and have greater resistance to the changing climate.[31,47] Currently, however, the mainstream discourse is one sided to support for higher yields and revenue, which limits the adoption of more agro-ecological methods.[44,50,51] Therefore, agro-industrial (which will be known as conventional for the rest of the thesis) systems may continue to be a prominent method used in agriculture.

In light of differing perspectives on the assumption of what “productive efficiency” implies and how this may be taken into consideration, it is worthwhile to evaluate the assumptions and values of farmers, and the degree to which farmers have agency in their decisions. In doing so, one would still need to consider the degree to which farmers themselves directly take consequences and benefits (to themselves, their communities, and the wider world) into consideration when they select growing options, albeit with choices that may be constrained by varying incentives and disincentives,[50,52] (which will be discussed later).

MCDA, a method often used in analyzing how and why alternative courses of action can be pursued, provides an approach that can help determine which agricultural production method will provide the greatest overall weighted benefit, for the goal of producing (in our case) blueberries, considering not only yields and revenue, but also other effects, such as, health effects and sustainability and their relative importance of each of these factors. The perspectives and potential constraints of producers is a critical first component in understanding the decision-making process in agricultural production and how criteria other than yields and revenue can be measured in order to consider under what conditions increased benefit is worth the cost associated with each agricultural production system. This could provide the basis for considering what could be affecting preferences for applying one method of agricultural production versus the other.

1.2 Research Approach

1.2.1 Thesis Objectives and Approach

This thesis seeks to examine how agricultural producers can and do take determinants of sustainability into consideration in their production decisions. Specifically, it seeks to consider how environmental and social factors of sustainability are balanced with economic factors of sustainability (e.g. costs) by those employing different farming techniques (e.g. conventional, mixed-methods, and organic). In other words, this thesis seeks to understand the preferences of farmers using a MCDA, considering not only yields and revenues, but environmental and social factors, and the relative importance of each of these factors to ultimately provide policymakers with a better understanding of farmer preferences to aid them in promoting and incentivizing farmers to continue to farm, have sustainable, healthy, and profitable agricultural processes in the short- and long-term.

The research approach was two-pronged. First, noting that the influence of perceptions of different criteria is often analyzed by health economists in considering optional and optimal ways for delivering health services, I sought to take stock of how such techniques have been applied in agricultural settings, with particular attention to the degree to which health has been addressed. Complementary to this review, I then conducted a specific analysis among agricultural producers to test feasibility of MCDA in the agriculture setting and consider the insights that could be generated more broadly from farmer preferences around agricultural production methods and their relation to population health.

I carried out a systematic review to investigate if and how MCDAs have been done in the agricultural setting, and the degree to which they consider costs and health in the analysis. Specifically, it was evaluated how articles took stock in the results of their studies on the determinants of health. Studies were also reviewed to determine whether costs were implemented in a CBA and *not* as a criterion in the MCDA (reasoning for this will be provided starting in Chapter 4.3.2). This systematic review helped situate the subsequent MCDA feasibility study's objectives.

The primary objectives of the systematic review are to determine the extent of use of MCDAs in agriculture that consider costs, and to what degree these MCDAs also consider health.

The primary objectives of the MCDA-CBA study are to determine what producers see as the best or most preferred agricultural production method for pursuing the goal of producing blueberries; to consider under what conditions farmers would practice towards their preferences, if they are not already; and, to consider the constraints that farmers are faced with to better understand their decision-making process in a comprehensive and transparent method. Lastly, these results were reflected how they fit into concepts of population health. The secondary objectives of the MCDA-CBA study are to determine weights or the rank of importance/preference for each criterion; to assess whether MCDA-CBA is helpful, useful, and feasible for use in farmer decision making or policy-making; to assess MCDA-CBA's potential in agriculture, including other agricultural settings than the one studied; and by extension to assess the feasibility of MCDA-CBA in evaluating the determinants of health.

1.2.2 Organization of the Thesis

Building on the above introduction of this thesis as way to consider how agricultural producers can and do take influences on sustainability and health into consideration in their production decisions, as well as how this fits into concepts of population health, the remainder of Chapter 1 details the research setting of the MCDA case study. The unique geographic context of British Columbia (BC), Canada and the Lower Fraser Valley is described, with a lens on blueberries and their importance in the region and in Canada as a whole. The concept of constrained choice is then introduced, illustrated through the social context to which farmers operate under, such as the constraint from environmental and climate change factors, and economic factors.

In Chapter 2, a literature review is conducted to present MCDA techniques that are commonly used. A description of each technique is provided, together with a discussion of strengths and weaknesses. The chapter concludes with a rationale for the specific MCDA technique selected for the case study: analytic hierarchy process (AHP).

In Chapter 3, the two-pronged methodological approach is described. First, in Chapter 3.1, the methodologies and intentions of the systematic review (in its eligibility criteria and search strategy) and bibliometric analysis are established. This helps layout the methodology for the MCDA case study. Settings and participants, setting up the AHP, and the data collection are outlined in detail.

In Chapter 4, the bibliometric findings are presented to show the trends in the included studies from the systematic review. The main findings with regards to cost and health considerations from each study are depicted.

In Chapter 5, the results of the MCDA case study are presented. The results of the MCDA identify the necessary criteria for farmers when making decisions, and farmer preferences towards a specific agricultural production method, first without and then with costs. Qualitative data are then used to understand farmers opinions on the validity and feasibility of the MCDA results.

Chapter 6 and 7 summarizes findings from the MCDA, discusses strengths and limitations, relevant applications, and future directions for research, with attention given to how they relate to concepts of population health.

1.3 Research Setting

1.3.1 Geographic Context

1.3.1.1 British Columbia, Canada

BC is one of the most important agricultural regions in Canada, particularly for fruit farming. As of 2016, the number of fruit farms (defined as farms whereby fruit production represents 50% or more of total farm cash receipts) in BC is 3,180, representing just over 40% of the 7,845 fruit farms across Canada.[53] BC has 24,948 hectares (ha) of fruit area, ranking second between Quebec (43,013 ha) and Ontario (19,771 ha), with 19% of Canada's 130,038 ha of fruit area.[53] Although Quebec ranks first in fruit farm area, BC generates the highest farm gate value (defined as the pricing point of production, excluding charges for transport or delivery)[54] of any province, with over $475.3 million. This equates to 41% of the $1.15 billion total farm gate value in Canada. Ontario (27%) and Quebec (23%) rank second and third respectively.[53] Most of BC's high ranking can be attributed to the southwest region of the province – specifically an area known as the Lower Fraser Valley.

1.3.1.2 The Lower Fraser Valley

Located in the southwestern part of BC, the Lower Fraser Valley's (LFV) geographical location offers it many advantages that make it a strong agricultural centre for the province and country. One advantage is that the climate of this region is ideal for fruit production, particularly blueberries. LFV experiences 1,700 millimeter (mm) of precipitation per year, 1,400 mm of it falling between October and April.[55] The precipitation helps replenish aquifers used for irrigation during the drier summers, where average temperatures reach just above 24°C.[55] This mild and temperate climate creates the ideal conditions for high quality soils and water access and allows the region to enjoy 180 frost-free days per year (the most in the country along with southern Ontario).[53]

Another advantage is the LFV's geographic location. The LFV is in close proximity to 2.5 million people in Metro Vancouver, a city that is projected to increase to 3.5 million people by 2041, as well as the United States (US) border.[55] Aside from the local market opportunity, the LFV has a lot of export opportunity through air, rail, and port facilities, providing access to develop export markets in the US, Europe and Asia Pacific.[55]

These advantages have developed a thriving agriculture industry in the LFV. The LFV and Metro Vancouver produce 65% of provincial gross farm receipts, generating $3.1 billion in annual economic activity. This translates to 11,700 full-time jobs in farm-based production and $1.4 billion in expenditures; as well as, 3,300 full-time jobs and $1.69 billion in expenditures in the value-added sector.[55] Blueberries share in part the responsibility for this success, and thus blueberries make up a significant portion of both the province's and country's agricultural system.

1.3.1.3 Blueberries

Blueberries are native to Canada and fall into two broad families: high bush and low bush. High bush blueberry plants are typically 2 metres (m) high, grow a larger berry, are planted and managed a lot like other berries and orchards, and are typically more prominent in BC. Low bush blueberry plants are up to 60 centimetres (cm) high and are typically found in Eastern Canada.[56–58] The statistics in the following section combine both high bush and low bush together, however, for this thesis beyond this chapter, it should be assumed that each reference to blueberries is the high bush variety.

1.3.1.4 Statistics on Blueberries

Blueberries of course, are a significant part of BC's regional food system, and a significant crop in the agricultural sector in Canada as a whole. The total value of fruit increased 6.1% in 2018 to $1.1

billion, and blueberries, along with cranberries, were largely responsible for this growth.[59] This growth happened despite a drop of 5.4% in production for blueberries; though blueberries did manage to increase in value by 13.6% to $244 million, driven by a 20.1% increase in prices.[53]

Between 2014 and 2018, blueberries averaged 77,440 ha of total fruit area, making up 59% of the total fruit area in Canada, surpassing apples (13%) and grapes (10%).[53] In the same time frame, blueberries averaged just over $233 million in total farm gate value, with 21% of country's overall total, slightly edging out apples (20%), and grapes (16%).[53] Apples and blueberries have traditionally traded positions in ranking, though blueberries have generated a higher farm gate value for four of the five years, with 2017 being the exception.[53] Blueberries rank third in the country by fruit marketed volume, with 148,964 metric tonnes in 2018, topped by apples (41%) and only recently being surpassed by cranberries (19%) in 2018.[53] Comparing high bush and low bush blueberries, the former rose 13.8% to $177.4 million in 2018, as marketed production grew 10.3% and prices were up 3.1%.[59] Low bush blueberry, on the other hand, decreased 13.8% in marketed production over the same year, which was partly offset by a 13.3% increase in value in 2018, to $66.5 million, as prices rose 35.7% (which was still a lower price point than the five year average).[59]

Canada's total fresh fruit exports rose by 18.1% to amass $820 million in 2018.[53] Blueberries represent the BC's and Canada's number one primary agricultural production export (excluding fisheries, aquaculture, food preparations for manufacturing and natural health products, and baked goods and cereal products).[60] Among fruit exports, blueberries make up 58% of export value, amassing almost $475 million in 2018, with sweet cherries (11%) and cranberries (10%) a distant second and third respectively.[53] Similarly, blueberries rank first in fruit export volume, with 143,227 metric tonnes, or 45% of Canada's total export volume, with cranberries and apples a distant second and third respectively.[53] Globally, between 2012 and 2018, Canada produced an average of 171,962 metric tonnes of blueberries, comprising of 32% of the world's total blueberry production,[53] ranking second globally.[61] Frozen blueberries represented 67.5% of total blueberry export dollars, and 77.9% of blueberry metric tonnage in 2018.[53] 98% of BC blueberry exports are destined for the US, though markets in Asia are growing.[62]

1.3.1.5 Rise of Blueberries in British Columbia

The significance of blueberries in the agricultural economic landscape has steadily increased since the 1990s and they are not just important for British Columbia, but have also become Canada's most significant fruit production crop.[63] This growth is a result of several economic forces, including, increased competition in the international market for other crops, especially after the Norther American Free Trade Agreement (NAFTA) (1994). Around that time, blueberries became a new opportunity for BC farmers to capitalize on instead of competing with Mexico and California's cheap production of field vegetables and strawberries.[64,65] This coincided with increasing global interest in the health benefits that blueberries have (i.e. antioxidant characteristics).[66] As a result, demand for blueberries increased, and thus supply followed suit, and prices began increasing, peaking at $1.19 per pound in 2006.[67] The growing demand and high price of blueberries, as well as the suitability of local growing conditions, had many farmers converting crops to blueberries. Initially, farmers made good returns on their blueberry production,[68] however, prices for blueberries declined after the 2006 peak, as supply increased from other regions in the world (i.e. USA, Chile, and China).[68,69] In response, farmland dedicated to blueberry production continued to increase in the LFV, as farmers hoped that prices would return to levels seen in the first half of the 2000s.[69] Even if farmers wanted to change to another crop, disinvestment from blueberries to another crop can be costly and time intensive for farmers, constraining their choices to adapt to a new economic landscape.

1.3.2 Social Context

1.3.2.1 Constrained Choice of Producers

The study of economics concerns how scarce resources are allocated among *competing* wants. From this perspective, the concept of *competition*, free and fair competition, implies a dynamic process in which different parties bid against one another in the pursuit of their own self-interest by using human, physical and financial resources. This bidding extends to engaging in research and innovation in order to secure scarce resources or to improve the capacity to further bid in the market. The free characteristic suggests the absence of cost, barriers or constraint. Fair, possibly paradoxically, suggests that market entry should not be unfairly restricted by force by any agent. In their pure form, these features of competition define a perfect market, which requires individuals, in this case farmers, to produce efficiently in order to effectively compete against other farmers.[70] In other words, this concept is famously presented by Adam Smith as the invisible hand.[71]

Agriculture, according to neoclassical economists, arguably provide a setting that is as close to an example of a perfect competition market as there is.[70,72–74] The features of perfect competition include: many buyers and sellers, in some cases homogenous goods, perfect information, zero transaction costs, and no barriers to entry and exit from the market.[71] It can be argued however there are various market inefficiencies and inequities presented in agriculture such as the presence of monopsonies, information asymmetry (between farmers, distributors, supermarkets, and consumers), price volatility, and weather and pest pressures.[70] This is not to mention land grabbing, colonization, violence, racism, and inequitable access to capital and other resources.[75,76] Farmers are assumed to have the freedom to make decisions within their budget. However, in reality, individuals engage in information asymmetry, oligarchies, significant barriers to entry and exit from the market, and an environment where farmers break even financially at best. These behaviours and conditions lead to inefficient markets and sub-optimal solutions.[77–79]

Farmers decide what crop to grow (perennial or annual).[80] Farmers need to analyze the market, soil fertility, costs of production, among a number of other criteria, and are required to balance both short- and long-term priorities in this decision. One of the basic principles of sustainable agriculture is crop rotations in order to preserve soil health, and limit vulnerability to market price fluctuations, consumer confidence, pest and disease pressures, and changing weather conditions. The dilemma is, farmers can either maximize short-term profits for themselves and contribute to the global commodity market that incentivize farmers to invest in monoculture systems, or farmers can maximize the long-term productivity of their land and resources. Investing in the former puts the long-term sustainability at risk, because it takes years for soils to recover nutrients, resulting in diminishing returns over time.[81] The maintenance of the ecological aspects of farming often do not conform to the short-term goals of commodity markets, and often farmers cannot survive in times of low prices for their crop, ceding their share of the market to large producers, inadvertently developing the monopolistic share that larger farms enjoy.[80] Therefore, it can be argued, farmers' choices are constrained, and are prevented from practicing towards their preferences. It is critical to understand what these constraints are and how to mitigate them by understanding the criteria that are important to farmers to advocate for their decision-making in a way that is both profitable and sustainable in the short- and long-term.

Constrained choice is described as when the preferred option is restricted or unattainable, and there is greater incentive so that they choose less desirable substitutes. Often this is described when farmers prefer to adopt more environmentally friendly production methods, they are constrained, often by economic factors.[50,52] Producers have individual values and beliefs that they carry with them when making decisions and maintain varying degrees of ethical sensitivity towards different choices.[50] At the institutional level (i.e. government programs, business standards), external factors, such incentives and reward systems, affect producers' ethical behaviour.[50] Thus, producers are put into positions where economic incentives may run counter to their preferences, which may lead to the rationalization of choosing what they may perceive to be unethical behaviour, such as adopting agro-industrial methods, which would include pesticide heavy strategies.[50] For example as depicted in a study by Stewart,[50] there is certainly a group of farmers that believe that their primary goal is business – to produce food more efficiently, they may see taking out vegetation and eliminating wildlife as a necessary action to meet business goals if necessary. Contrarily, many farmers see themselves as environmental stewards and those who see it as their great responsibility may face constraints such as economic factors that influence and erode their morale or ethical position. For example, although farmers in the Central Coast of California supported environmental practices despite economic drawbacks, they were unable to support these practices that they considered to be ethical when their entire family's livelihood was threatened. This suggests that certain criteria, in this case environmental, which are deemed to be ethical by these farmers, are outweighed and constrained by contradictory values (i.e. economic criteria). [44,49,50,82] Specifically, once farmers choose agro-industrial methods, or conventional methods, yields and revenues become dependent on agro-industrial systems despite the high input costs for them, and so there is significant barriers to switch to agro-ecological farming.[44,50,51] Building on this analysis, it is time to focus our attention on understanding the ethical attitudes and behaviours of farmers when making decisions at the socio-political level.[52] In this section, a description of the type of constraints and challenges on farmer decisions will be presented in three main types: environmental or climate change factors, and economic factors (regionally and globally). For this thesis, understanding this concept through the lens of blueberry producers in BC will help clarify the decision-making process that leads to a penchant for one agricultural system over the other.

1.3.2.2 Environmental and Climate Change Factors

Environmental and climate change factors have profound impacts on agriculture and help further compound the challenges faced regionally and globally, that hamper farmer decision-making. The LFV region and blueberries are no exception to this relationship between the climate and micro- and macroeconomic drivers.[55] The LFV residents and businesses produced 1.9 million tonnes of carbon in 2010.[55] The need for energy is particularly true for the agricultural sector, and the sector's vulnerability to climate change needs attention. The impact of climate change can already be felt in a number of ways in the LFV. Average temperatures are rising 1°C and is expected to be warmer in the 2020s.[55,83] It is estimated that the region will have 15 more frost-free days annually and 184 more growing-degree days.[55,83] Although this sounds ideal, this will come with 7% more precipitation by 2050, with more precipitation in the winter, and less rain in the summer.[55] Extreme weather conditions are expected to be higher in magnitude, frequency, and intensity as time progresses.[55] With these changes come serious projected consequences:

a) *Drier summers* are expected to have 3.8 times more extreme heat days, which used to occur once per decade. This increases the risk of drought, regional forest fires (which have happened with increased intensity and frequency resulting in immense damage[84,85]), and more specific to farming, a disruption to farming, pollination, and increased pest and disease pressures. Agriculture relies on both surface and ground waters for irrigation. With rising temperatures, water sources are already stretched thin and the demand for water will only increase, not only from the agricultural sector, but from residents of the sprawling metro Vancouver area. Although higher temperatures present better harvest conditions, crop yields and crop quality will suffer with less water availability.[83,86–88]

b) *More precipitation and wetter winters* will increase the risk of flooding,[89,90] erosions and nutrient leeching, leading to crop damage. For example in 2010, heavy rains caused $6 million in damage to rot crops in southwestern BC.[90] A Fraser Valley Regional District (FVRD) report predicts that "A major flood event ... would cause over $800 million in damage to farmers' crops, buildings and equipment, and the agricultural losses and associated spin-off impacts would have a have an economic impact of $1.1 billion on FVRD communities"[89]

c) *Freshet floods* resulting from spring thaw will become more frequent with a worst case estimated loss of $800 million to farmer assets[55,83,91] The last few years have had news outlets reporting on the potential devastation of freshet floods, ranging from $1 billion in risk to agriculture in the Fraser Valley to $30 billion in total economic impact.[92,93]

d) More *pest pressures*, as seen in the recent rise of spotted wing drosophila (SWD)[94–96] that has damaged crops due to warming temperatures. Extreme temperatures have also reduced the effectiveness of *pollination* and threatened pollinator populations.[83,97] To try to mitigate the economic damage that pest outbreaks impose on crops, pesticide use has continued to increase in British Columbia,[98] which has led to concerns for soil and water quality (i.e. high residual levels of Nitrogen and Phosphorus have been found in blueberry fields),[99] the health risks of workers, and the long-term sustainability of pesticide-management. It should be noted that the BC government has identified that sustainable pest management is a major challenge for farmers and that the adoption of an integrated pest management practice is necessary to manage pests and reduce pesticide use, which in turn will help the long-term sustainability of agricultural production.[94,96,100]

e) Early season high temperatures affect *germination and establishment rates*, with early ripening forcing an early harvest, which puts further pressure on labour force challenges/constraints, when it is already difficult to find labour.[55]

1.3.2.3 Economic Factors

Many of the forces mentioned in this section have helped contribute to a larger focus on an agro-industrial model for blueberry production that hinders farmer ability to diversify income sources and increase adaptive capacity to economic and ecological threats.[101]

1.3.2.3.1 Regional and Microeconomic Factors

Farmer demographics in BC are a symptom of the agricultural landscape described above that has led to a more industrialized large farm model with significant barriers to land access and knowledge transfer to younger generations.[102] The average age of farmers rising from 47.5 in 1991 to 54.0 years of age in 2011.[103] This, in part, has resulted in a greater dependence on temporary/seasonal workers, often immigrants or foreign workers, who have their own occupational health issues that need to be considered.[104–108] Availability of workers continues to be limited as urbanization (e.g. the expansion of Metro Vancouver) competes for labour in the market.[109]

Population growth and the expansion of Metro Vancouver has put pressures on the land of the LFV by increasing land costs, straining water supply and quality, air quality, and land use. Particularly, the massively inflated cost of land in the region has put into question the financial viability of farm businesses as the cost per acre climbs near $100,000. The viability of small-scale farms (defined as less than 10 acres) have already been compromised and this size of farm comprises of 40% of the LFV farms.[55] As a result, farm sizes have increased, while the number of farms have decreased,[103] which has led to a rise in input costs for farmers, especially on seeds, fertilizers, and pesticides. Although farm revenues rose, the increase in revenue has not been enough to offset the input costs, in some cases, net profits being negative.[86] These financial constraints limit the choices that farmers have, putting many in debt, as they try to maximize yields in order to maximize revenues to offset costs. In order to do that, input costs increase in order to produce sufficient yields to turn a profit.[104,110] Many of these farmers turn to off-farm income, which may be a result of the financial constraint realities on many farms.[5,69]

The agricultural sector in BC is largely dependent on the LFV, as it is the only region in the province where certain agricultural products can be produced. The economic conditions presented by neighboring the Metro Vancouver area has the consequence of higher priced of food, or more dire, the loss of many farms altogether, leading to a trend where farmers try to maximize yield and profit whereby conventional methods continue to be the norm. Furthermore, government policies have moved away from the protection of Canadian farmers towards policies reliant on trade.[111,112]

1.3.2.3.2 Global and Macroeconomic Factors

As farmers become increasingly reliant on trade, competition has increased as well from other regions. For example, more blueberries are being grown from neighbouring Washington and Oregon states in the US. As a result, BC has been looking to markets in Asia-Pacific for opportunity to increase export. China was once seen as a potential market opportunity. In 2016, China approved 10 packing companies and 19 production facilities from BC for export to the Chinese market. That same year, Canadian blueberry exports were negatively impacted due to the early harvest that season, putting BC fresh cultivated blueberries in direct competition with the Chinese product and growing season. Although this was hoped to be an exception due to the early harvest season, Canadian blueberry exports were down 8% in China in the following year, despite the fact that harvest in BC returned to traditional times in mid-July, which is complementary to the Chinese growing season that usually winds down at that time.[62] The reasons for this may be due to lower crop leaving for exports, lack of demand from Chinese market, or high landed cost of Canadian fresh blueberries after tariffs. The tariffs levied on blueberries in China are 30% which present a barrier for market access in China for Canadian blueberry exports.[62] Although exports to other Asia-Pacific countries looked promising, exports began to fall in almost all the countries, except Hong Kong (who do not have tariffs on Canadian blueberries), as Australia and Japan made their own advancements in the blueberry sector in East Asia.[62] This has limited the Canadian export market to the US, which already receives 98% of Canadian blueberries. This lack of diversification in export has led to a situation that has forced Canadian farmers to maintain a certain level of production to turn a profit and compete with international competition. The possibilities are limited and as long as they cannot diversify their markets, farmers choices will continue to be constrained.[62]

2 Literature Review

2.1 Taking Health Determinants into Consideration in Decision-Making

Decision makers must often differentiate between solutions that are not easily differentiated, or from those where there are not any optimal solutions for the problem of interest.[113] Decision makers are forced to interpret solutions as "best" or "most preferred" alternative.[113] Henceforth, "best" and "preferred" will be used interchangeably throughout this thesis. MCDA provides a sophisticated group of decision-making methodologies that can be used to aid decision makers in finding optimal solutions by considering the factors that *they* themselves deem to be of importance.

A literature review was conducted to better understand what MCDAs are and their different types and uses. In order to establish which MCDA was most appropriate for the context of this thesis, it was critical to understand the differences between each MCDA technique, the steps for conducting each MCDA, and their strengths and weaknesses. This sets the stage for a systematic bibliometric review (outlined in Chapter 3.1) which will look at how these MCDA techniques have been used in the agricultural setting.

2.2 Multi-criteria Decision Analysis

MCDA is a well-known branch of Decision Theory[114] that helps decision makers evaluate, prioritize, and rank conflicting alternatives to determine the *best* alternative through the assessment of conflicting quantitative and qualitative criteria determined to be important and relevant to a decision problem.[115–122] Therefore, the goal of MCDA is to allow the decision maker to find a compromise solution, in other words, the optimal solution or scenario that suits a given problem given a set of competing criteria.[123–127] There are four main types of problems (i.e. problematics) that MCDA tries to aid in: choice problematic, sorting problematic, ranking problematic and description problematic.[123,124,128]

The phases of MCDAs begin by first clarifying problem statements by defining objectives and goals. Criteria are established to measure competing alternative systems that aim to achieve the goals. An MCDA tool is applied, which uses its respective mathematical algorithm to compute a ranking and *best* alternative.[120–122,124,129] If the final solution is not accepted, new data is collected and the MCDA is redone until optimized.[120–122]

The major strengths of MCDAs are that they depend on accurate information that lead to rational, justifiable, and explainable decisions.[124,130,131] MCDAs can generally consider a wide range of data types, including quantitative and qualitative information.[125,126,132] MCDAs offer a structured and transparent process to handle complex problems to facilitate discussions.[124,133,134] MCDAs also have the capacity to present decisions graphically, where these graphs breakdown the contribution of each criterion to how the alternatives have been prioritized.[124,133–135] It should be noted that quality of data can be a significant source of uncertainty which can skew MCDA results. Furthermore, attention must be given to the degree of completeness, redundancy, and mutual independence of criteria which can complicate MCDA decisions.[125,136]

2.3 Techniques of Multi-Criteria Decision Analysis

MCDA methods have been used in the agriculture setting, commonly for decisions regarding system sustainability,[137,138] land suitability,[139,140] land use/optimization/restoration,[141,142] waste and water management,[143,144] alternative energy sources,[145,146] technology innovation,[147,148] climate change and environmental hazards/risks.[149,150] Other topics include crop management, crop variety selection, diversification, pesticide strategies, soil management, and system sustainability. These topics will be discussed further in the results section.

This thesis specifically focuses on the use of MCDA in agricultural sustainability. MCDA has the capacity to aggregate sustainability indicators (i.e. environmental, economic, and social).[124,135] MCDA in sustainability assessment provides a simple and cheap but holistic tool to evaluate the degree of sustainability of agricultural systems (e.g. conventional, mixed-methods, and organic/ecological).[124]. Agricultural sustainability assessment is increasingly regarded as a typical decision-making problem[151] and requires a tool that provides the capacity for data integration, transparency, and robust analysis, while eliciting opinions of engaged stakeholders.[124] There are several MCDA tools that can be applied to agricultural settings. Specifically, this thesis will discuss Multi-Attribute Value Theory (MAVT) and Multi-Attribute Utility Theory (MAUT) which are frameworks of MCDA, and then discuss four main MCDA tools: AHP, Analytic Network Process (ANP), Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE), and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

2.4 Multi-Attribute Value Theory (MAVT) and Multi-Attribute Utility Theory (MAUT)

MAVT can be used to address problems that involve a finite and discrete set of alternatives that are evaluated on the basis of conflicting objectives.[152] The performance of each objective or alternative is measured against a set of criteria.[152] MAVT is a compensatory technique, in other words, it allows compensation for weak performance of one criterion by a strong performance in another. The performances of each option across all criteria are then aggregated to deliver the *best* solution.[152] This method allows for the attachment of real numbers with each alternative reflective of a decision maker's values.[152] Well known MAVT methods include weighted summation and AHP, the latter being the subject of the next section.[152]

The first step of MAVT is to define the alternatives which are to be compared with each other. Second, relevant criteria are selected and defined. Third, each criterion is assigned a value. Finally, the alternatives are ranked by calculating a total score for each alternative through aggregation of its performance on each criterion.[152]

An extension to MAVT is MAUT, which is based on stronger assumptions of expected utility theory. MAUT is a more rigorous method for considering risk preferences and uncertainty.[153,154] MAUT is therefore based on a stronger theoretical foundation; however, a major related drawback is that it requires precise preferences from decision makers and a large amount of data input, which is time consuming and resource intensive.[154] Another weakness is that transparency of this model can be limited, because the methodology can be complex and thus can be difficult to grasp.[152]

MAVT and MAUT have been used in economic, financial, actuarial, water management, energy management, and agricultural settings, due to the presence of significant amounts of uncertainty and enough available data to make MAVT and MAUT appropriate for decision-making.[154] Specifically, in agriculture, these methods are useful to assess the sustainability of an objective or policy, through environmental, economic, and social dimensions. However, attention needs to be given to the fact that since this is a compensatory method, from the perspective of an individual decision-maker, weak performance of one criteria can be completely compensated for by strong performance in one of the other criteria.[152] In other words, if conventional farming does poorly in environmental factors, this can be compensated by strong performance in economic factors.

MAVT and MAUT show potential in their approach to understand the sustainability of agricultural and have been extensively used in this area of study before. MAVT and MAUT's handling of uncertainty make them especially appealing for the agriculture context. Many farming decisions have significant uncertainty, for example as a result of environmental and climate change factors or regional and global economic factors (as discussed in Chapter 1.3.2). Farmers need to make the best decisions in the face of these conditions and constraints in order to develop a sustainable and healthy agricultural system that is viable both in the short and long term.

2.5 Analytic Hierarch Process (AHP)

The AHP (Figure 2. 1) is one of the most popular MCDA methods developed by Thomas L. Saaty, in the 1970s.[154,155] Although considered a type of MAVT/MAUT, the AHP has different assumptions on value measurements and is developed independently of MAVT/MAUT. The AHP uses a hierarchal structure that consists of an overall goal, a group of options/alternatives that can reach the goal, and a set of criteria that the alternatives can be measured against. These criteria can further be broken down into sub-criteria.[156]

The first step of AHP is the structuring of a decision problem and selecting and defining a set of alternatives that aim to solve the decision problem, along with a set of criteria that the alternatives can be measured against. The hierarchy is structured in a way that the goal is at the top level, followed by the criteria at the middle level, and the alternatives at the lowest level. This process involves significant discussion and research. The second step is known as weighing. In this step, the decision makers evaluate and judge the criteria by comparing them to each other two at a time with respect to their impact on the problem of interest. This method of comparing is also known as pairwise comparisons using a 9-point scale, where 1 means equal importance/preference and 9 means extremely important/preferred. See Table 2. 1 for the Saaty 9-point scale. In other words, decision makers are asked: “how important is criterion A relative to criterion B?” A numerical weight is then derived for each criterion after all comparisons have been exhausted. These weights always add up to 100%. The third step is known as scoring, whereby each alternative is awarded a score through pairwise comparisons using the same 9-point scale as seen in step 2. The consistency of judgements made by decision makers should be checked after steps 2 and 3. If the consistency ratio (CR) is above 0.1, the pairwise comparisons need to be revisited. Finally, the fourth step sees that the criteria weights and the alternative scores are combined through simple weighted summation; this provides an overall relative score, and thus a ranking for each alternative. The alternative with the highest rank should be discussed among the decision makers to ensure that it is in fact the option that they would like to move forward with. [125,157]

Figure 2. 1: AHP

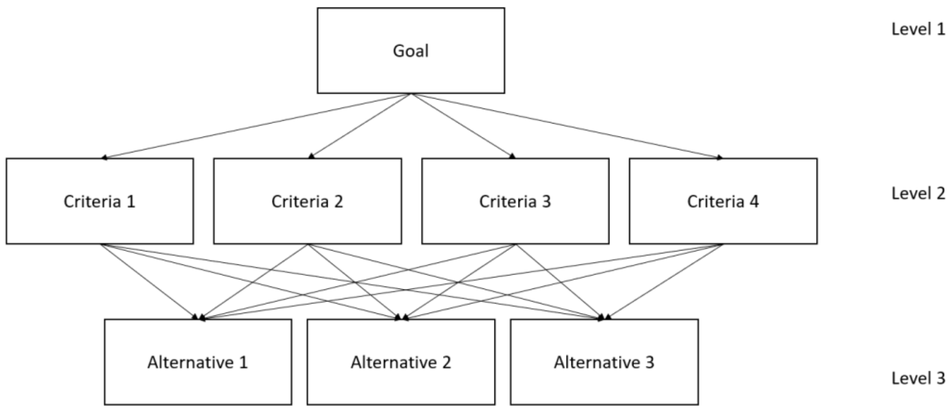


Table 2. 1 Saaty 9-Point Scale for AHP

Scale	Definition	Explanation
1	Equal importance/preference	Two activities contribute equally to the objective
3	Moderate importance/preference of one criterion over another	Experience and judgement moderately favour one criterion over another
5	Essential or strong importance/preference	Experience and judgement strongly favour one criterion over another
7	Very strong importance/preference	Experience and judgement very strongly favour one criterion over another
9	Extreme importance/preference	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two judgements	When compromise is needed

There are a few notable strengths of AHP. It is a flexible approach that is intuitive and easy to explain and use for decision makers.[157] Users often find the pairwise comparisons straightforward and convenient.[157] The importance of each criterion is clear relative to one another, as the decision problem is broken down to its parts and formed into a hierarchy.[157,158] It makes the decision much more visual and intuitive. Furthermore, AHP is capable of capturing both subjective and objective data,[159] as well as quantitative and qualitative measures.[157] Also, the CR helps to measure the consistency in decision-maker judgements in the pairwise comparison portion of the AHP, and to make sure their judgements follow a logic and are not entirely random.[157,160] The bias in decision making is quite low due to its capacity to evaluate consistency in decision maker judgements during the pairwise comparison process.[157] AHP also allows for both individual decision-making as well as group decision-making through the calculation of geometric means.[157] Although AHP requires a sufficient amount of data to do the pairwise comparisons, it does not require as much data as MAUT.[154]

Though AHP is not without its weaknesses. A primary concern is that it can be difficult to determine mutual exclusiveness of criteria and alternatives.[125] Rank reversal can also pose a problem, which is described to occur when an alternative that is not mutually exclusive from existing alternatives, is added to a model that was evaluated.[157] This is one instance of a ranking irregularity that can occur; however, sensitivity analyses can be done to help mitigate some of these issues and see how alternative rankings would change if criteria weights were altered. Another issue is that the AHP method is a compensatory method, which means that poor performance in one criterion by an alternative can be compensated by a strong performance in another criterion.[157] A third criticism has to do with the use of the 9-point scale, which is considered by some to be an artificial limitation.[157] Fourth, calculations can be complex,[157] but can be addressed through the availability of free software, including Excel.[161] A final issue is that AHP can be time consuming and costly depending on the subject.[157]

Although MAUT/MAVT are generally complex and resource intensive techniques, AHP as a type of MAVT that shows a lot of potential in its application for this thesis. One of the main goals of this thesis was to make the case for a different strategy for assessing agricultural sustainability and health, in a way that is transparent and still comprehensive to facilitate discussions at a policy level. What makes AHP appealing is its ability to develop a visual hierarchy that breaks down the problem intuitively. This hierarchy breaks down the criteria into a ranking of relative importance. Understanding the degree to which these criteria are important (depicted by their relative weights) could be important in understanding the nuances of farmer decisions and constraints when developing policy for more sustainable and healthy systems.

2.6 Analytic Network Process (ANP)

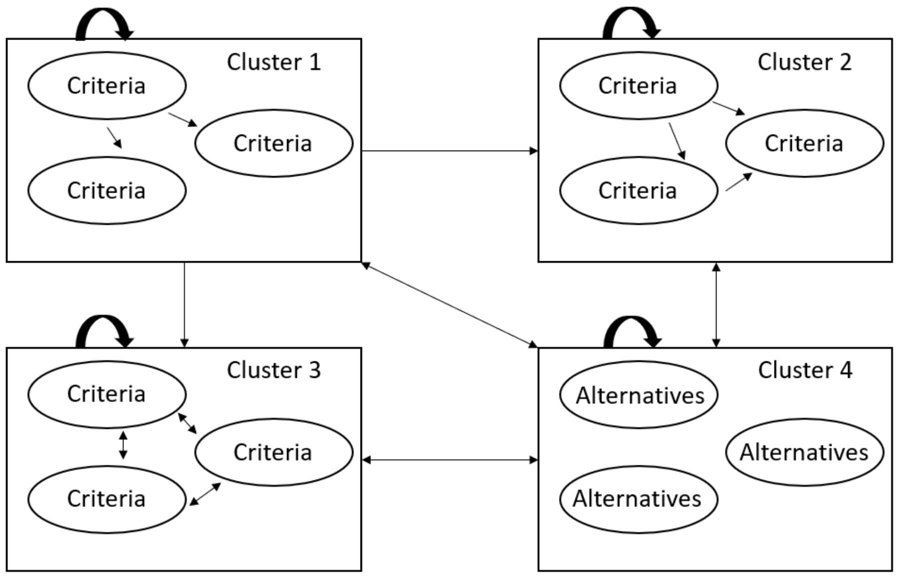
ANP (Figure 2. 2) is a more general form of AHP. ANP structures a decision problem as a network, which is different from AHP, that structures the decision problem as a hierarchy. ANP still uses pairwise comparisons to measure the weights of each component of the network to ultimately rank the alternatives. In other words, AHP does pairwise comparisons of the criteria to determine their weights and then apply the weights of the criteria to alternatives to determine the ranking of the alternatives, in ANP, criteria, sub-criteria, and alternatives are treated equally, as components in a network, with relationships between each other. These components are thus all compared. Therefore, ranking of alternatives depends on both the criteria's effect on the alternatives, but the alternatives effect on criteria.[162–164]

The network of ANP is represented by a super matrix. The super matrix is populated by first, pairwise comparisons of criteria compared to other criteria. Second, pairwise comparisons of alternatives compared to other alternatives are conducted for each criterion individually. These first two steps are the same to what happens in a hierarchal process. The next step, unique to ANP, pairwise comparisons of criteria compared to other criteria are compared within one alternative at a time. In other words, the impact of alternatives on the importance of criteria is considered. Finally, the matrix is normalized and synthesized into what is called a limit matrix, which provides the ranking of alternatives.[162]

The major strengths of ANP compared to AHP are that it improves on some of the biases and inconsistencies associated with mutual independence of criteria and alternatives. Independence is not required in ANP.[165] ANP looks at each alternative's performance independent of the other alternatives, which limits the effect of compensation that is present in AHP. The issue of rank reversal is also avoided.[166] However, although it is a more comprehensive approach than AHP, it is more time consuming to complete, and explaining the model and process is a lot more difficult than with AHP. Also, ANP requires specific software to conduct accurately, and it is too complex for implementation as the standard model.[162,167]

Although ANP would have been appropriate to use in this thesis, and despite it being the more comprehensive approach than AHP, it is far more time consuming and complex and difficult to explain. I determined this model to be unnecessarily more complicated than AHP. With careful application of AHP (i.e. ensuring mutual independence of criteria and ensuring that the criteria are comprehensive) this will avoid a lot of the biases present in AHP that ANP sets to solve. I thought it was necessary to have a model that was as simple and easy to use as possible to use on a population that has varying degrees of education and/or a lack of experience using MCDAs; as you will see in Chapter 6, with some participants, even explaining the AHP process can be difficult.

Figure 2. 2: ANP



*Curved arrow represents that each element could depend only on itself, though not a necessary component of a cluster
*Relationships (represented by the arrows) can be one-way or two-way

2.7 Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE)

The PROMETHEE method was first developed by J.P. Brans in 1982 (PROMETHEE I) and expanded by Brans and Vincke in 1985 (PROMETHEE II), with further subsequent expansions.[127,168] PROMETHEE is a family of outranking methods whereby PROMETHEE I determines a partial ranking of alternatives and PROMETHEE II determines a complete ranking of alternatives. These two methods will be the focus of this section. Subsequently developed versions include: PROMETHEE III (for ranking based on interval), PROMETHEE IV (for complete or partial ranking of alternatives when a set of viable solutions is continuous), PROMETHEE V (for problems with segmentation constraints), and PROMETHEE VI (for the human brain representation).[154,169] Another popular outranking method is ELimination Et Choix Traduisant la REalité (ELECTRE),[154] though this method will not be a focus of this chapter.

PROMETHEE is a well-established decision support system which deals with the appraisal and selection of a set of alternatives and the basis of several criteria, with the objective of identifying the pros and cons of the alternatives and obtaining a ranking among them.[168] This is determined through evaluating the performance of each alternative against each criterion.[168] There is a degree of compensation in the performance of alternatives, with poor performance of an alternative in one criterion being compensated by strong performance in another criterion.[168,170] Thus, the performance of alternatives against criteria determines a ranking, and the degree of dominance of one alternative over another is determined by *outranking.*[168]

The first five steps of PROMETHEE I and PROMETHEE II are the same, the latter will be the first described below. The first step of PROMETHEE II is to determine the criteria weights. This can be done through discussion and debate, or through pairwise comparison (e.g. as seen in AHP). The second step is to construct an evaluation matrix with alternatives on the far-left column, and alternatives on the top row. The data in the matrix may be collected from several sources and be real values. The next step is to determine which criteria are beneficial (criteria that you want alternatives to have higher real values on) and non-beneficial (criteria that you want alternatives to have lower real values on). This will allow for normalizing the matrix. First, take the difference in the normalized value of each individual alternative with respect to other alternatives (i.e. pairwise comparisons). The difference in the normalized value in alternative A compared with the normalized value of alternative B until all comparisons are exhausted. The third step calculates the preference function. For each of the values attained in step two, if the value is ≤ 0, then substitute 0 in for that value, and if the value is > 0, keep the value the same. 0 signifies no difference between alternatives, where 1 signifies a big difference. Step four calculates an aggregate of the preference function, determining the outranking degree of alternatives. First, the preference function is multiplied by the corresponding criteria weights determined in step one. Then, the values are summed (i.e. the rows are summed) which represent the sum of the values of each pairwise alternative comparison. The sums are divided by the sum of the weights, which is typically equal to 1. A matrix of global preferences is constructed (e.g. a 4x4 matrix if you have 4 alternatives). In step five, the leaving and entering outranking flows are calculated. Leaving flows are the average of the values in the rows divided by the number of alternatives minus 1. This represents the strength of the alternative (dominance). Entering flows are the average of the values in the columns divided by the number of alternatives minus 1. This represents how much an alternative is dominated by other alternatives (sub-dominance). A linear ranking is obtained by subtracting sub-dominance (entering flows) from dominance (leaving flows) (i.e. leaving – entering = net outranking flow values). Each net outranking flow value is given a relative rank, with the bigger the value the higher the rank.[125,168]

PROMETHEE I is different than PROMETHEE II in that it demonstrates a partial ranking instead of a complete ranking described above. Specifically, the methodology differs after step five, whereby instead of calculating an average of the leaving and entering flows, PROMETHEE I calculates a sum. All incomparable alternative comparisons are eliminated, and a ranking is determined from the remaining situations. If an alternative is at least as good on one criterion and the other alternative is better on another criterion, these alternatives are incomparable without more information. This is a partial ranking, because in getting rid of incomparable alternative comparisons there is a loss of information between alternatives. The degree to which one alternative outranks another is also lost.[127]

The strengths of PROMETHEE are that this methodology supports group level decision making, as it is a good platform for debate and consensus building.[168] It also has the capacity for both quantitative and qualitative data, and ability to deal with uncertain data.[168] Furthermore, data can be used in their own units and true values.[127] Finally, it is a transparent method and easy to use.[154,168] However, these strengths present some related weaknesses. First, a lot of data is needed to fill a matrix.[168] Second, the amount of expert judgement required can be high.[168] Third, the ways in which preference information is processed is complicated and hard to explain to users, therefore, comprehension and interpretability can be difficult and thus, decision makers may have difficulty structuring decision problems.[168] Fourth, as with other methods seen in this chapter, rank reversal after the introduction of new alternatives can occur.[168] Finally, there is no formal weighing guidelines for criteria[154,168]; it is assumed that decision makers can provide their own, however, this can be mitigated through use of pairwise comparison methods, such as AHP.[158]

PROMETHEE presents an attractive option for ranking alternatives. This can be used as an extension of AHP, though would require a lot more data in order to rank the alternatives compared to an additive or multiplicative model or even another AHP. Although PROMETHEE as a ranking system is more complicated to describe and explain, it is more robust. It would be interesting to model a ranking of these alternatives with real world data to support farmer preferences, if enough data is available.

2.8 Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

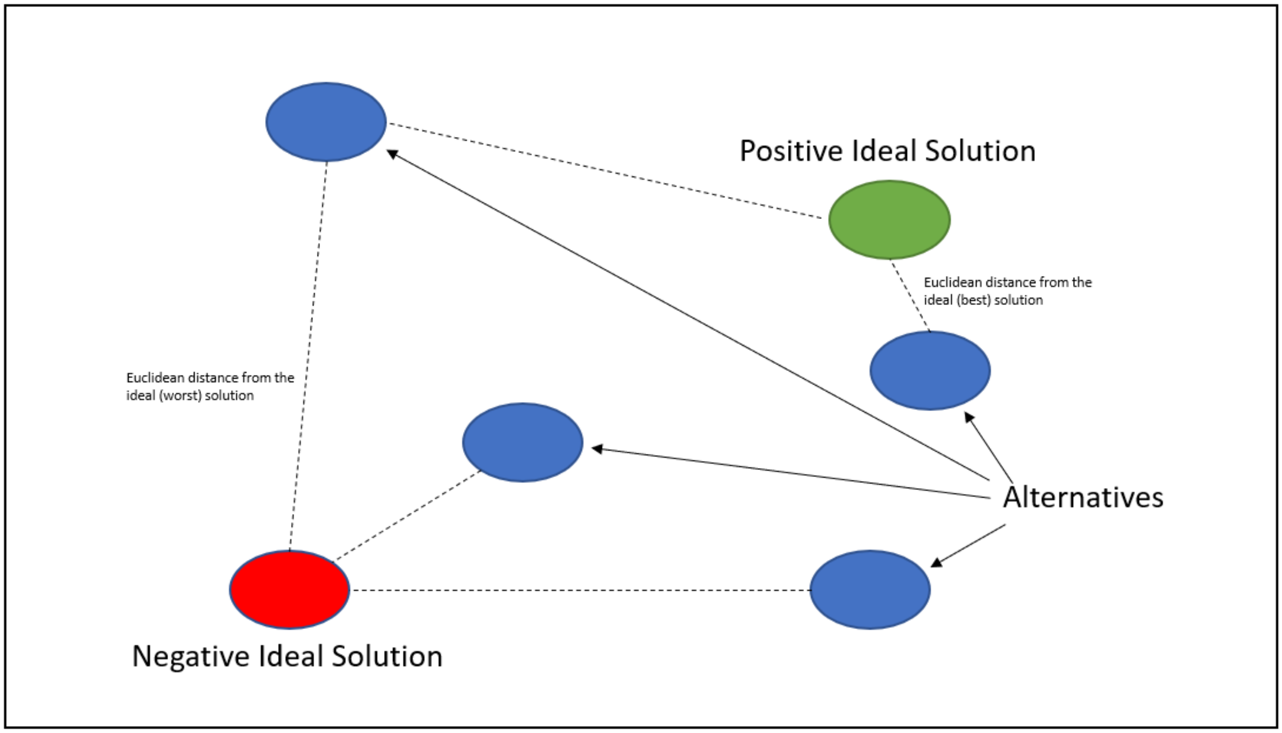
TOPSIS (Figure 2. 3) is a MCDA method, originally developed by Hwang and Yoon in 1981, with subsequent iterations developed in 1987 and 1993.[120,171,172] TOPSIS aims to identify solutions from a finite set of alternatives.[173,174] The basic concept of TOPSIS that differentiates itself from other MCDA tools is that the chosen alternative is the one that has the shortest distance (also called the Euclidean distance) from the ideal (best) solution and farthest distance from the negative ideal (worst) solution.[132,175,176] This follows the idea that a solution is always a compromise, in that no solution satisfies all criteria simultaneously—a solution may perform well on certain criteria, and less so on other criteria.[119]

The first step of TOPSIS is to calculate a normalized matrix through vector normalization. The second step is to calculate the weighted normalized matrix, which is the normalized values multiplied by the respective criteria weights. Step three is to determine the positive ideal and negative ideal solution for each criterion.[177] This requires the decision maker to determine the beneficial criteria and the non-beneficial criteria: for the beneficial criteria, the highest value is the positive ideal solution, and for non-beneficial criteria, the lowest value is the positive ideal solution. Contrarily, for the negative ideal solution, for beneficial criteria, the lowest value is selected, and for non-beneficial, the highest value is selected. In step four, the separation measures are calculated (i.e. the Euclidean distance).[113] This calculation provides the positive separation score and the negative separation score for each alternative. In step five, the performance score is calculated from the separation scores in step four, and in the final step a rank is determined based on the performance scores.

The strengths of TOPSIS are that it is an easy to understand and intuitive method.[122,178] It has straightforward computation and can be used in numerous settings (universal applicability)[178]. Also, it requires the same number of steps to complete, regardless of the decision problem size.[154] However, TOPSIS does present some weaknesses. First, it is difficult to consider the correlation of attributes in separation/Euclidean distance.[154] Second, it is difficult to weigh attributes and keep consistency of judgement.[154] Third, rank reversal is an issue with the introduction of new alternatives.[119] Fourth, presenting ideal best and worst solutions potentially introduce fictitious alternatives.[119] Lastly, there are no guidelines, and thus uncertainty, as to how criteria weights are obtained[173,174]; although this can be mitigated through use of pairwise comparisons as seen in AHP and suggested in PROMETHEE.

Farmer decisions are constrained and any of their decisions are a compromise between their preferences and these constraints. TOPSIS is a technique that allows for modelling of an ideal solution for their farming practice (i.e. their preferred way of farming) and the negative ideal solution (i.e. their least preferred or most constrained way of farming). Farmers make compromises and land somewhere in the middle. Having a visual of farmer preferences (ideal solution) and where agricultural production alternatives land relative to those preferences lends itself to an interesting discussion. Like PROMETHEE, this way of ranking alternatives can be done as an extension of AHP, though again, would require a lot more data than additive or multiplicative models or AHP alone.

Figure 2. 3: TOPSIS



2.9 Other MCDA Methods

Other commonly used MCDA methods include ELECTRE, multi-objective programming and goal programming, Decision Expert (DEX), Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH), Weighted Product Model (WPM) and Weighted Sum Model (WSM). Also, MCDA methods have various ways of considering uncertainty, including one-way sensitivity analysis, probabilistic sensitivity analysis, and scenario analysis. A commonly used method for considering uncertainty in MCDA techniques such as AHP and ANP is the use of fuzzy logic.

2.10 MCDA Selected for this Study

There have been many studies that have shown the potential for MCDA in agriculture, notably a thesis by Talukder tested different MCDA tools to assess the agricultural sustainability of different agricultural systems.[124] The MCDA selected for this study was AHP. One of the objectives of the MCDA study is to elicit preferences from farmers and determine the relative importance of the criteria or factors they deem to be most important; AHP is an excellent simple to use tool for this kind of application that has been used in many settings.[179] The reason for its selection over other

MCDAs were, first, its popularity. AHP is used extensively in both health and agriculture MCDA research studies. Second, the simplicity in its design, compared to TOPSIS for example, makes it easier to explain to participants. Although TOPSIS has simpler computation than AHP, it can be difficult to consider the distance between a solution and an ideal solution because comparing to an ideal solution is fictitious and not easy to process. AHP, on the other hand, asks decision-makers to judge, via pairwise comparisons on a 9-point scale, which criteria are more important to them than others. This process uses easy to follow diagrams of the scale and has immediate results for feedback. Although the 9-point scale is criticized by some to be an artificial and arbitrary limitation, other MCDA techniques, such as TOPSIS and PROMETHEE, do not present any guidelines for weighing criteria, and solutions for this often use AHP anyway. As an aside, it would have been interesting to conduct an MCDA to choose which MCDA tool to use in the pilot study of this thesis.

Although AHP has some weaknesses, for example it is a compensatory method whereby a weak performance of one criterion by an alternative can be compensated by a strong performance in another criterion, alternative methods require a lot more data, and thus require more time and money to implement. For example, ANP improves on AHP by mitigating the risk of mutual dependence of criteria and alternatives and limiting potential biases and inconsistencies. However, ANP is more time consuming to complete, more difficult to explain and implement, and its complexity is not warranted for this context.

The objective of this study was to first establish a ranking of importance for the criteria across different agriculture production methods (i.e. their preferences). It is critical to understand the relationship between these criteria because of the focus this thesis has on integrating together the determinants of health and agricultural sustainability. Since methods like PROMETHEE and TOPSIS can use AHP to provide validity to their weights (instead of using a direct weighting method), I determined them to be superfluous for this study. The same can be said for methods like WSM. Although this is the *easiest* method, it does not lend itself well to one of the purposes of this study, which is to understand which are the most important criteria and their relative weights to understand the balance between economic, environmental, and social factors. The purpose of this study was not exclusively centred on ranking the alternative agricultural production methods. While I appreciate that future versions of this study can do a sensitivity analysis with PROMETHEE to establish the ranking of the alternatives, and TOPSIS can be used to develop a visual for how farmers have compromised from their preferred solutions, they would require a lot more time and data.

Further, the overall goal of the MCDA study was to understand the constraints, particularly costs, that prevent farmers from practicing towards their methods. In my opinion, this requires the MCDA to not consider costs in its analysis, but in a CBA. AHP lends itself intuitively to a CBA where costs can be divided by the aggregate scores of the AHP. See Table 2. 2 for summary of rationale for selection of MCDA criteria.

Table 2. 2: Summary of Rationale for Selection of MCDA Technique

Technique	Arguments for (Strengths)	Arguments against (Limitations)	Applications in context of this study	Rationale for selecting or not selecting
MAVT & MAUT	• Handling of uncertainty	• Limited transparency • Resource intensive • High data requirements	• Assess the sustainability of agricultural systems	• Complex and data intensive • AHP is a type of MAVT that is still robust but more intuitive
AHP	• Intuitive visual hierarchy • Robust establishment of criteria weights	• Attention required for mutually exclusive criteria • One criterion compensating for another is possible	• Establishing a ranking of importance for the criteria across different agricultural production methods (their preferences)	• The results of the MCDA can be used in the CBA to understand how costs constrain growers from practicing towards their preferences
ANP	• Mutual independence not required • Criteria compensating for other criteria not a worry	• Complex • Time consuming	• Same application as ANP	• Too complicated for this study to the point that it may be too difficult to explain to participants
PROMETHEE	• More robust ranking technique	• No established criteria weighting procedure	• As an extension of AHP	• More complex than other ranking methods, and more time consuming and complex than necessary to justify for this study. CBA application more difficult
TOPSIS	• Visual method	• No established criteria weighting procedure • Introduces fictitious scenarios • More data intensive	• Visualize the compromises made by farmers in relation to their ideal and least ideal solutions • As an extension of AHP	• Although it would have been a good visual tool, time constraints would not allow for this methodology to be applied. CBA application not relevant

3 Methods

3.1 Methodology – Systematic Bibliometric Review

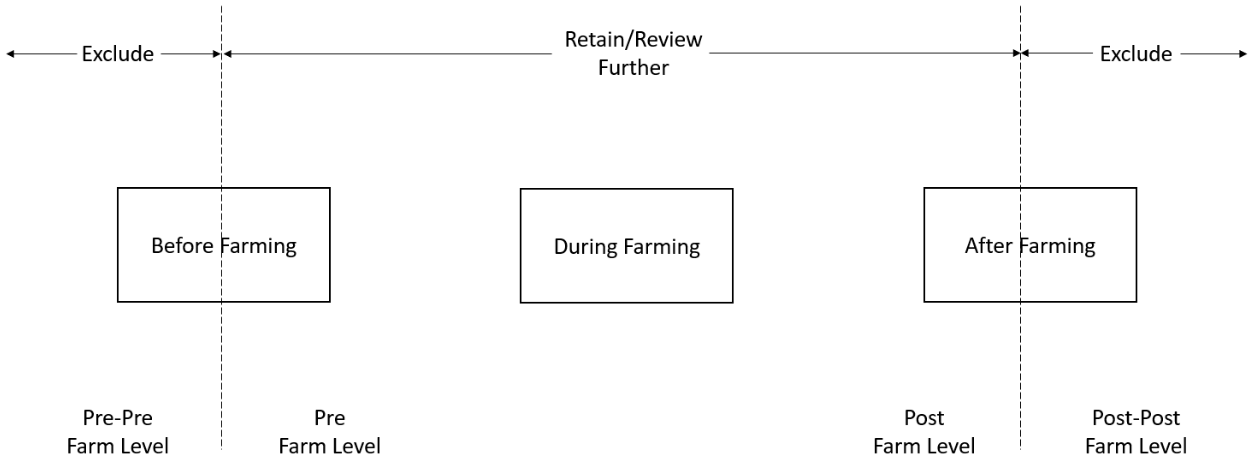
3.1.1 Eligibility Criteria

A systematic review of the literature was conducted to identify studies that applied the use of MCDA techniques within the agricultural context, while also considering costs at a certain point in the analysis.

The systematic review was inclusive to all MCDA techniques and no time frame was provided, in order to capture a wide range of MCDAs and studies. The review was also inclusive to all types of publications. The assumption for this was that there may not be enough studies conducting MCDA in agriculture with the inclusion criteria outlined below. So, reviews and other publications were not excluded. The search strategy excluded all non-English language studies during the screening process. To be included, studies had to contain the following inclusion criteria:

- Studies had to use an MCDA technique
- Studies had to pertain to an agricultural problem, question, or decision.
- Studies had to elicit a stakeholder at the farm level
    - Decision had to be a farmer level decision, or at the very least the decision-makers were acting as a proxy to the farmers' values and/or preferences (i.e. policy makers or grower organizations)
    - Decisions had to be based on the directly on the farm with consequences to farming practices or growing, and not agricultural decisions that happen outside this setting. Therefore, this would exclude what we termed as *pre-pre* and *post-post* decisions (see Figure 3. 1 for diagram)
        - Pre-pre: decisions that were too broad in the sense that they happened way before the farm or farming/growing practice (e.g. land selection for farming)
        - Post-post: decision that were too broad where these decisions happened in post-operations on farm (e.g. waste-water management)
- Studies had to demonstrate the use of economics or costs in the analysis.
- Health was not employed as an inclusion criterion because it was assumed that this would make the review too narrow – but its being addressed was a focus for analysis

Figure 3. 1 Diagram for Inclusion/Exclusion Based on "Pre-Pre" and "Post-Post"



3.1.2 Search Strategy

Relevant studies were identified, with consultation of a UBC librarian (whose areas of focus are agriculture and health) using the following electronic databases: *Web of Science, CAB Direct*, and *Agriculture & Environmental Science*. Databases were searched using three concept groupings:

- Concept 1: MCDA terms: multi-criteria decision analysis, multi-criteria decision making, multi-criteria decision aid, multi-attribute utility theory, multi-attribute utility, multi-attribute value theory, weighted product method, weighted product model, simple additive weighting simple multi-attribute technique, analytic hierarchy process, AHP, analytic network process, measuring attractiveness by a categorical based evaluation technique, elimination and choice expressing reality, ELECTRE, preference ranking organization method of enrichment evaluation, PROMETHEE, technique for order preference by similarity to ideal solution, TOPSIS
- Concept 2: Agriculture terms: farm, agriculture, agricultural, agroecologic, agro-ecologic, agroindustrial, agro-industrial
- Concept 3: Cost/economic terms: cost, economic

Terms within each concept were combined using the Boolean operator *OR*. Concepts were combined using the Boolean operator *AND*.

The reference lists of previously published literature reviews and studies identified through the electronic databases above were also scrutinized to identify relevant studies. Other sources such as the Food and Agriculture Organization were also searched for examples of MCDA use.

Identified studies were independently screened by two reviewers (RA and JM) to determine whether they met the inclusion criteria. Disagreements were resolved by a third party (JS). Each article was assigned a value out of 5 that represented how well the article met the inclusion criteria, with 5 being the highest value where the article unquestionably meets the inclusion criteria, and 0 being the lowest value where the article unquestionably does not meet the inclusion criteria. This value system was used in the event of a disagreement. The values given by each reviewer were averaged and if the average was 3 or above, it was included for full-text screening. Reviewers were conservative, and usually chose to include when there was doubt.

Eligibility criteria were given a priority ranking as basis to exclude the article. During the abstract screening, availability and use of MCDA in the article was the first criterion to be assessed. If the article did not contain an MCDA it was eliminated without necessarily checking if other criteria were satisfied. Then, the second criterion assessed was whether the article was framed around agriculture. If the article did not pertain to agriculture, it was eliminated without proceeding to identify if other eligibility criteria were satisfied. The third criteria assessed is whether the article was determined to be too broad from farm-level decisions (i.e. pre-pre or post-post). Cost was not assessed during abstract screening, as it was determined to be too difficult to evaluate whether this criterion was considered from the abstract alone. During full-text screening, the same priority order of criteria was applied as in the abstract screening process, though the availability of cost in the article was assessed as well.

If reviewers identified multiple criteria as reason for exclusion, priority was given to MCDA, then agriculture, then broad/farm-level, and then cost. Not all articles were assessed further upon discovering one criterion for exclusion.

3.1.3 Bibliometric Analysis

Bibliometric methods are commonly applied to assess patterns and trends in publications in a designated area of interest.[180] Although such analyses have not been widely utilized in the area of agriculture, it is noteworthy that two such applications[181,182] were recently published, so perhaps this is indicative of a growing interest in such approach.

For this thesis, a bibliometric analysis applying methods discussed by Ellegaard and Wallin (2015)[180] was carried out to describe and analyze the trends of MCDA applications in the area of agriculture. This bibliometric analysis is meant to scope what has been addressed and situate the MCDA study conducted for this thesis into the literature. Trends were analyzed for all included articles. For all articles, year of publication, topics covered, and reason for exclusion were tallied. For included articles only, years of publication, country of publication, article type, MCDA technique used, crop analyzed, topics covered in agriculture practice were all tallied, as well as how were costs considered and how was health considered in the analysis if at all. The bibliometric analysis was performed using Microsoft Excel (Microsoft Corporation, Redmond, Washington, US).

3.2 Methodology – MCDA Study

3.2.1 Settings and Participants

3.2.1.1 Recruitment

Farmers that grew blueberries in the LFV were recruited between November 28, 2017 and March 2018 to participate in the study. The BC Blueberry Council (BCBC) acted as an intermediary for their members to join in this methods/pilot study. Inclusion criteria included farmers in the LFV, BC. The final list of participants had to be representative of the different agricultural production methods (conventional, agro-ecological/organic, integrated farming/mixed-methods; small, medium, larger growers). This will allow us to get insight to the heterogenous insights of current production practices and preferences.

The BCBC held events, such as grower meetings, shows, and courses, to which the researchers were invited to attend and recruit. At these events, a short presentation, explaining the study and how it could benefit growers, was given. Flyers were also given out, and there were opportunities to interact with the growers. In addition to these events, online directories and websites, including the BCBC's, and producer/packer websites were used to recruit farmers. Some snowball sampling was also used, as farmers who signed up suggested to farming neighbours and friends to participate.

In total, there was four sessions for each participant. The first sessions were done as face-to face meetings either on the participant's farm, or in a private room at the BCBC office in Abbotsford. The final three sessions were done as phone interviews. In total, 9 growers participated in this pilot study, and $20 Coffee Shop gift cards were provided to compensate for their time. Although this is a small sample size and the sample's distribution across farming methods may not be representative of the total BC blueberry farmer population, it should be noted that this is meant to be a pilot study.

I personally led the sessions and encouraged farmers to discuss and share their perspectives. All sessions were audio recorded, except for one participant, who did not give permission to be recorded.

3.2.1.2 Interview Sessions & Data Collection

3.2.2 Pre-Data Collection Phase

3.2.2.1 Identify Agricultural Production Methods

Prior to the interview sessions and data collection, it was necessary to identify the agricultural production options and research definitions in the literature. The terms identified were agro-industrial, conventional farming, agro-ecological, organic farming, mixed-methods farming, and integrated pest-management. Some other ways of categorizing the farming methods were by the size of the farm (small, medium, large). In the end, based on literature and expert opinion and informal conversation (which included Dr. Jerry Spiegel, Dr. Craig Mitton, Dr. Hannah Wittman, BCBC and BC Ministry of Agriculture, and informal conversations with farmers), it was concluded that conventional farming, agro-ecological/organic farming, and mixed-methods farming were to be the agricultural production method terms brought to the interviews. Table 3. 1 for definitions of the alternatives.

3.2.3 Identify and Define Alternatives and Criteria

Prior to the interview sessions and data collection, it was necessary to identify and define criteria thought to potentially be the most important to growers. The first iteration of these terms and definitions were identified through the literature. Suggested edits were made by Dr. Jerry Spiegel prior to presenting them to Dr. Hannah Wittman, who provided topic expertise to inform the terms and their definitions that should be included in the analysis. This process yielded ten relevant criteria. Dr. Craig Mitton was consulted prior to organizing mock interviews at the BCBC and the BC Ministry of Agriculture. Dr. Mitton's role was to confirm that the MCDA was being properly constructed, and that mutual independence of the 10 criteria was considered.

Mock interviews were conducted with agriculture experts in blueberries from the BCBC and BC Ministry of Agriculture. These interviews were used to validate the terms and definitions to ensure the appropriateness and sensitivity in the BC blueberry farm setting and the farmers that were the target of the study. This was done by having the experts go through the MCDA exercise to ensure that the terms and definitions made practical sense, were easy to understand, and accurate to the context. This stage was also used to further fine tune the MCDA tool more generally, such that the language used during the data collection was in layman terms (i.e. not too technical) and to ensure that the study was feasible (i.e. such that the goal of the MCDA to help inform policy was communicated). A total of four iterations were made of the terms and definitions prior to data collection, though the final list was mostly informed by literature with some iterations for language and context sensitivity as explained above. See Table 3. 1 for definitions of the criteria.

Table 3. 1: Pre-Data Collection Definitions of Alternatives and Criteria

Terms		Definitions
Alternatives		
Conventional		Monoculture agricultural systems (large as well as smaller scale) dependent on high inputs of synthetic fertilizers and pesticides to achieve and sustain high yields[183–185]
Organic/Ecological		Practice of applying ecological concepts, principles and knowledge to design and management of sustainable farms; sometimes with organic certification[186–189]
Integrated-Farming (Mixed-Methods)		Mixes both methods (ecological and conventional)[190,191]
Criteria		
Environmental	**Agricultural Sustainability**	Ability to ensure that resources required to function optimally over time are maintained without deterioration (e.g. soil depletion; energy use)[192,193]
	Adaptability	Ability to respond to changing conditions (also referred to as resilience)[17,18]
	Biosecurity	Contamination of the environment (air pollution, water pollution, genetic contamination of crops, soil quality and erosion, wildlife protection)[194,195]
Economic	**Crop Yield**	Volume of crops that are produced (pounds/acre)[196]
	Net Revenue	Amount of money crop generates ($/acre)[197]
Physical	**Health Effects**	Health issues as a result of exposure to toxic substances, work conditions, stress, etc.[198]
Social	**Sovereignty**	Degree to which agricultural processes are within producer control, and the extent to which one can utilize own strategies (i.e. autonomy, self-reliance, and empowerment)[199]
	Solidarity	Extent to which positive and healthy social networks are established or reinforced (e.g. with other producers, communities or consumers)[33]
Other	**Food Safety**	Pesticide residue that remains on the blueberries is safe for consumption[200–202]
	Nutrition	Health benefits from blueberry consumption (antioxidant properties)[203]

3.2.4 Conducting the MCDA

3.2.4.1 Validation Phase (Session 1)

The first session with growers focused on describing and understanding the study and the methodology, what is required from participants to participate, and validating the terms and definitions of the agricultural production methods and the criteria.

First, an explanation of the study was given to the farmers. This involved a slideshow presentation describing MCDA, the benefits to the farmers, and a car example exercise that farmers went through to understand MCDA more clearly. (see Appendix 1). Once it was clear that there was clear understanding, farmers were given an opportunity to read the consent form (see Appendix 2) and ask any questions.

To validate the terms and definitions, farmers were given a chance to read through the agricultural production method terms and definitions created in the pre-data collection phase. This was first done by situating concepts of sustainability and health together (see Appendix 1). They were asked to either agree, disagree, or elaborate on the terms and definitions. In other words, they could keep the terms and definitions as is, adjust them, or provide their own or change the definitions entirely. They were also asked to provide some detail and examples on how they themselves farm. Since farming methods exist on a spectrum of more industrial methods to more organic, this exercise is helpful to situate the realities of farming method practices, defined within this given context of blueberry farming in BC. The farmers were then given a chance to read through the criteria list and definitions (see Table 3. 1), and were required to repeat the steps taken, as described above with the agricultural production methods terms and definitions. A key assumption and requirement for participants to understand is that in selecting criteria, each criterion is mutually exclusive to avoid double counting. Criteria must be collectively exhaustive to ensure all relevant criteria are included.

Farmers would categorize the criteria into three tiers. Tier I was the most important to them, followed by Tier II and Tier III. I then tallied how each farmer categorized each criterion to see any trends. Based on Tier I (most important) categorization, agricultural sustainability was the most selected, followed by biosecurity and net revenue, followed-by food safety and health effects. Among conventional growers, environmental criteria were most selected, with all four growers selecting agricultural sustainability, adaptability, and biosecurity. Both mixed-methods growers selected agricultural sustainability, crop yield, and net revenue. Biosecurity, and health effects were the two criteria that got the three organic votes.

Farmers were also asked to try to eliminate some of the criteria. The most commonly eliminated criterion was sovereignty, followed by nutrition and crop yield. With some criteria, farmers were less comfortable eliminating them but did not deem they should be selected either. These farmers decided to have tiered groups for their criteria. The first tier was criteria selected as mentioned in the previous paragraph. Second tier important criteria but not as much as the first tier, and third tier followed the same logic, being less important than tier two. The criteria most commonly in tiers two and three were solidarity, followed by food safety. After these initial discussions I tallied the responses in terms of which tier each farmer put the criteria in including which criteria were eliminated by some farmers. I determined that there was not enough evidence to suggest that there was consensus or majority to remove any criteria (See Table 3. 2 for full tally chart).

Table 3. 2 Tally Chart

Criteria		Conventional (n=4)	Mixed-methods (n=2)	Organic/ Ecological (n=3)	Total (n=9)	Tier II & III	Combined Total
Environmental	Agricultural Sustainability	4	2	2	8	0	**8**
	Adaptability	4	1	0	5	2	**7**
	Biosecurity	4	0	3	7	2	**9**
Economic	Crop Yield	2	2	1	5	1	**6**
	Net Revenue	3	2	2	7	1	**8**
Physical/Mental	Health Effects	3	0	3	6	2	**8**
Social	Sovereignty	1	1	1	3	2	**5**
	Solidarity	3	0	0	3	4	**7**
Other	Food Safety	3	1	2	6	3	**9**
	Nutrition	2	1	1	4	2	**6**

After listening to the farmers thoughts, including some around how they would combine the criteria, the farmers agreed in the next iteration to combine certain criteria or rename them. The environmental criteria were renamed ecological sustainability, and this was subdivided into ecological processes, resilience, and biosecurity. Net revenue was decided to be better defined as gross revenue. Sovereignty and solidarity were renamed and combined as empowerment and autonomy. Food safety and nutrition were combined. Lastly crop yield and health effects remained as they were.

The final list of criteria came down to: ecological sustainability, gross revenue, crop yield, health effects, empowerment and autonomy, and food safety and nutrition. Ecological sustainability was further broken down into: eco-system processes, resilience, and bio-security. No criteria were eliminated, but they were renamed and/or combined. The new criteria were presented via email to all the growers for confirmation, with only minor edits (i.e. small wording changes) (see Table 3. 3 for final criteria after farmer input).

Table 3. 3: Final Alternatives and Criteria Definitions

Terms	Definitions
Alternatives	
Conventional	Agricultural, often monoculture, systems (large as well as small scale), that include inputs of synthetic fertilizers and pesticides to produce their crop and counteract pest and disease stresses
Organic/Ecological	Practice of applying ecological concepts, principles and knowledge to the design and management of sustainable farming to produce their crop and counteract and control pest and disease problems (*organic certification required for farms using the term organic*)
Mixed-methods	Mixes both ecological and conventional methods (often including integrated pest-management approaches)
Criteria	
Ecological Sustainability	Capacity of ecosystems (e.g. land, water, etc.) to maintain their essential functions, processes, and bio-diversity over time, without deterioration (e.g. soil depletion; diminished quality; pollination; energy use effects) or contamination (e.g. toxic effects), including the ability to respond to changing weather/climate conditions
Crop Yield	Volume of crops that are produced and harvested (pounds per acre)
Gross Revenue	Amount of money crop generates ($ per acre)
Health Effects	Health issues for you, family members, and other workers as a result of exposure to toxic substances, work conditions, stress, etc.
Empowerment & Autonomy	Degree to which your choice of agricultural practices is within your control; and with access to supportive social networks (e.g. other producers, communities, organizations, and consumers) to further develop self-reliance, including the ability to respond to changing market conditions
Food Safety & Nutrition	Provision of health benefits from blueberry consumption (e.g. antioxidant properties) without negative effects from production practices, handling, preparation and storage of food, in ways that prevent food-borne illness (e.g. from pesticide, fungus, other contaminants)
Sub-Criteria for Ecological Sustainability	
Ecosystem process	Capacity of ecosystems (e.g. land, water, etc.) to maintain their essential functions and processes over time without deterioration (e.g. soil depletion and diminished quality; pollination; and energy use effects)
Resilience	Ability to respond beneficially to changing conditions (e.g. change in weather conditions)
Biosecurity	Management practices designed to reduce the introduction of pests onto a farm and to minimize their spread within the farm and beyond

At the end of this session, a summary of the session was provided along with what to expect moving forward in the next stages of the study and data collection.

3.2.4.2 Weighting Phase (Session 2)

Prior to the weighting phase, a qualitative analysis was conducted to amalgamate the terms and definitions established from phase 1. An email was sent to every participant to get any feedback on the criteria and definitions, as after this, these lists would be final for the rest of the study (see Appendix 3) for an example of a redacted email sent to the growers).

The weighting phase was the first of three phone sessions. During this session, participants were asked to conduct pairwise comparisons of the criteria to rank importance to the farmers (see Appendix 4 for final list of criteria). These comparisons were done using a 9-point scale to establish the weights (known as priority weights) (see Table 2. 1 for scale and Appendix 4 for pairwise comparison exercise). The criteria were to be weighted according to grower preferences. These weights represent the farmer's trade-off between the criteria.[204] In other words, they were asked: *"how much do you prefer one criterion over the other?"* Farmers performed the pairwise comparison exercise using www.123ahp.com, which calculated the priority weights instantly, as well as a CR. If the CR was below 0.1 the exercise was redone (which happened twice). To ensure robustness of results, priority weights and CRs were also confirmed on a software called Super Decisions ,[205] developed by Satay's organization.

3.2.4.2.1 Questionnaire on Costs of Production (Phase 2)

The farmers were then asked to complete a survey, asking specific questions related to each criterion. They were also asked to provide their costs of operation. See Table 3. 4 for cost components collected. The responses to this survey are aimed to help situate each agricultural production method for each criterion, and to provide overall context (see Appendix 4 for full questionnaire).

Table 3. 4 Cost Components Collected

<table>
<tr><th>Cost Type</th><th>Cost Amount on average per year ($)</th></tr>
<tr><td>Land</td><td></td></tr>
<tr><td>Labour</td><td></td></tr>
<tr><td>Inputs (i.e. agrotoxins)</td><td><table>
<tr><th>Input</th><th>Cost Amount on average per year ($)</th></tr>
<tr><td>Pesticides</td><td></td></tr>
<tr><td>Fungicides</td><td></td></tr>
<tr><td>Fertilizers</td><td></td></tr>
<tr><td>Machinery</td><td></td></tr>
<tr><td>Equipment</td><td></td></tr>
<tr><td>Other</td><td></td></tr>
</table></td></tr>
<tr><td>Certifications</td><td></td></tr>
<tr><td>Transportation (selling/shipping product)</td><td></td></tr>
<tr><td>Marketing</td><td></td></tr>
<tr><td>Health care and insurance for yourself and employees?</td><td></td></tr>
<tr><td>Safety and protection</td><td></td></tr>
<tr><td>Administration</td><td></td></tr>
<tr><td>Depreciation</td><td></td></tr>
<tr><td>Waste management</td><td></td></tr>
<tr><td>Other</td><td></td></tr>
</table>

After this session was complete, the individual priority weights of all growers were aggregated by geometric mean.

3.2.4.3 Scoring Phase (Session 3)

In third phase, growers were asked to score their agricultural production method using a rating scale (0-3). In other words, they were asked: “how would you rate the performance of your farming method for each criterion on the 0 to 3 scale provided?” The rating scale and the points along the scale were validated by two experts at BCBC and BC Ministry of Agriculture. The score along with the priority weights from the previous phase were multiplied by each other to establish aggregate scores. These aggregate scores reveal which agricultural production method aligns with farmer preferences. The aggregate scores are then to be compared against the costs (i.e. a cost-benefit ratio) that were attained in the previous phase. This ratio reveals farmer preferences when costs constrain their choices (see Appendix 5 for Session 3 questionnaire and 0-3 rating scale).

3.2.4.4 Sensitivity Analysis

The original cost-benefit ratio outlined in the Chapter 3.2.4.3 is defined as all costs presented in Table 3. 4. However, not all farmers were able to be as nuanced in their costing, and thus to account for the variability a sensitivity analysis was conducted to adjust for discrepancy in reporting. Also, to control for land costs (it was assumed that land costs could be the biggest constraint with high costs of land near Metro Vancouver) this cost variable was controlled for. Therefore, the costs per acre without land (defined as the total cost per acre minus land costs), the costs per acre without other (defined as total costs per acre minus costs of certifications, marketing, health care and insurance, safety and protection, administration, depreciation, waste management, other), and the costs per acre without other and land (defined as total costs per acre minus costs of land and minus costs of certifications, marketing, health care and insurance, safety and protection, administration, depreciation, waste management, other) were all calculated to determine the robustness of the original results.

3.2.5 Qualitative Data Collection: Farmer Opinions on Results and Feasibility of MCDA

3.2.5.1 Concluding Results Phase (Session 4)

In this final phase, the results were revealed individually to growers. Growers were reminded of the priority/criteria weights, aggregate weights (scores) of each farming method, and average costs per acre. The cost-benefit ratios were also provided and explained. After the calculation of results, concluding follow-up questions were developed that sought to uncover the participants opinions on the results and feasibility of the study. See Appendix 6 for Concluding Questionnaire Survey, including the full list of questions asked to farmers.

Questions Related to Results of MCDA

Farmers were asked whether the results of the study reflected their preferences accurately, as well as whether they were surprised by the results. These questions helped to validate and situate the results, especially considering the sample size of the MCDA study was small. It was important to assess whether the farmers believed that the results were reflective of reality. It was equally important to confirm if the MCDA did in fact assess their preferences or provided more insight into how they come to make their decisions.

Additionally, farmers were asked about their biggest constraints. This thesis hypothesized that, farmers prefer to be more ecological, but when introducing costs and other constraints, farmers tend to lean towards more conventional methods. Thus, it is important to establish why farmer decisions are constrained, especially after they come to better understand their preferences before costs are accounted for. If we can understand these constraints, together with the transparency and comprehensiveness in communicating farmer preferences and expertise through MCDAs, we can better lay a constructive path towards addressing these constraints with farmer participation. This process can help them practice towards their preferences. The idea is that MCDA can help them think through not only what their preferences are but also extrapolate the conclusions of the MCDA exercise to their reality and how they can get to their ideal farming practices.

In relation to these constraints, farmers were then asked about policies/instruments/tools to help them practice towards their preferences. This was done to establish agricultural policy implications that can be presented in relation to their preferences and constraints.

Questions Related Feasibility of Study

In the final stage of questioning, farmers were asked about the feasibility of MCDA. Since this was a pilot study, farmers were asked about the potential of MCDA in the agricultural context. For example, acknowledging that this study may have some limitations, farmers were asked how they believed the process could be improved. They were also asked to provide ideas on where they thought MCDA can best be used in agricultural settings. Their responses can then be used to consider future applications of MCDA in agriculture.

4 Results – Systematic Bibliometric Review

4.1 Systematic Bibliometric Review

The systematic bibliometric review identified 1,258 articles (453 from the Web of Science database, 418 from the Agriculture and Environmental Science database, and 387 from the CAB Direct database). Of these 522 were duplicates, and one French and one Spanish article were excluded due to the language criterion. 734 articles were screened for title and abstracts. This step excluded 588 articles. Full-text screening was done on the remaining 146 articles, with a further 123 excluded. A total of 23 articles met the inclusion criterion. This included 22 full publications (2 of which were dissertations) and 1 abstract, all of which were original studies. (See Appendix 7 for PRISMA Diagram).

All publications included were organized by year (most recent to oldest), journal source, country of publication, MCDA technique, crop studied and/or farming technique analyzed, area of application, decision/problem, and how costs were considered. See Appendix 8 for article list.

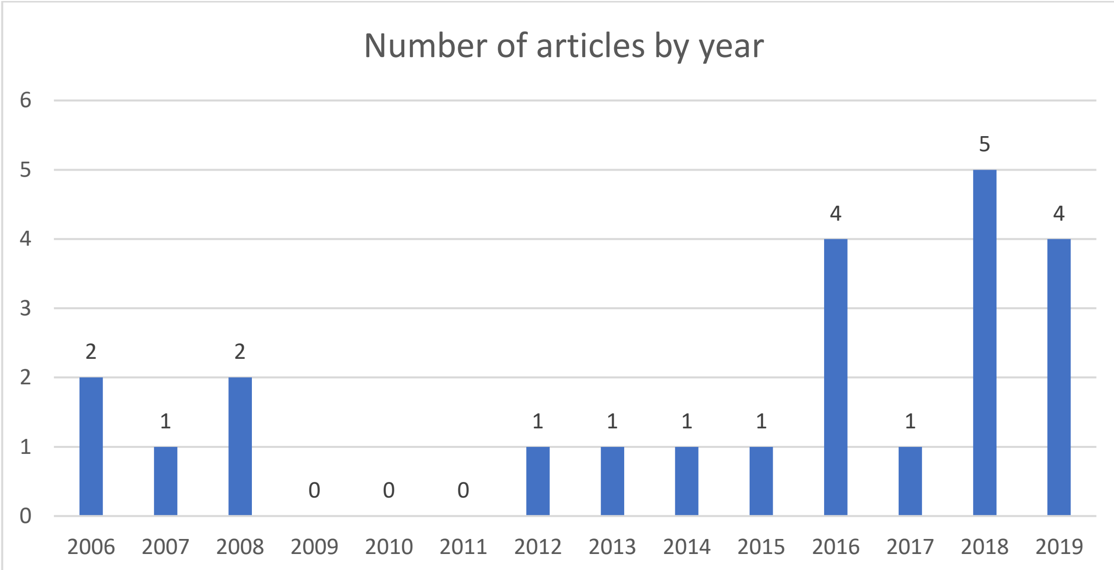
4.2 Bibliometric Analysis

Publication trends of MCDA methods applied in agriculture, that also consider costs, are presented through a bibliometric analysis by year, country of publication, MCDA technique, crop technique, area of application, and how costs were considered.

4.2.1 Year of Publication

The articles that met the inclusion criteria were published between 2006 and 2019. Figure 4. 1 shows how publications have increased over time. Since 2016, overall, there have been noticeably more publications, with 2017 being the only exception with 1 article published. 2018 had 5 publications and 4 publications in both 2016 and 2019. This contrasts with years between 2009 and 2011, where 0 articles were published in each year, and between 2012 and 2015, where 1 article per year was published. Thus, before the rise in 2016, the trend remained steady near one annual publication.

Figure 4. 1: Number of Articles by Year



The correlation coefficient, which is a number that represents the degree of linear dependence between the number of articles and the years of publication, was 0.55 (p=0.04). This is a moderately positive correlation. The coefficient of determination, used to explain the amount of variability that one factor can be caused by its relationship to another factor, was R^2=0.30. Therefore, this indicates statistically significant increase in number of published articles over time between 2006 and 2019; which reflects an increasing number of papers being published in total. The graph in Figure 4. 1 shows that there is 30% of variation in the number of publications explained by year.

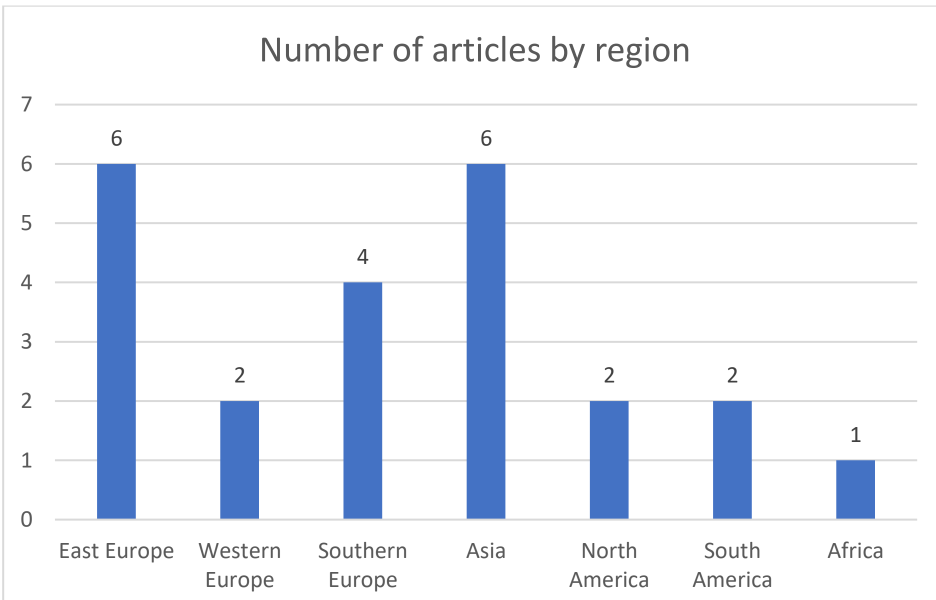
4.2.2 Journal of Publication

All 23 articles were distributed in 21 journals. The highest number were published in *Sustainability, Erwerbsobstbau, and Ecological Economics,* with 2 each. The remainder of journals published 1 each. While it is surprising that no articles published in the Journal of Agricultural Economics met the inclusion criteria, this is largely due to strict inclusion/criteria set out in this review (see discussion section for further examination).

4.2.3 Country of Publication

All 23 articles had research settings in a total of 18 countries. Since the sample sizes were too small, these countries were grouped by region. The largest number of articles were published in Asia (n=6), represented by Iran (n=3), India (n=1), Vietnam (n=1), and Bangladesh (n=1), and East Europe had (n=6), represented by the Western Balkans (Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Montenegro, and Macedonia) (n=5), and Poland (n=1). Southern Europe had 4 publications, represented by Italy (n=3), and Spain (n=1). Western Europe, North America, and South America were each had 2 publications (n=2). North America and Western Europe were solely represented by the Netherlands and the United States respectively. South America was represented by Argentina and Brazil. Africa was solely represented by Swaziland with 1 publication. The Western Balkans had the highest number of publications (defined together since source studies grouped these nations together in their analysis, therefore, for consistency were grouped together), followed by Iran, Italy, and Netherlands. Argentina, Bangladesh, Brazil, India, Philippines, Poland, and Spain had the least with 1 each. See Figure 4. 2 for graph depicting number of articles by region.

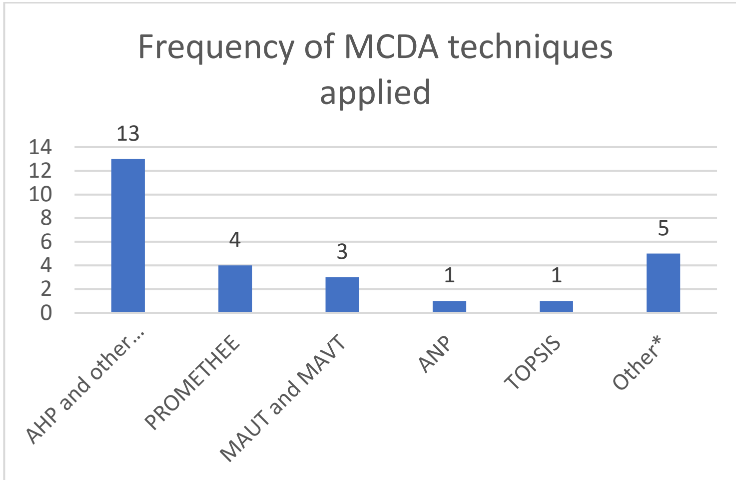
Figure 4. 2: Number of Articles by Region



4.2.4 Type of MCDA Applied

There was a variety of MCDA techniques used. AHP was the most used (n=13), one of which was an AHP-NPV hybrid method, and another was a stochastic analytical hierarchy process (SAHP) hybrid method. PROMETHEE (n=4) and MAUT/MAVT – undefined MCDA tool (n=3) (MAUT (n=2) and MAVT (n=1)) were the second most applied methods. ANP, TOPSIS, simple additive weighting (SAW), multi-objective programming (MOP), weighted product model (WPM), and decision export (DEX) were all applied once. See Figure 4. 3 for graph depicting number of articles per MCDA technique.

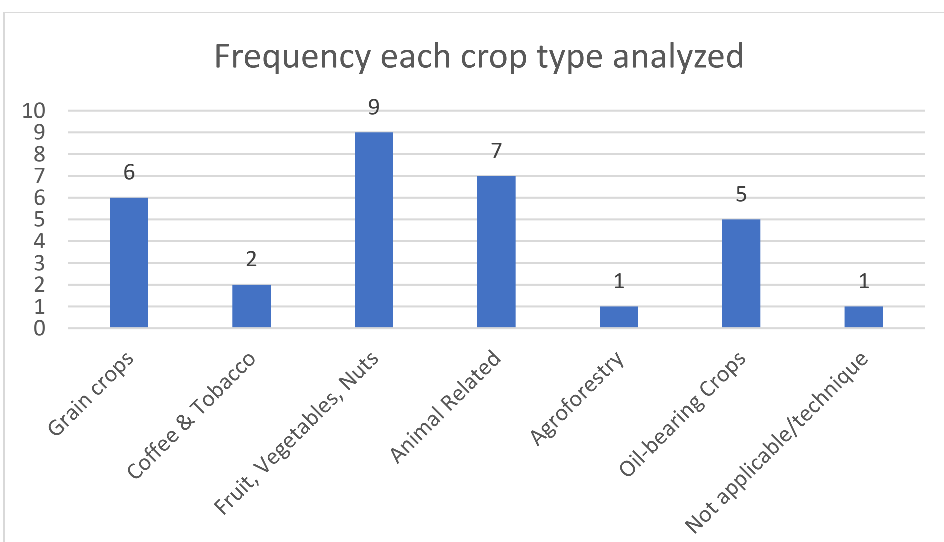
Figure 4. 3: Frequency MCDA Techniques Applied in Included Studies



4.2.5 Crop/Farming Type and Farming Technique Analyzed

Fruits, vegetables, and nuts (n=9) were the most common crop type analyzed; represented by olives and walnuts with 2 each, and apples, cucumbers, hazelnut, plum, and wild rocket, with 1 each. The second most was animal-related farming (n=7); represented by dairy (n=3), and one application for fish, poultry, pig, and eggs. Oil-bearing crops (n=5) were the third most analyzed crops, represented once by biomass, mustard, soybean, safflower, and sunflower each. Coffee and tobacco (n=2) and agroforestry (n=1) were the least applied crop types. One study did not apply a MCDA to a specific crop, but instead analyzed sustainable agricultural theories. See Figure 4. 4 for graph depicting number of articles per crop/farming type or technique.

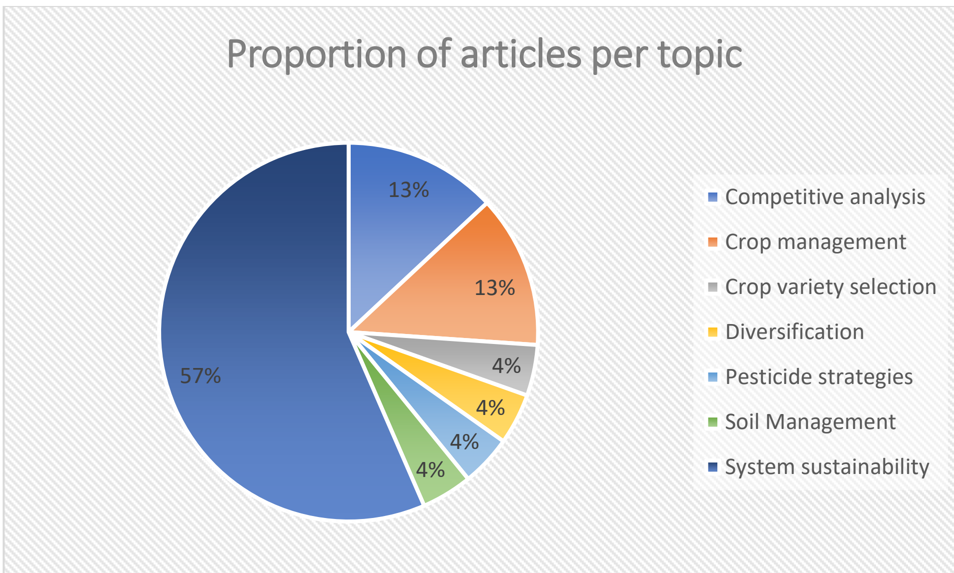
Figure 4. 4: Frequency Each Crop Type Analyzed in Included Articles



4.2.6 Topics Covered

The articles of this review covered 7 areas of application. The highest proportion of these articles covered system sustainability (54%, n=13), followed by competitive analysis and crop management (13%, n=3 each). These were followed by crop variety selection, diversification, pesticide management, and soil management (4%, n=1 each) were the least common topics covered. See Figure 4. 5 for proportion of articles per topic.

Figure 4. 5: Proportion of Articles Per Topic Covered in Included Articles



4.2.7 How Costs were Considered

The first trend related to cost that was assessed was the moment that cost was considered in the analysis or study. 5 articles considered cost as a criterion in the MCDA technique and 18 considered cost as a sub-criterion. 2 articles analyzed cost before the application of MCDA, and 1 after the application of MCDA. One article could not be assessed since there was only access to the abstract.

The second trend related to cost that was assessed was how costs were considered as (i.e. cost type). Cost was most often considered as production/operating cost (n=11). Profitability (n=7) was the second highest, followed by net income/gross margin (n=6), CBA or cost-effectiveness analysis (n=4), and lastly net product value (NPV) (n=2). One article could not be assessed since there was only access to the abstract, however, the abstract mentioned cost as part of life cycle costing (LCC).

The third trend related to cost was whether real cost/money values or amounts were used in the analysis. Real values were used in 11 cases, while the remainder (n=11) did not use real values. One article could not be assessed since only the abstract was available.

4.2.8 Consideration of Health

The number of articles that considered health totalled 11 (6 directly and 5 indirectly), while the remaining 23 did not consider health. One article could not be assessed on its consideration of health since only an abstract was available.

4.3 Main Findings

4.3.1 Cost Considerations

Cost-Benefit/Cost-Effectiveness Analysis & Net Present Value

Rozman et al[159] consider costs in their analysis in two ways: production costs and in a CBA. An AHP was conducted to compare an integrated apple production system against a zero-residue apple production system. The criteria analyzed included economics, which consisted of yield and variable costs sub-criteria. Variable costs were measured by machinery costs, material costs, and labour costs. Second, all of these costs were noted, analyzed, and compared between both production systems through a CBA and technical efficiency analysis. In this kind of analysis, inputs (i.e. cost of fertilizers, plant protection, labour, and machinery) and outputs (i.e. first-class yield and cumulative yield) are compared and an efficiency ratio is calculated.

A different study by Rozman et al[206] implemented cost through a CBA to compute a net present value, which is defined as the difference between the sum of the discounted investment of cash flows and the investment costs, and the internal rate of return. The authors argued that using a CBA alone is insufficient as its limitation is that it does not consider any interactions between different impacts, and it is difficult to convert all effects into monetary units. Thus, they suggest using CBA in combination with MCDA.

Rozman et al[207] considers costs in numerous ways as criteria in an MCDA. The aim of the MCDA is to determine the best plum variety for a new orchard establishment. The economic criterion consists of attributes that describe the financial state of the fruit planting choice, which include investment costs, NPV. The economic criterion also is measured by economic success measurements, which considers productivity, profitability, and cost-effectiveness.

Bogdanović & Hadžić et al[208] aimed to determine the cost-effectiveness of investing in classic crop production (e.g. maize, wheat, soybean) in comparison to perennial plantations (e.g. walnut, hazelnut, or apples). The authors used the NPV method to calculate the cost-effectiveness of both alternatives, and AHP was used as a strategic decision-making tool. The NPV is a method that starts from future net incomes, and by using a discount rate, it is reduced to the present value. Therefore, the aim is to determine whether the present value of cash inflows is sufficient to cover the present value of cash outflows and to achieve planned returns. This means, this study, through NPV, is calculating the difference between the present value of net inflow (the effects of an investment) and the present value of the cash outflow (the initial investment itself). The NPV is then used as one of the sub-criteria in the AHP to measure economic factors. NPV represented the largest weight (most important criterion) in the AHP.

Profitability & Net Income/Gross Margin

Profitability and net income are not direct measures of costs, however, do take into consideration costs associated in calculating the profits, net income, or gross margins. Certain articles depict what these associated costs are, whereas, other articles are more implied.

Troiano et al[209] assessed and compared the sustainability of wild rocket production systems (conventional, biodynamic, organic) using MAVT, whereby one of the factors of sustainability evaluated was economic. The indicators selected to evaluate the economic criterion included a number of operating costs, such as fertilizers and crop production costs, irrigation costs, fuel costs, certification costs, and labour costs. These along with seven other economic indicators (e.g. wild rocket crop sales, revenue, gross saleable production) were used to compare the production systems in terms of financial viability or profitability.

Crnčan et al[210] developed an AHP to evaluate various systems of table egg production (cages, indoor, free-range, organic). Three criteria were used to do this evaluation, one of which was economic. Economic indicators included financial results, labour productivity, and costs were specifically included in the efficiency indicator (total income/total cost) and profitability of production indicator (net profit/annual cost).

Król et al[211] investigated the impact of reduced or no tillage on maize yield and related environmental indicators using PROMETHEE. Six criteria were set covering environmental, financial, and socio-economic factors. The two financial criteria were mean gross profit and standard deviation gross profit. Gross profit measures the profit made after deducting the costs associated with producing maize, and standard deviation gross profit takes into account time series of ten annual average yields provided by experimental fields (the lower the standard deviation, the higher the farm's income stability, and therefore, its economic sustainability.

Tran et al[212] conducted an AHP to evaluate the livelihood, flood management, and environmental effects of flood based farming systems, in rice, vegetable, and aquaculture farms. Three criteria were identified for the AHP, one of which was livelihood, which used profitability as one of the sub-criteria. Profitability was defined as net income from agricultural production, being the total gain from crops and fish per year (i.e. production benefit (total product sales) subtracted from production cost (pumping, seeds, pesticides, fertilizer, labour, etc.)).

Rocchi et al used PROMETHEE to evaluate the overall sustainability of an integrated livestock-orchard system, compared to a non-integrated free-range system and an intensive system. The three main principles of sustainability were used as criteria (environmental, social, and economics). Net income per kilo (€/kg) was considered as one of the economic sub-criteria. Net income per kilo is defined as the difference between gross production and all the costs (both fixed and variable). This was estimated using data from the farms.

Emamzadeh et al[213] used MCDA to develop an optimal pattern of organic and non-organic cucumber management, which would cover both economic and environmental indicators simultaneously. Gross margin (also known as gross profit), which is the difference between revenue and cost of cucumbers sold and divided by revenue, was used as an economic indicator in the analysis.

Chavez[214] used AHP to explore opportunities to diversify specialized tobacco farms. Cost was included as one of the criteria, as contribution to income. A higher contribution to income a new (diversified) activity presents, the more risk averse the option is for farmers, and the more financially viable it is.

van Calker et al[215] considered economic, social, and ecological criteria to construct an MAUT model to help maximize overall sustainability of dairy farming systems (conventional or organic). One of the economic sub-criteria was profitability, which was measured by net farm income (€). Gross revenue and costs were also considered.

The primary objective of a dissertation by Masuda[216] was to compare the efficiency, profitability, and environmental impacts of organic Kona coffee production. In terms of efficiency, farms were evaluated by looking at the yields (lbs per acre) compared to the inputs such as fertilizers (dollars per acre) and other inputs (dollars per acre). Net returns were calculated per acre.

Rezai-Moghaddam & Karami[217] use an AHP to select between two sustainable agricultural development models. The authors use economic, social, and ecological criteria to evaluate the sustainability. Within the economic group, cost is considered as both productivity and profitability.

van Calker et al[218] used MAUT to determine the overall sustainability of dairy farms. Profitability was considered as a sub-criterion of economic sustainability in the analysis. Profitability was measured using the net farm income (€ per year).

Production/Operation Costs

Production and operation costs were considered by numerous studies.

Devatha & Thalla[219] used cost of cultivation (Indian Rupee per hectare) as one of the criteria in analysis, and pertains to costs associated with plant production and plant protection.

Ndwandwe & Weng[220] conducted a SWOT AHP to assess the current production and market performance of smallholder pig farms in Swaziland. Within the SWOT analysis, cost was considered under the weaknesses portion, as high costs of feed. This, along with the other factors in the SWOT analysis became criteria of the AHP.

Azizi & Mohammadzadeh[221] conducted an AHP with the goal of gaining familiarity with effective criteria of poplar plantation development. Economic and financial factors were one of four main criteria groups. The economic and financial factors included costs of plantation, preservation, harvest, credit, and insurance.

Olveira et al[156] aimed to use AHP to rank the milk production systems (extensive, semi-extensive, and intensive systems) based on their sustainability across social, economic, and environmental criteria. Under the economic criteria, cost was considered as cost of producing one litre of milk (Brazilian Real per litre of milk).

Palash & Bauer[222] use PROMETHEE to identify the most important criteria to farmers that influence their choice between rice and fish farming. Two of six criteria considered costs: conversion cost (Bangladeshi Taka per hectare) and operating cost (Bangladeshi Taka per hectare). Conversion cost is defined as the initial cost of land conversion of the household plus a 10% interest rate. Operating costs would be the costs of inputs and production for each alternative.

Cobuloglu & Buyuktahtakın[223] used a stochastic AHP to study biomass crop type selection, using economic, environmental, and social factors of sustainability. Costs were considered in the economic factor, through the seeding criteria, production and harvesting, and storage and transportation. Seeding is defined as the cost of establishment associated with land preparation, machinery, fertilizers, pesticide, and labour. Production and harvesting is defined as the cost of production including fertilizers, herbicides, irrigation, and labour, along with harvesting cost of certain biomass type. Storage and transportation is defined as the cost of transportation and cost of storage requirements associated with a certain biomass type.

Carmona-Torres et al[224] implemented an ANP to evaluate the multi-functionality of olive growing, according to the farming techniques used by farmers. The concept of lower production costs was used to represent costs as one of the criteria in the analysis.

4.3.2 Summary of Findings for Cost Considerations

All included studies of the systematic bibliometric review considered costs as a criterion in the MCDA their MCDA analysis in some capacity. Although there are some examples of cost-effectiveness or CBA, they still include cost as a criterion in some capacity.

Therefore, this bibliometric systematic review provides evidence that a CBA that is calculated by dividing the aggregate score of the MCDA (excluding costs as a criterion) by the costs of production is a novel approach in the agriculture setting. This is the approach that is taken in this MCDA study, as outlined in the Methods section (Chapter 3.2), borrowing from the traditions that I have learned from health economics and health technology assessment (HTA) MCDA approaches, specifically the work done by Baltussen.[225]

Moreover, while I do not dispute that the authors of the included studies in the review consider cost as a potential constraint in decision-making and to farming as a whole, I do not believe that the authors appropriately analyze costs in context of an MCDA.. These articles consider costs just like any other criteria in the MCDA. However, it can be assumed that costs, if included as a criterion in the MCDA, will always be the dominant criteria (i.e. the most important or among the most important criteria). This was demonstrated in many of the studies included in the review, where costs had the highest weight among all criteria.[208,212,214,215,218,219,223,226] Therefore, if the assumption is that costs are a constraint, than they should be controlled for, otherwise results may be (predictably) disproportionately influenced by costs, masking the effects of the other criteria on decision making. It is important to understand the criteria that are important to farmer decisions without the consideration of costs; but this is not to say that farmer decisions with the consideration of costs is unimportant. The MCDA study conducted in this thesis constructs an MCDA in a novel way[225] within the agriculture setting. The idea is that by conducting the MCDA without costs, I produce the aggregate scores that represent the farmers' preferences (less constrained – mainly unconstrained by costs). Then by taking these aggregate scores and dividing them by the costs of production (i.e. CBA), I can appropriately treat costs as a constraint, and this gives us farmer preferences with the constraints of costs. I can then attempt to understand the gaps between farmer preferences unconstrained *and* constrained. This provides the basis for discussion on how to potentially limit these constraints in order for farmers to practice towards their unconstrained preferences. In other words, this MCDA study examined the degree to which farmers themselves directly take criteria or factors of decision-making into consideration both with and without costs. By extension, my MCDA study looked to appropriately assess *both* farmer perspectives and constraints as critical components in understanding the decision-making process of farmers.

Lastly, the idea of willingness to pay is never addressed in the studies included in the systematic bibliometric review. Each production method has relatively higher or lower costs of production and it is essential to assess under what circumstances increased benefits are worth the increased costs. For example, if in fact my study shows that organic/ecological farming is the most preferred method (without consideration of costs) but is also the most expensive option, under what conditions would farmers be willing to move towards this preference despite the costs (e.g. constraints and policy conditions).

4.3.3 Health Considerations

The importance of considering health and health determinants in decision making has been considered in a number of studies, some studies doing so directly, and others indirectly. For example, Troiano et al[209] demonstrates how the concept of sustainability is indirectly related to health. This study identified various sub-criteria for economic, social, and environmental factors of sustainability. The study did not measure a single criterion of health directly. Instead the results were split into two scenarios, economic and ecological, to help decision-makers identify which growing technique to adopt. Assuming an economic farming scenario, conventional farms have the best result. The study acknowledged that by adopting an economic scenario, farmers are primarily led by profit maximization, though consideration to the environment and its risks to human health are still considered. Conversely, in an ecological scenario, there is greater sensitivity to human impacts on the environment, which produces externalities that safeguard the environment and create benefits for the whole community. Therefore, although health is not directly measured in these scenarios, their externalities on health are appreciated.

Crnčan et al[210] did not measure health directly in its aim to analyze and evaluate the most favoured table egg production method. The most favoured option was the indoor system for housing hens, while the least favoured was organic. Some socio-economic determinants of health can be extrapolated from the analysis, for example, the potential of small farms providing the possibility of self-employment and creating additional income that can contribute to overall economic and social development and well-being of rural areas. However, the authors did acknowledge that perhaps a consideration of health benefits for consumers, as well as consideration of environmental indicators would have potentially allowed for organic production to be more favoured.

Emamzadeh et al[213] also did not include health directly in their analysis due to a lack of quantitative data available on health. Health was instead considered in terms of the effect on human health if environmental health is not taken into account. The aim of the study was to identify an optimal pattern of organic and non-organic cucumber management, which would cover both economic and environmental indicators concurrently. This objective is in accordance with other goals, one of which is keeping both producers and consumers in a healthy condition by satisfying physical, mental, and socio-economic determinants of health. The results of this study had organic farming replace non-organic farming, and economic and environmental indicators rose 11.97% and 21.40% respectively. The primary objective of every farmer is to maximize profits. The results of this study argue that economic considerations are improved in organic adoption, but also shed light on the lack of attention given to organic agriculture in Iran. Furthermore, it concludes that the problems chemical toxins and fertilizers cause on human health and the environment should force us to reconsider agricultural practices to minimize the application of pesticides and chemical fertilizers.

Rozman et al[159] does not consider health in its analysis, however acknowledges its importance in discussion. The aim of this MCDA was to compare integrated apple production systems against zero residue apple production systems. The authors discussed how demands for pesticide residue reduction are increasing, as consumers comprehension of pesticide residues is that they would have adverse health effects at any concentration level. Consumers always prefer fruits with the lowest amount of residue, which makes zero residue systems more attractive.

Chavez[214] uses health risks of tobacco consumption as one of the primary factors that make tobacco production uncertain in the future. The negative impacts of tobacco consumption on human health, along with soil degradation and a dependence on subsidies, served as the primary motivation for this study to explore opportunities for diversification for specialization tobacco farms.

A dissertation by Masuda[216] set the primary objective to compare the efficiency, profitability, and environmental impacts of organic Kona coffee production against conventional production by use of multi-objective programming. Masuda measures health through, through proxy, using environmental spillovers as a criterion in analysis, whereby it is the objective of society to minimize negative environmental externalities and maximize positive externalities. As a negative externality, for example, the use of chemicals may lead to harm to the health of producers, their families, employees, and neighbours.

Ndwandwe et al[220] conducted a SWOT-AHP analysis to identify pig production strategies that are resilient to both market and climate changes. Health was considered directly in the SWOT analysis in the threats categories. The study found that the swine industry to be threatened by emissions from pig manure, which creates pressures on the environment, while putting human health at risk. This manifests in numerous ways, including improper handling of manure and disposal from pig farms results in water, air, and soil pollution. Also, emissions of dust, nitrous gases, and bad odour from pig farms have been held responsible for higher incidences of human respiratory problems of those nearby. Furthermore, consumers have become more aware of health concerns from eating certain types of meats, opting for lower fat meats. The results of the study demonstrated minimal concern about environmental pressures on human health, and instead considered increased manure's impact on greenhouse gas emissions and worsening climate change conditions as a major threat.

Olveira et al[156] analyzed human health as one of the criterions in the AHP. Health was defined to correspond to social criteria of sustainability. Human health is one of three criteria that are used in the AHP to aid decisions in milk production systems based on their sustainability. Social criteria (and by extension human health) was measured by three proxy indicators: hours of labour per litre of milk produced, hours of labour per year, average worker's wages. Therefore, the indicators address occupational and socio-economic determinants of health, with less (direct) consideration to physical or mental health.

Rezai-Moghaddam & Karami[217] considered health directly in the MCDA, measured as life quality (health, well-being…) under the social criterion. The objective of the MCDA was to use AHP for selecting between two competing sustainable agricultural models. Nine criteria were selected to evaluate the agricultural models, and life quality ranked relatively as the second least important criterion. The authors also acknowledged health indirectly, in terms of agriculture's various contributions, including to public health.

Van Calker et al[215] in their study, aimed to apply a model that maximizes the overall sustainability of conventional and organic farms using the perceptions of consumers, producers, and society. One of the criteria used to measure this was internal social sustainability, also defined as physical health as it relates to qualitative and quantitative working conditions for the farm operator and employees. The indicator used to measure this was physical load index, which is defined as physical load index for back disorders, and physical load index for upper extremity. The maximum score for individual sustainability aspects were analyzed (i.e. maximization of economic sustainability or ecological sustainability etc.). The maximization of internal social sustainability, and therefore health, is not maximized like the other criteria, due to insufficient change in the physical load index (i.e. the weights for internal sustainability were 0.38 for consumers, producers, and society for both conventional and organic dairy farm approaches).

Rocchi et al[227] directly measures health as one of the sub-criteria in the social category. In this study, health falls under the labour safety sub-criterion, defined as the occupational health and safety risks that include chemical hazards and air quality (impacted by dust and toxic gases). Preferences were assigned to each criterion, with labour safety being the most important for farmers, and moderately important for consumers and scientists.

4.3.4 Summary of Findings for Health Considerations

The degree to which the studies included in the systematic bibliometric review consider health is quite limited. Most of the studies that do consider health are very narrow in scope, defining health to only cover physical and mental health, and by extension occupational health and environmental hazards to the farmers and their community. This application of health does not consider the broader impacts that agriculture may have on population health.

As introduced in Chapter 1, health is intertwined in agriculture. For one, the determinants of health and agricultural sustainability are similarly defined, going beyond the mental and physical or occupational health discussed in some of the studies included in this review. Without a broader framing, as Chapter 1 suggests, there may be a tendency focus on productive efficiency, which in turn has led to expansion of industrial approaches and ignoring of externalities on health and sustainability. Thus, my MCDA study aimed to assess health more broadly and as part of the same process with similar goals as agricultural sustainability. Limiting health to its mental and physical components ignores the many other factors of health that agriculture tackles. The MCDA study of this thesis tries to forward the idea that agricultural policy in many ways is health policy, and by considering them together through an MCDA, more sustainable and healthy agriculture can be advocated for. See the Results of the MCDA and Discussion section (Chapter 6) for an assessment of farmer preferences with regards to agricultural sustainability and how they are intertwined and connected with concepts of population health.

5 Results – MCDA Study

5.1 Descriptive Statistics

In total, 56 growers were considered eligible for the study. This was determined by the total number of farmers that expressed interest in participating and shared their contact details. Among those, 9 farmers agreed to participate in the sessions. One of the 9 growers dropped out after session one. Therefore, the main results encompass 8 farmers. Four conventional farmers (three after session one), 3 organic farmers, and 2 mixed-method farmers made up the total sample. It was decided to include the session one contributions of the participant that dropped out of the study. This is because this contribution would not bias the overall results of the study, since they did not participate in the MCDA exercises, and only contributed in the defining of criteria and production methods. Since this participant is a blueberry farming expert, the input was valued. All growers stated that their current farming method was their preference, except for both mixed-methods growers who preferred to be more ecological.

5.1.1 Farmer Characteristics

Table 5. 1 summarizes the characteristics of individuals included in the analysis. Participants were not asked their age, instead they were asked to report the number of years they have been farming blueberries, which was between 5 and 40 years (7, 20, and 40 years conventional farmers; 5, 12, 30 years for organic farmers; 15 and 22 years for mixed-methods farmers). 100% of respondents were male, and all owned their farm. For the conventional farmers, one owned with mortgage paid, one owned with mortgage owed and lease, and the last one owned with a combination of mortgage paid, mortgage owed, share, and lease). For the organic farmers, all owned with mortgage paid. One mixed-methods farmer owned with mortgage, and the other with mortgage owed.

5.1.2 Farm Characteristics

Table 5. 2 summarizes the characteristics of the farms of the participants in the analysis. Organic farms tended to be the smallest on average, followed by mixed-method farms. Conventional farms were the largest on average. The average acres of blueberries on all farms between 2015 and 2017 was 44.67 acres (range of 4-100 acres). Conventional farms averages 83.3 acres for conventional farms (range of 60-100 acres); 8.16 average acres for organic farms (range of 4-15 acres); and 42.5 average acres for mixed-methods farms (range of 13 -72). The top three blueberry varieties grown on all the farms are Duke, Reka, and Bluecrop. On average, conventional farmers employ the most

people, followed by organic farmers and then mixed-method farmers. conventional farmers employ 2 full-time employees, 35 seasonal employees, and 2.33 family members; organic farmers employ 0.33 full-time employees, 17 seasonal employees, and 1.67 family members; and mixed-method farmers employ 1 full-time employee, 6.5 seasonal employees, and 1 family member.

Table 5. 1 Farm Characteristics

	Conventional (n=3)	Mixed-Methods (n=2)	Organic/Ecological (n=3)	Overall (n=8)
Total acreage (average)	251.4	66.5	13.3	115.9
Total acreage of blueberries (average)	83.4	42.5	8.2	45.0
Blueberry variety (%)				
Bluecrop	67%	0%	33%	38%
Bluejay	33%	0%	0%	13%
Duke	100%	100%	100%	100%
Draper	33%	50%	0%	25%
Hardyblue	67%	0%	0%	25%
Liberty	0%	50%	33%	25%
Northland	33%	0%	0%	13%
Reka	67%	100%	33%	63%
Spartan	0%	0%	33%	13%
Land tenure system (%)				
Own (mortgage paid)	33%	50%	100%	63%
Own (with mortgage)	33%	50%	0%	25%
Share	0%	0%	0%	0%
Lease*	33%	0%	0%	13%
Other	33%	0%	0%	13%
Crop picking strategy (%)				
Handpicking	3%	1%	78%	31%
Machine picking	97%	99%	22%	69%
Number of employees (average)				
Year-round full time	2	1	0.3	1.1
Year-round part time	0	0	0	0
Seasonal full-time	7	1.5	0.7	3.3
Seasonal part-time	25	3	15.6	16
SAWP	4.7	2	0.7	2.5
Family Labour	2.3	1.5	1.7	1.9
Volunteers	0	0	0	0
Difficulty hiring (%)				
Yes	33%	50%	67%	50%
No	67%	50%	33%	50%

*One farmer had a lease on part of his land, but the majority of it was owned in some capacity

Table 5. 2 Farmer Characteristics

	Conventional (n=3)	Mixed-Methods (n=2)	Organic/Ecological (n=3)	Overall (n=8)
Age (average)	55.3	53.5	58.0	55.6
Sex (male/female)	All male			
Years farming (average)	43.3	15.0	26.7	28.3
Years in blueberry farming (average)	22.3	22.0	16.7	20.3
Practice towards preferences				
Yes	100%	0	100%	66.7%
No	0%	100%	0%	33.3%
Hours worked per week (average)				
Harvest season	58.3	37.5	45.0	46.9
Winter season	50.0	15.5	8.3	24.6
Working other jobs (%)				
Yes	100%	50.0%	70.0%	38.9%
No	0%	50.0%	30.0%	61.1%
Role on farm (%)				
Owner	0%	50%	0%	16.7%
Operator	0%	0	0%	0%
Manager	0%	0	0%	0%
Other	0%	0	0%	0%
All	100%	50%	100%	83.3%

*Some farmers were born into farming

**One participant only 5 of 38 years farming have been organic

***Role of All defined as the participant performs all roles on the farm

5.2 Criteria Weights (Session 2)

According to grower preferences, after pairwise comparisons were conducted, the criteria weights for all production methods combined were highest for gross revenue (0.2677), followed by crop yield (0.2464) and food safety and nutrition (0.1692). The lowest weights were assigned to empowerment and autonomy (0.0713), followed by ecological sustainability (0.0874), and health effects (0.1579). Ecological sustainability's sub-criteria, broken down in order of weights were ecosystem processes (0.0437), resilience (0.0247), and biosecurity (0.0189). This means that gross revenue was the most important criterion, followed by crop yield, food safety and nutrition, health effects, ecological sustainability, and empowerment and autonomy. The most important ecological sustainability sub-criterion was ecosystem processes, followed by resilience, and biosecurity and autonomy (Table 5. 3 for criteria weights for all agricultural production methods).

Table 5. 3 Criteria Weights Overall for All Agricultural Production Methods

Criteria	Criteria Weights
Gross Revenue	0.2677
Crop Yield	0.2464
Food Safety & Nutrition	0.1692
Health Effects	0.1579
Ecological Sustainability	0.0874
Ecosystem Processes	0.0437
Resilience	0.0247
Bio-Security	0.0189
Empowerment & Autonomy	0.0713

Results were similar when broken down by production method. For conventional, the criteria weights were highest for gross revenue (0.2601), crop yield (0.2445), and ecological sustainability (0.1584). The lowest weights were assigned to empowerment and autonomy (0.0679), followed by health effects (0.1246), and food safety and nutrition (0.1443). Ecological sustainability's sub-criteria, broken down in order of weights were ecosystem processes (0.0711), biosecurity (0.0509), and resilience (0.0365). The order of criteria preference was mostly unchanged from the combined results, however, ecological sustainability changed places with food safety and nutrition, though the latter still had a higher weight than health effects and empowerment and autonomy. The order of preference for the sub-criteria of ecological sustainability differed from the combined results with resilience and bio-security trading places. See Table 5. 4.

Table 5. 4 Criteria Weights for Conventional Farmers Only

Criteria	Criteria Weights
Gross Revenue	0.2601
Crop Yield	0.2445
Ecological Sustainability	0.1584
Ecosystem Processes	0.0711
Bio-Security	0.0509
Resilience	0.0365
Food Safety & Nutrition	0.1443
Health Effects	0.1246
Empowerment & Autonomy	0.0679

For mixed-methods, the criteria weights were highest for gross revenue (0.3362), followed by crop yield (0.2071), food safety and nutrition (0.1711), health effects (0.1296). The only difference in criteria order between mixed-methods and the combined results are empowerment and autonomy

(0.0544) and ecological sustainability (0.0544) traded places. Ecological sustainability's sub-criteria order remained unchanged from the combined results: ecosystem processes (0.03155), resilience (0.0121), and biosecurity (0.0067). See Table 5. 5.

Table 5. 5 Criteria Weights for Mixed-Methods Farmers Only

Criteria	Criteria Weights
Gross Revenue	0.3362
Crop Yield	0.2072
Food Safety & Nutrition	0.1711
Health Effects	0.1296
Empowerment & Autonomy	0.1015
Ecological Sustainability	0.0544
Ecosystem Processes	0.0316
Resilience	0.0121
Biosecurity	0.0067

For ecological and organic methods, crop yield (0.2615) and gross revenue (0.2221) switched places for top spot when compared to the combined results. Health effects (0.2144) and food safety and nutrition (0.1846) switches places for third and fourth most important criteria when compared to the combined results. Ecological sustainability (0.0621) and empowerment and autonomy (0.0554) remain in the same order as the combined results. Ecological sustainability's sub-criteria remain in the same order as the combined results as well: ecosystem processes (0.0297), resilience (0.0198), biosecurity (0.0125). See Table 5. 6.

Table 5. 6 Criteria Weights for Organic Farmers Only

Criteria	Criteria Weights
Crop Yield	0.261541
Gross Revenue	0.222051
Health Effects	0.214407
Food Safety & Nutrition	0.184558
Ecological Sustainability	0.062078079
Ecosystem Processes	0.029722
Resilience	0.019841
Biosecurity	0.012516
Empowerment & Autonomy	0.055365

5.3 Aggregate Weights and Average Costs (Session 3)

5.3.1 Aggregate Weights

Each farmer individually was asked to provide a score on a scale of 0-3. This number represented the score for their production method for the criterion being assessed (i.e. how they would rate their performance (or their farming method's performance) for each criterion on the 0-3 scale provided). This score was multiplied by the corresponding criteria weights (Table 5. 6). The product of that calculation is the weighted score. The weighted scores for all criteria were summed for each participant, and the geometric mean for each agricultural production method was calculated using the sums of the weighted scores for each participant of a given production method. See Table 5. 7 for the raw and weighted scores calculated for each participant within each production method. The geometric mean is what provides the aggregate scores. Mixed-methods has the highest aggregate weight (2.617), followed by ecological/organic (2.281), and conventional (1.795). See Table 5. 8 for aggregate scores by production type. This means that, assuming the average of this study sample (n=8), when considering all criteria (excluding costs) farmers indicated interest for more ecological methods, specifically mixed-methods followed by organic, and then conventional (i.e. these aggregate scores reveal which agricultural production methods best align with farmer preferences).

Table 5. 7 Raw and Weighted Scores

CRITERIA	CRITERIA WEIGHTS	Organic Farmers						Mixed-Methods Farmers				Conventional Farmers					
		P4 Raw Score	P4 Weighted Score	P6 Raw Score	P6 Weighted Score	P8 Raw Score	P8 Weighted Score	P2 Raw Score	P2 Weighted Score	P3 Raw Score	P3 Weighted Score	P5 Raw Score	P5 Weighted Score	P7 Raw Score	P7 Weighted Score	P9 Raw Score	P9 Weighted Score
Ecological Sustainability	0.0874																
Ecosystem Processes	0.0437	2	0.0874	2	0.0874	1	0.0437	3	0.1311	2	0.0874	2	0.0874	1	0.0437	0	0
Resilience	0.0247	3	0.0741	1	0.0247	2	0.0494	2	0.0494	2	0.0494	2	0.0494	2	0.0494	2	0.0494
Bio-Security	0.0189	1	0.0189	2	0.0378	1	0.0189	1	0.0189	2	0.0378	1	0.0189	0	0	1	0.0189
Crop Yield	0.2464	2	0.4928	1	0.2464	2	0.4928	2	0.4928	3	0.7392	3	0.7392	2	0.4928	2	0.4928
Gross Revenue	0.2677	3	0.8031	3	0.8031	2	0.5354	2	0.5354	3	0.8031	2	0.5354	2	0.5354	1	0.2677
Health Effects	0.1579	3	0.4737	3	0.4737	2	0.3158	3	0.4737	3	0.4737	2	0.3158	1	0.1579	1	0.1579
Empowerment & Autonomy	0.0713	2	0.1426	2	0.1426	0	0	2	0.1426	3	0.2139	2	0.1426	1	0.0713	1	0.0713
Food Safety & Nutrition	0.1692	3	0.5076	3	0.5076	3	0.5076	3	0.5076	3	0.5076	2	0.3384	3	0.5076	2	0.3384
	1.000		2.6002		2.3233		1.9636		2.3515		2.9121		2.2271		1.8581		1.3964

Table 5. 8 Aggregate Weights

Farming Method	Aggregate Weights (Score)
Organic	2.281
Mixed-Methods	2.617
Conventional	1.795

5.3.2 Average Costs

The average overall cost per acre was highest for mixed-methods ($10,872), only slightly higher than organic ($10,833), followed by conventional ($6,681) (see Table 5. 9).

5.4 Cost-Benefit Ratio

The aggregate scores in Table 5. 8 were then divided by the average overall costs per acre for each production method. This equates to the cost-benefit ratio which determines the agricultural production method that farmers favour when considering costs in the equation (i.e. how costs offset the other criteria). The highest cost-benefit ratio belonged to conventional (0.000269), followed by mixed methods (0.000241), and organic (0.000211) (see Table 5. 10). This means that once costs are considered, farmers indicated that they prefer to be more conventional. This suggests that costs have a considerable impact on farmer preferences for more ecological methods as presented in the results of Chapter 5.3.1.

5.5 Sensitivity Analysis

5.5.1 Average Cost Sensitivity Analysis

Without considering land costs (defined as the total costs per acre minus land costs), the average costs per acre were highest for organic ($10,327), followed by mixed-methods ($8,846), and conventional ($6,251). The average cost per acre without other costs maintained the same order, with organic ($9,882) as the highest, followed by mixed-methods ($9,533) and conventional ($5,096). Finally, the average cost per acre without considering land or other costs had organic with the highest ($9,377), followed by mixed-methods ($8,507) and conventional ($4,667). Therefore, conventional was consistently the lowest, and organic was the highest in all cases except the average overall cost per acre considering all costs, where mixed-methods narrowly edged organic. See Table 5. 9 for breakdown of costs by farming method.

Table 5. 9 Average Costs Per Acre

Farming Method	Cost per acre (with land)	Cost per acre (without land)	Cost per acre (without Other*)	Cost per acre (without Other* and Land)
Organic	$10,833	$10,327	$9,882.07	$9,377.02
Mixed-Methods	$10,872	$9,846	$9,533.12	$8,507.48
Conventional	$6,681	$6,251	$5,096.48	$4,666.67

**Other: Certifications, transportation, marketing, health care and insurance, safety and protection, administration, depreciation, waste management, other*

5.5.2 Cost-Benefit Ratio

The cost-benefit ratio results were robust, in that conventional still had the best cost-benefit ratio, followed by mixed-methods, and organic for all cost categorizations. See Table 5. 10 for cost-benefit ratios by cost categorization.

Table 5. 10: Cost-Benefit Ratio and Sensitivity Analysis Results

		Sensitivity Analysis		
Farming Method	**Cost-benefit ratio (with land)**	**Cost-benefit ratio (without land)**	**Cost-benefit Ratio (without Other*)**	**Cost-benefit Ratio (without Other* and Land)**
Organic	**0.000211**	0.000221	0.000231	0.000243
Mixed-Methods	**0.000241**	0.000266	0.000275	0.000308
Conventional	**0.000269**	0.000287	0.000352	0.000385

**Other: Certifications, transportation, marketing, health care and insurance, safety and protection, administration, depreciation, waste management, other*

5.6 Qualitative Results: Farmer Opinions on Results and Feasibility of MCDA

5.6.1 Farmer Opinions on Results

Were the Farmers Surprised by the Results and Were Their Preferences Reflected?

Farmers were generally not surprised about the results of the MCDA, regardless of farming method, and the results were in line with their preferences.

Conventional growers generally expressed a desire to be more organic, however, once considering costs, would prefer to be conventional, which is reflected in the results.

"This isn't much of a surprise [that mixed-methods and organic are preferred over conventional] … but if you are going to be organic you have to start from day 1 and I don't know how guys are

doing it with managing weeds and getting appropriate labour. Perhaps this shows that it can be feasible to be mixed-methods."

Generally, there is concern among the conventional farmers that the additional cost of going more ecological prevents farmers from going towards their preferences, which is more ecological farming. Thus, the costs force growers to think differently and practice conventionally: "*conventional is just more feasible and easier*".

"I am not surprised [by these results]. In conversations with other growers, there's better and good enough, but better comes at a cost. Your personality will determine if you do better."

Mixed-methods growers also were not surprised by the results, and similarly expressed that their preferences were more aligned with more ecological approaches.

"Although I am a bit surprised that mixed-methods is higher than organic [without considering costs], though if this was a higher sample size, I would definitely be surprised that mixed-method is higher than organic. It doesn't surprise me that farmers prefer to be more ecological – I am happy to hear that. And I am not surprised that conventional would be most preferred once considering costs."

Organic growers were not surprised by the fact that growers preferred to be more organic without considering costs, however, their preferences were unchanged, despite the cost-benefit ratios of conventional and mixed-methods dominating the cost-benefit ratio of organic farming. Organic growers did suggest that farm size can also play a role in determine farm method, as it was suggested that smaller farms lend themselves more favourably to organic methods.

"I still prefer to be organic regardless of the cost-benefit results. Aside from it being moral to me, [I have] a small acreage and the price point of organic … to do conventional would be financial suicide. I have never had a berry sell for less than $3 per pound. Conventional would be around $0.80 per pound."

Furthermore, smaller farms would require a higher price point to be financially viable, thus organic methods may be more logical.

"I would actually prefer to be mixed-methods [as the results without costs suggest], but I have to do organic to get a higher price, even though it is easier to be conventional or mixed-methods. But I am not surprised. Most people are at a point where they want to be healthier and more

organic, but they aren't being helped. Agronomic and chemical companies want to push their products, and governments don't want to incentivize. So, they stay organic because of the costs and constraints."

Additionally, it was important to mention that health effects, food safety, and empowerment and autonomy were not discussed in much depth by the farmers. When prompted about these criteria some farmers expressed that health effects are already considered sub-consciously and so do not enter the every day decision-making process. As one farmer put it: "it's just a given". Farmers did vocally express more concern over food safety. As one farmer put it:

Just look what happened to lettuce. Food safety concerns have devastated their industry and farmer profits. You lose the trust of the consumers, it's hard to earn it back. This would hurt us a lot if it happened here."

However, the farmers share the same sentiment as they did for health effects that "it was just a given".

"*If I do my job right, food safety will be considered automatically"*

Unfortunately, for autonomy and empowerment, it seemed that this did not enter the consciousness of the farmers much at all. Some farmers considered it simply as a non-issue and not something they think about, while others expressed that "*it is what it is and there is not much they can do about it"*

Biggest Constraints

Farmers discussed what they perceive to be regulatory barriers (i.e. organic certifications, long transition period between organic certification from conventional farming, etc.) as a major challenge in being an organic grower. It is difficult to control for weeds and pests using organic methods available to Canadian farmers, which causes farmers to refrain from committing to organic methods.

"There isn't an organic solution to SWD. Canada is not considered a large enough market. So, companies don't register these solutions. This holds me back from converting my acreage [to organic]. Market size in Canada limits access to some tools compared to the USA. It costs too much to get them registered."

Farmers mentioned this is compounded by the fact that organic farming has lower blueberry yields. Furthermore, it is feared that with lower production, any cost attained from a higher price point could be offset by requiring more labour and thus higher labour costs to manage the farm.

A large barrier that farmers perceived that limits organic methods from being more prominent is a lack of education. This education should be catered to the needs of a specific farmer.

> *"Education is the biggest constraint – you need the right information from the right people."*

> *"There is a lack of consultation with all farmers – it can't just be with the biggest farmers."*

Overall, the issues could be summarized by this quote from an organic farmer:

> "*Farmers stay conventional because they see other methods as harder, more red tape, more learning curve, and requires less time in farming activities. It's just a numbers game. Not to say there aren't good conventional farmers."*

Policies/Instruments/Tools That Can Help Farmers Practice Towards Preferences

There was hesitation among most farmers with regards to taxation and subsidy tools. Though some suggested it could be helpful in transition from conventional to organic, since there is a transition period where farmers cannot sell their blueberries at the organic price. Therefore, they have less blueberry yields in those transition yields, while still having to sell at the conventional price, making this a huge barrier for many farmers wanting to transition to organic.

> *"Subsidies maybe could help while switching to organic for a year or two transition phase."*

There was a sentiment that organic blueberries should be rewarded, and a levy should be implemented on the processors, not the farmers, since the power of control is in the hands of the processors rather than farmers.

> *"Governments should put something like 1-2 cent levy on the whole thing. Nobody wants to spray, but levy should be put on processors, not farmers. There should be a reward for not putting [chemicals] or least amount of [chemicals]. Almost like a quota of good like in Quebec, where dairy and egg farmers are more organized and protected – all food should be protected like this."*

There was suggestion that taxes and subsidies could be less beneficial to those without a mortgage and may not benefit every type of farm business, as it depends on their business structure, as well as the farmer's mentality.

> *"I don't believe in subsidies, and taxation is a maybe. But I am not the right person to ask because I don't have a mortgage. I can make ends meet this is different for someone else. Since I don't have a mortgage, I have the flexibility now to try to go more mixed-methods or ecological [instead of conventional], and I have always been a proprietor, so not sure how taxation would help."*

> *"You can't force another guy to be greener [even with taxation] has to be within to have desire to learn and have the financial flexibility necessary."*

Generally, farmers believe it is difficult to farm organically, and taxes and subsidies may help but not solve the true challenges of being an organic farmer. Dealing with pests and weeds, for example, would remain a challenge with or without taxation.

> *"Maybe preferential taxation. But I think there will be a push towards relaxing what gets labelled as organic or maybe a discovery of an organic herbicide spray."*

Related to this point, there is significant concern for the regulations around the farming inputs allowed to be certified organic in Canada. This concern is compounded by the fact that imported (i.e. from USA) blueberries are permitted to be certified organic according to US standards, which are less stringent than Canadian standards. For example, imported organic blueberries were grown using inputs for pest management that are not certified organic in Canada.[228,229] This puts Canadian farmers at what they perceive to be a significant disadvantage. With less organic growers, even processors have no incentive to invest in organic product.

> *"It is difficult to grow organically, and to certify organic in Canada is very difficult. I want to be more organic, but constraints make it difficult. We allow organic products to come across the border that wouldn't be organic if grown in Canada. Plus, there's no processors [in Canada, because there isn't much organic product], which is because the standards are so high – processors would have to invest so much to be organic. And to compete with the US, it is hard to keep costs down in Canada to compete with US exports."*

Some farmers suggested some solutions for this certification issue ranging from better consultations with organic growers, more harmonization with Canada and the US, and doing a better job diversifying the destinations of blueberries by marketing locally or domestically while also enhancing export markets (i.e. minimizing tariffs in some countries).

> *"There needs to be better government policies on inputs allowed. Better consultation with organic farmers themselves rather than with organic certification people."*

> *"Working with Health Canada and the [Pest Management Regulatory Agency (PMRA)] on issue of access to organic products, though perhaps more harmonization with Canada and the USA to smooth access."*

> *"A major concern is world production; within own country we can do a better job marketing Canadian. Everything produced in this country should have a red maple leaf. But we should also concentrate on our exports. The China deal hasn't gone as expected with high tariffs on Canadian blueberries, but Chile has been able to export with low tariffs. Canada needs to be more aggressive."*

Though not all farmers are comfortable with the idea of relaxing regulations, and instead would like to see Canada tighten regulations on imported organic blueberries. The more organic producers, the less price premium a farmer can achieve.

> *"I don't want Canada to relax organic standards. I want other countries to tighten their standards, but I don't expect that to happen. So, this puts Canadian organic growers at a significant disadvantage globally."*

A more immediate suggestion by many farmers to help alleviate some of the constraints is more education to aid farmers at different times of the year, or with their specific needs.

> *"More education, such as what [BCBC] did with seasonal charts, what needs to be done each month [i.e. timing and temperatures].*

> *"A cheat sheet personalized to farmers. For ways to deal with pests and weeds. If you are going to do it organically, what are some tips…"*

5.6.2 Feasibility of MCDA

Potential of MCDA in Agriculture

One of the main suggestions for the potential of MCDA is its ability to track trends in a longitudinal study. These trends include understanding in depth the costs, the attitudes and perspectives, as well as assessing whether policies and instruments are working as intended. The MCDA does not have to be exclusively done on growers, but other players in the industry, as well as consumers.

> *"If you are planning out 10-15 years for blueberries, is organic most profitable? Is it what everybody wants? The potential is there to do bigger study, track some trends on consumers and growers."*

> *"If MCDA was done with other players in the industry, [we can] compare and contrast with these results [of this study's MCDA] to see how we can improve or move towards more organic."*

It was also suggested that the ability for MCDA to be transparent and simple and suggest to farmers where to put their efforts on the farm, while quantifying complex qualitative information could be a significant advantage at making MCDAs useful in policy or farming decisions.

> *"MCDA is very important because it unpacks very complex and important attitudes and perspectives. If I did this longitudinally, I can see how attitudes progress and if we have made progress or went backwards. What [MCDA does] is very simple and transparent, and in turn, you [can] identify and measure policies and instruments that work [or don't work] and to what effect and how. We can see if we are doing what we are trying to do."*

> *"There is already a trend towards organic, so [MCDA] could be useful tool to drive that trend and educate towards more sustainable production."*

> *"[MCDA] provides more awareness, more information. [MCDA] has quantified what farmers are thinking which might be more accountable than difficult qualitative statements alone."*

The farmers also have already seen its potential to be used beneficially in other farming sectors, particularly farming businesses or sectors that are heading into new directions, rather than ones already established. This potential is related to the suggestion by some farmers that MCDA would be useful in business plans and templates, communicate findings, including when thinking of transitioning to more organic farming.

"Recommend going into canola. With changes to NAFTA, this tool can be useful in that setting because of changes in the trade agreement impacting that sector. Huge potential for MCDA in a more "new frontier" setting."

"I don't know anyone who went into [farming] with a business plan. The plan is to work [hard] and get paid. But [MCDA] gives a baseline for trends for costs, what other farmers are doing, especially when thinking of transitioning [to more ecological farming]."

"Could be very helpful and useful tool in templates and business plans. A good way of communicating and structuring the whole system/process."

Suggested Improvements

The number one suggestion by most farmers was for the MCDA to be done with a higher sample size that is representative of the blueberry farmer population in BC. Other suggestions included making the process more efficient and maintaining clarification on the technical terms. Another suggestion was to incorporate scale and size of farm into the analysis as alternatives (conventional, mixed-methods, and organic) in the AHP.

6 Discussion

This thesis was carried out to examine how agricultural producers can and do take influences on sustainability into consideration in their production decisions. In this section, I discuss the significance of the study's findings, including some reflection on how this aligns with previous thinking on this subject and how this fits with conceptions of population health.

6.1 Considering Health Consequences and Costs in Agricultural Production Decision-Making

The pilot MCDA study conducted as part of this thesis included consideration for how agricultural sustainability is thought of by farmers, and how their preferences can be advocated to achieve more sustainable and *healthy* processes. The MCDA Pilot study of this thesis suggests that from the perspective of an individual farmer, the costs of more sustainable processes offset the weights of the criteria, and therefore, the costs may be too big of a constraint or a prohibiting factor when considering more ecological preferences. Despite the results indicating interest from farmers for more ecological methods, they are not "willing-to-pay" for this. Furthermore, despite concerns about the need for greater consideration of determinants of health, as expressed in population health literature[1,2,16], and a similar need for attention to sustainability in the framing of Sustainability Goal number 2[3], there is generally very limited explicit mention of broader health implications in agricultural production decision-making.

System-wide analysis of food production have commented on the policy approach being applied as being far too siloed.[230] The current state of agriculture policy heavily emphasizes the economics of farming (i.e. securing farm incomes and ensuring stable food supply). Despite these objectives, however, food processors have accumulated the majority of profits instead of farmers, taking advantage of the subsidization of monocultures and promotion of diets reliant on lower-cost fats, sugars, and oils production. This focus can have eventual contributions on not only the obesity epidemic, but also the destruction of natural resources and the environment, as well as increased concerns for food safety.[230]

Further to this, the treatment of health in agriculture decisions made by individual producers is often too narrow. Agriculture can have a range of consequences on the determinants of health. As presented in the introduction, discussions should not only consider the health attributes for the commodity that is produced (i.e. the health benefits of blueberries) but should also extend to the direct and indirect implications of production choices on health.

One commonly applied tool for the analysis of the determinants of effects of development activities is health impact assessment (HIA), which is a broad or general toolkit that can be used to analyze the determinants of health in different settings, including agriculture.[231–233] HIA is defined as "a systematic process that uses an array of data sources and analytic methods and considers input from stakeholders to determine the potential effects of a proposed policy, program, or project on the health of a population and the distribution of those effects within the population."[234] However, despite hundreds of HIAs done in the USA, few have been done on agriculture, food and/or nutrition. Those that have been done lack monitoring and evaluation of the impacts on health outcomes, possibly due to a lack of funding.[234,235] HIAs across all applications have faced challenges that have limited their success, such as high resource and time demands, lack of relevant data availability, highly technical methodologies, and difficulty involving decision makers in the HIA process.[235] MCDAs, particularly AHP, have the potential to be an intuitive tool that is still comprehensive, which has had success in other settings like health economics.

Although the MCDA study in this thesis more explicitly evaluated constructs of agricultural sustainability, it does introduce the potential for the use of MCDA as a transparent and comprehensive methodology that tries to marry agriculture and population health policies. In the introduction, agricultural sustainability and the determinants of health were shown to be similarly defined with similar constructs. It should be noted, that in doing the MCDA with participants, during the defining of terms phase of the data collection, participants did not have trouble thinking of agricultural sustainability and the determinants of health as similar with overlapping criteria and goals. As described throughout this thesis, since agricultural sustainability and the determinants of health often have conflated goals and the consequences of agriculture on health are considerable, it would be wise to consider both of these concepts together in future policies.

In the introduction section, this thesis began with a question of how factors such as health and overall costs could be incorporated in agricultural decision-making. My MCDA study tries to tackle these considerations by first examining the degree to which such focus has been present in published literature. While it would be helpful to conduct a thematic or metanarrative synthesis of the literature to examine in greater depth the pathways whereby health is perceived as being affected, this was not the point of this bibliometric review. This review was meant to scope what specific subject areas have been addressed and contextualize the MCDA study conducted for this thesis within the literature to note where gaps or recognized areas for analysis exist, particularly with regard to how these articles have looked at health and costs in their analysis. This style of review is consistent with bibliometric reviews done on MCDAs in the past.[236–238]

The systematic bibliometric review of studies carried out in the agricultural setting revealed that MCDAs have been widely applied to consider a variety of criteria and for a range of purposes, such as crop management, pesticide strategy, soil management, and system sustainability decisions. It should be mentioned that although the final number of included articles may be considered small, this "low" number is a result of strict inclusion/exclusion criteria, specifically the criterion that restricted the analysis to articles that focused on agricultural activity that occurred on the farm (e.g. excluded land suitability studies) and as part of day-to-day farming specific activities (i.e. excluded "pre-pre" and "post-post" agricultural activity). While it is somewhat surprising that there were not any articles published in the Journal of Agricultural Economics, there were studies excluded from the final analysis as a result of the strict inclusion/exclusion criteria. Also no other agriculture stakeholder was to be included other than the farmer (e.g. producers, packers, policy-makers, etc. were to be excluded) Also MCDA is not exclusively an economic method, and MCDAs recent increase in popularity (which is supported by other bibliometric analyses[181]) can help explain its omission from this journal, as many of the included studies did not demonstrate the MCDA as part of a CBA as done in this thesis or in HTA studies. Although MCDAs have gained popularity in recent years, despite the fact that these methods have been around for decades, this can be explained by the fact that these methodologies are often first introduced in the area of operations research and management science, followed by information technology, and thus application in areas like agriculture is delayed. Also, decision-making in agriculture is often done by a single person, in this case the farmer, and decisions are made based on experience rather than computational methods. However, with the availability of user-friendly software and increased awareness of the benefits and feasibility of MCDA, this is changing and hence, the increase in popularity.[181] Furthermore, while studies have tended to directly include assessment of costs, treated as a factor that is analyzed separately from other criteria, the degree to which they consider health is quite limited. The only study that considered determinants of health incorporated this concern within a broader category of sustainability.

In conducting a pilot MCDA study that uses the AHP technique, I aimed to consider costs in a similar way that MCDAs have been conducted in HTA and health economics. For example, Baltussen et al[225] discussed the approaches of including costs in the MCDA for HTA. Some studies may choose to include costs or a cost-effectiveness measure as a criterion, as did all of the included studies in the systematic bibliometric review of this thesis. This approach requires participants of the MCDA to weigh the value of costs among other criteria. However, this is unrealistic because people are unlikely to fully grasp budget constraints and alternative ways of using resources, resulting in criteria weights that would not appropriately capture opportunity costs and may lead to confounding.[15,225,239,240] Instead, it can be advised to use what is called a cost-per-value allocation rule. In this method, costs of an alternative are divided by the aggregate value scores of all the other criteria. The alternatives are ranked based on their calculated "benefit-cost ratio" with the "best" alternative having the highest ratio. This "best" alternative is the one that should be selected, or this selection should be based on a willingness to pay threshold[15,225,239,241] (the maximum amount an individual is willing to pay for an incremental increase of benefit).[242] This was the approach used in the thesis.

One of the main reasons for the separation of costs from the criteria, is that it is considered a big factor in constrained choice, and it has been hypothesized that if included in the MCDA, it would far outweigh the other criteria, and principles of productive efficiency would be deemed most important.

There is debate on how to handle cost in a MCDA. One school of thought believes costs should be included just like any criteria; reasoning that is consistent across the studies included in the MCDA. The belief is that economic factors, namely costs are a critical criterion in decision-making, and should be weighed relative to all other criteria. However, the other school of thought posits that this is problematic for many of the reasons I explained above – which makes it much more akin to current applications of cost-effectiveness analyses (i.e. calculating the efficiency of a technology or method; comparing the benefit measures against the costs). By including costs as a criterion, we cannot determine the willingness to pay. If we are trying to determine the tipping point for farmers to become more sustainable, then it is critical to assess what the benefits of each agricultural system are, and the opportunity costs associated. I believe the benefits need to be determined independent of the costs associated with them.[243] This thesis is my attempt at the latter approach, and after doing this pilot study, I still believe that costs should not be handled as a criterion, however, there are some challenges to note in this pilot study. Namely that gross revenue was a criterion in the analysis. Even if net revenue was used as a criterion, perhaps it is questionable if the farmers were able to separate the costs associated with the concept of revenues. However, farmers did express that they make decisions that are independent of costs in order to increase revenues. Also, the criteria that were presented to farmers in the first phase included net revenue, and the majority of farmers wanted this changed to gross revenue. Related to the inclusion of revenue, it is fair to question the mutual exclusivity of revenue on health effects and food safety. It is hard to ignore the potential influence revenue has on the other criteria and the potential impact on the model results. While this is a concern, farmers expressed that they make decisions towards health effects and food safety independent of revenues. Perhaps a future version of this study, to avoid potential issues, would consider how costs and revenues are related (or unrelated) in decision-making.

We failed to reject this hypothesis, as mixed-methods farming techniques outranked organic/ecological farming, and further outranked conventional farming when costs were not included (see aggregate weights in Table 5. 8). Once costs were included in the form of a benefit-cost analysis, the rankings were reversed, with conventional farming the most preferred alternative, and organic/ecological the least preferred. These results and rankings were robust and consistent in the sensitivity analyses, whereby the costs were altered (i.e. costs with land costs, costs without land costs, costs without other (defined as costs of certifications, transportation, marketing, health care and insurance, safety and protection, administration, depreciation, waste management, other), and costs without land and other costs). This sensitivity analysis was conducted to try to adjust for the different mortgage/land payment arrangements that farmers possessed. Other costs were also adjusted for because of the lack of consistency in reporting by farmers. In fact, the effect was larger in favour of conventional when adjusting for different costs. This is assumed because conventional farms are typically larger, and thus may carry bigger mortgages to pay off. Although the results are robust, the MCDAs validity (i.e. internal, external, construct, and content validity) should be explored.

6.2 Feasibility of Applying MCDA to Assess Health Determinant Considerations

This study assessed what blueberry producers see as their preferred agricultural production methods and considers the conditions and constraints affecting these preferences that provide a basis for assessing the feasibility of applying MCDA techniques. In this section, I discuss the validity of the findings – and then consider how such an analytic approach contributes to the consideration of how health determinants can be understood and addressed.

First, the systematic bibliometric review assessed the feasibility of applying MCDA in the agricultural setting. In going through the included articles, studies were validated through a process modeled after the ISPOR Task Force Report Good Practice Guidelines.[15] This process confirmed whether the MCDA design, inputs, and outputs were consistent with decision-maker objectives and stakeholder preferences. See Table 6. 1 for checklist of MCDA good practice guidelines adapted from the ISPOR Task Force Report. As part of this identification, the systematic bibliometric review identified the way costs and health were considered. It was determined that the feasibility of conducting a MCDA in the agricultural setting was strong. Further, this bibliometric review helped situate the MCDA study of this thesis in the current literature. It was determined that my study could present a novel approach in how it assesses costs in the agricultural setting. MCDAs in the agricultural setting do not assess the benefits of alternatives (e.g. agricultural production methods) independent of costs and then divide them by the costs of production. This school of thought has not been done in agriculture as it has been done in health economics and HTA,[225,243] and therefore, I sought to determine if this same approach was feasible in the agricultural setting (i.e. why has this approach not been used in agriculture?). This bibliometric review provided some support to suggest that MCDAs in this setting can *potentially* be improved on by this different approach.

As introduced in chapter 1.1, health and agricultural sustainability are concepts that cannot be separated. Furthermore, this study's application of costs in a CBA, by taking the aggregate scores of the MCDA alternatives and dividing them by the costs of production. This approach is validated and supported in the literature according to the ISPOR Task Force Guidelines, and further other applications of MCDA such as in health economics and health technology assessments outlined in Baltussen et al.[225]

Table 6. 1: Checklist Adopted from ISPOR Task Force Guidelines of MCDA Good Practice[15]

MCDA Step	Recommendation
1) Defining the decision	a) Develop a clear description of the decision problem b) Validate and report the decision problem
2) Selecting and structuring the criteria	a) Report and justify the methods used to identify criteria b) Report and justify the criteria definitions c) Validate and report the criteria and the value tree
3) Measuring performance	a) Report and justify the sources used to measure performance b) Validate and report the performance matrix
4) Scoring alternatives	a) Report and justify the methods used for scoring b) Validate and report scores
5) Weighting criteria	a) Report and justify the methods used for weighting b) Validate and report weights
6) Calculating aggregate scores	a) Report and justify the aggregation function used b) Validate and report results of the aggregation
7) Dealing with uncertainty	a) Report sources of uncertainty b) Report and justify the uncertainty analysis
8) Reporting and examining of findings	a) Report the MCDA method and findings b) Examine the MCDA findings

6.2.1 Internal Validity

Internal validity refers to how well the study was done, by avoiding confounding or bias. Internal validity refers to the ability of a study's results to represent true findings, and not because of methodological errors. There were a few potential threats to validity in this study. Namely, the threats that could interfere with internal validity were history, maturation, and instrumentation.[244,245] History is a threat when other factors external to the subjects or farming occur across a long period of time.[246] Maturation is a threat whereby the subjects change (e.g. biologically or psychologically) over the course of the study.[246] In this study specifically, there were relatively long follow-up periods between data collection sessions. During this time, events outside of the study could have influenced the results. Changes in policies and changes in farming practices by the farmers themselves could have changed their preferences over time. Since this study is meant to be a snapshot into their preferences at a point in time, ideally, the data collection should have been completed within weeks rather than months. Although it is unlikely that farmers would radically change their production practices (or that policy shifts would occur) over a period of a few months, the application of this measurement instrument is usually done in a shorter timeframe and present less risk of losing people. Still, there was no evidence to suggest that any big events changed participant attitudes or behaviours. Sessions were still completed within the year, and it was observed that farmers were consistent in their perspectives throughout. However, it would have benefited farmers to have quicker turnarounds between sessions, so that they would have clarity throughout the process of the MCDAs purpose, and how each step/phase in data collection related to one another. This was mitigated by exploring what was done in the previous session, what would be done in the current session, and how it related to the rest of the process. The transparency and the simplicity of the AHP model lent itself well for consistency in its application despite the long turnaround periods, without compromising the robustness and exhaustiveness of the results. There was no evidence to suggest that this caused any real confusion among farmers once they were reminded of the process. Also, time for questions and clarifications was allowed at the beginning of each session.

Another threat to internal validity is the effect of changing the data collection method from focus groups to one-to-one sessions. It was initially identified as the preferred method to collect data. This turned out to not be possible in the BC blueberry context. Some farming contexts are set up as more cooperative, where the BC blueberry context was expressed by participants to be much more independent and competitive. Aside from difficulties that arise from trying to coordinate multiple schedules to conduct a focus group, there is a lot of hesitation from farmers to share their perspectives and the details of their farming practice with other farmers present. Respecting this, the data collection structure was converted to one-to-one sessions. This could have presented a threat to internal validity (instrumentation),[246] however, not only were there not any sessions conducted in a focus group, but this conversion to one-to-one presented a strength of the study. This adaptability was allowed using geometric mean to combine the weights elicited from farmers (as seen in other studies, such as those included in the systematic bibliometric review[210,217]). It should be noted that although some may believe that the sample sizes are not sufficient to use averages, this is a pilot study, and the intention of it was to demonstrate a protocol for what one should do; but if the sample size is not sufficient, individual evaluations should be considered.

Further, the qualitative data collected in the study reached saturation whereby growers expressed similar impressions on the results and feasibility of the study.

An important consideration to ensure the internal validity of the criteria was the mutual exclusivity of the criteria. It is important that the criteria are mutually exclusive to avoid double counting.[247] The criteria are mutually exclusive as supported by the literature from other studies, such as those included in the systematic bibliometric review. It is possible that participants could have conducted the pairwise comparisons by assigning a rate of 1 or 0 to all the criteria. However, in doing the mock interviews, and through doing the exercise with the participants, this did not happen and therefore, was not an issue. If it were, this would have been indication to revisit the criteria and consider a different approach.

Another question for validity is related to the costs. Not all farmers account for costs in as much detail as was laid out in Table 3. 4. With a larger sample size, this could have helped mitigate this issue. However, in presenting the results in the sensitivity analysis, it showed that regardless of how the costs were accounted for, the results remained unchanged and proved to be robust.

The final concern for internal validity is potential social desirability bias. This refers to the potential tendency for participants in a study to respond or provide information that they believe to be more socially acceptable instead of their true thoughts.[248] This concept has been studied by researchers in agriculture as many farmers understand that organic farming is more socially desirable to conventional farming, particularly, in the eyes of consumers.[249–252] To further this point, as will be seen in Chapter 6.2.3, ecological sustainability ranked so high for conventional farmers and so low for mixed-methods and organic farmers. This could be evidence to suggest some social desirability bias. To try to mitigate social desirability bias, it was emphasized that participants would remain biased. However, this issue touches on another potential bias: sampling bias. It is possible that all the participants in this study were “good” and “responsible” farmers (i.e. do not extensively use pesticides blindly) and my sample did not capture all types of conventional farmers. I was under the impression that the farmers typically make a business decision when determining their farming method once costs were considered, and based on farmers qualitative responses, it can be said that the results of this study are reflective of the real world.

6.2.2 External Validity

External validity refers to the extent that the results of the study can be generalized to the real world.[244,245] It should be noted that embedded in a MCDA design is the fact that the results are context specific, and not meant to be generalizable to other contexts of agriculture. This is distinct from assessing the feasibility of the study in other settings – which I observe that there is a strong case for the use of MCDA in other settings. However, there are some threats to the external validity with regards to real world implications with BC blueberry farmers. The two main issues were the small sample size and the sample's distribution across farming methods not being representative of the total BC blueberry farmer population, particularly with regard to gender.

Firstly, the entire sample owned their land and were male. This is a limitation of the study that should be addressed in future versions since different land agreements and women face different constraints and have different preferences in their decision-making. This population would provide different perspectives and ideas that would be valuable in a MCDA analysis. For example, one study explored the key barriers to sustainable agriculture among land renting farmers, the key themes these farmers expressed were: self-censorship (e.g. fear of discussing sustainable practices with landlords); uncertainty (e.g. the uncertainty inherent in one-year leasing inhibit willingness and adoption for sustainable practices); lack of technical knowledge and need for information dissemination; emphasizing production at the expense of profitability (e.g. farmers can perhaps emphasize that farms can be more economically viable if they show that the input costs do not outweigh the prices earned for the crop produced, and instead can farm crops that can fetch premium prices at reduced costs); problems with cash-rent leasing agreements (e.g. the concentration of risk is on the tenant which makes "taking a chance" on sustainable agriculture less likely); alienation of female farmers (e.g. females described inequitable power relations).[253] As for the absence of female farmers in this study, this is in light of an increasing number of women farming. Women face unique challenges and value different elements of agricultural work than their male counterparts.[254] The rise of female farmers may lead to a trend of more sustainable agriculture. Female farmers have presented different paths and challenges to land and capital than their male counterparts (e.g. where land ownership is usually passed down from father to son especially under conditions where capital is difficult to attain for anyone). To address some of these barriers, female farmers have responded by emphasizing smaller scale farmers, diversification of high-value and value-added products, unique marketing strategies, and sustainable practices that are often community-oriented. Female farmers face barriers in networks established by males and have created their own networks in response. This context presents a vitally different and necessary perspective for future versions of this study.[255]

Second, while fortunate to have a relatively high turnout from organic/ecological growers, as BCBC suggested to me that there are not many more organic blueberry growers in the province (unfortunately they do not have official numbers or estimates to support this claim).. It is the case that blueberry farms are disproportionately conventional, and future versions of this study would not only benefit from a larger sample size, but also a sample size that is a more representative sample. However, the results of the MCDA did not seem impacted by the size and distribution of the sample, as farmers expressed that they were not at all surprised by the results, and expressed that they would be surprised if a larger sample size would present different results. The results were reflective of the concept of constrained choice introduced in chapter 1, in other words, farmers believed that they prefer to be more ecological in their methods, but constraints (specifically costs) prevented them from practicing towards their preferences. This brings up the question of whether the MCDA appropriately elicits the preferences of farmers.

6.2.3 Validity of Criteria Rankings

An interesting piece to come out of the ranking of the criteria was that ecological sustainability ranked so high for conventional growers (third most important criteria), and so low for organic and mixed-methods (second least and least important respectively; second least for all growers combined as well). One would assume that ecological sustainability would rank higher for organic growers, or at least higher than conventional. A potential reason for this is that an intrinsic characteristic in organic farming is ecological sustainability. Some organic farmers suggested that they do not have to think about the environment as much as conventional growers because of this (and this may be true, to a lesser extent for mixed-methods farmers as well). Organic farmers may go into this type of farming with the environment at the forefront of their decision to do so; however, it is conventional farmers that see themselves in a more caretaker role for the land than organic farmers. This could be because conventional farmers have to think more intently about the sustainability and quality of their soil, for example, as a result of the inputs (e.g. pesticides) they put into growing their crops.[256] Organic farmers should perhaps think more intently about ecological sustainability in their day-to-day decisions, as some studies have expressed the lack of certainty on whether organic farming systems provide such sustainable benefits for ecological sustainability factors such as biodiversity.[257] Additionally, with more consideration to ecological sustainability in daily decision-making on the farm, improvements can be made to the efficient use of water and fertilizers, reduction to post-harvest losses, among other things.[258] Therefore, although, organic farmers' values and attitudes have been surveyed to be more eco-centric than conventional farmers,[257] there may be evidence to believe that in day-to-day decisions, organic farmers assume that ecological sustainability is already "taken care of" by virtue of being organic.

Gross revenue and crop yield are the highest ranked and therefore carry the most weight (i.e. the most important criteria) for all alternatives. The reason for this could be explained by the fact that farming is still a business. Gross revenue and crop yields will always be the most important in order to survive. Achieving a productive efficiency is crucial for the economic sustainability of the farm, and a constrained focus on that limits farmer capacity to focus on other aspects of sustainability, such as the rest of the criteria in this MCDA. Non-organic farmers see that the production costs for organic foods are typically higher due to greater labour inputs and economies of scale are more challenging than in conventional farming. Post-harvest handling of crop is expensive, especially since organic output has lower yields, and is required to be separated from conventional crops. Furthermore, marketing and distribution is not cost-effective and relatively inefficient due to the smaller yields. However, with increasing demand for organic food, technological innovations and economies of scale can reduce costs of production, processing, distribution and marketing.[259] Ultimately, farming is a business that needs to be financially viable. Although organic farming has significant potential, guaranteeing profitability is a primary concern for farmers that would consider changing to organic methods. Other barriers include a farmer's land structure, their mature age, low education level, and perceived uncertainties in the market, the certification process, and knowledge of new technologies (e.g. crop protection).[260] These constraints need to be mitigated in order to provide farmers the confidence to invest their farm into organic farming.

Health effects and food safety were next highest in ranking (third and fourth respectively). This is likely a high concern for a lot by farmers because without food safety, farmers could lose revenue. For example, the romaine lettuce industry saw multiple E. coli outbreaks over the last few years, which has led to organizations such as the Center for Disease Control (CDC) to urge consumers to avoid buying or eating romaine lettuce, leading to loss of confidence from consumers, which has economic consequences in the millions of dollars, further causing a ripple through food-supply chains.[261–263]

Farmers often see their health as a means of their capacity to work. As stated in section 1.1.2, poor health reduces work capacity, reducing income and productivity, which further contributes to poor health.[28] Some farmers in this study expressed that health is considered subconsciously, however this may be a result of pride rather than actual attentiveness to personal health, especially for conventional farmers, who had health effects ranked low. Farmers endure highly strenuous physical occupational health conditions, that may lead to injury and chronic illnesses,[24–28] compounded by the mental health issues that plague farmers, especially male farmers. Male farmers are at higher risk of experiencing high job-related stress and mental health challenges compared to female farmers and men in other jobs. Additionally, male farmers are characteristically reluctant to seek mental health or social services for help, making them susceptible to self-medicating and suicide. This masculinity is a core effect on the mental health crisis.[264–270]

Empowerment and autonomy ranked as the lowest criterion. The low ranking can be examined by understanding that empowerment and autonomy are often limited to certain groups, and opportunities to participate in the socio-political process of civic engagement and governance are not equitably distributed due to socio-political and economic status.[271,272] For example, grain farmer voices have been diminished in their decision-making process with the dismantling of the Canadian Wheat Board in 2011, as Canada's grain is now more susceptible to access from transnational corporations (five of which control 80% of the global grain trade already).[273] The argument for dismantling the board is that it is not needed. In times of prosperity, things that support empowerment and autonomy, such as the Canadian Wheat Board, are not at the forefront of thought. However, when conditions inevitably become harder, empowerment and autonomy and the channels that support farmer voices are critical. Ultimately, a reduction of farmer empowerment and autonomy, constrains their choices, where they are incentivized to achieve productive efficiency or business efficiency/viability.[52] Ideally, the process of empowerment and autonomy is practiced by all players in the food system to gain power and control over decision-making processes. This can be done through democratic participation and engagement. This process can empower farmers and their communities to more strongly contribute and make decisions on their food processes and the overall food system.[274] The process of regaining empowerment and autonomy augments the potential of farmers, their food chains and local markets, and ultimately can have more independence in making strategic choices concerning growth and development at both a micro- and macro-economic level.[77] Re-appropriation of power can have direct benefits to the farmer. One strategy would be to diversify a farmer's investments in their farm (i.e. a portfolio strategy), whereby farmers grow various crops that target different markets and consumers, which reduces the impact of price fluctuations in commodity markets. This has the potential to increase farmer income and also increases the likelihood for farmers to take advantage of potential new opportunities, including research and innovation, and self-governance.[77] Therefore, improving on empowerment and autonomy can have a trickle-down effect on farming efficiency, and therefore revenues, and other criteria. It would be interesting to analyze the results of a future version of this study that uses food sovereignty (which empowerment and autonomy are major components of) as the overall goal of the MCDA to test this trickle-down hypothesis.

6.2.4 Overall Reflections on Selecting Preferences

Putting this all into consideration, mixed-methods farming were considered to be the most preferred without the consideration of costs. Perhaps better elicitation of ecological sustainability from organic growers would have placed ecological sustainability higher in the rankings, and organic farming or mixed-methods would have maintained its position as the most preferred method once costs were considered. It should be noted that all farmers were not surprised by these results, and that it reflected their reality that although they prefer to be more ecological, once costs are considered it prevents them from practicing towards their preferences, suggesting that the results are valid.

6.3 Implications for Policy and Research

In real world circumstances it is unavoidable that farmer decisions are constrained, and not completely their own. Farmers are influenced by many factors and other players with similar or competing interests, and it can be assumed that costs are the central component behind the decision-making process. The results of this MCDA demonstrate that farmers prefer (i.e. are more interested in applying organic production practices) to be more organic, and to elaborate on these results it would be crucial to expand the study to other farming sectors (e.g. applying it to banana farmers in Ecuador, a group closely associated with the international collaboration this study is part of), and other stakeholders, such as processors, consumers, and policy makers. Gaining their perspectives can help understand the current context of farming preferences, but also how to better incorporate farmer preferences moving forward, in order to become more sustainable.

Future applications of MCDA in agriculture could look into doing an incremental costing analysis design. Cost analyses are tricky and there can be huge variation between farmers depending on their own contexts (e.g. financial situation, land ownership, etc.). An incremental cost analysis would be helpful to see the actual tipping point, termed in dollars, for farmers in the conversion to more ecological methods (or perhaps a discreet choice experiment).

Governments often use MCDAs to make choices around what options to invest in, such as in healthcare, which technologies doctors can use. To encourage more sustainable farming that promotes health – financial incentives can be elicited from farmer preferences learned from this kind of exercise. Incentives only work for those who deem them to be important, and if policymakers understand what farmers deem to be important, then they can structure their incentives more effectively. Accordingly, MCDAs strengthen the evidence-base for policies. But, if future versions of this study have similarly small sample sizes, the study can be framed in a way that the model numbers can report back to individual farmers to help them in their decision-making.

While this thesis' MCDA only looked at the preferences and constrained choices of farmers, further adaptations of this approach can include or have separate MCDAs for processor preferences, consumer preferences, policy makers, or even an MCDA with all stakeholders together, to reach a path that is suitable for all parties, that simultaneously achieves a mutually beneficial sustainable agricultural production system.

Specifically, to help with the cost constraints, better help from governments during transition periods from conventional to organic, where farmers attain lower yields while receiving a lower price than organic premium pricing needs to be addressed. This barrier is restrictive to most farmers. Better education and consultation on sustainable methods could help farmers as well. There seems to be a belief that organic and ecological methods are too difficult in the BC climate, especially when farms get a lot bigger. Suitability studies are necessary, and it is necessary to appreciate and explore what farmers perceive to be stricter regulations around the products permissible for use in Canada as certified organic compared to other countries who sell their exported product as organic in Canada. Feasibility studies (with the help of MCDAs) can help identify an appropriate course of action for policy makers to limit these barriers and help make production more sustainable in BC.

MCDA can be used in many other agricultural applications. Some farmers already suggested that this method would be useful in helping farmers decide where to put their efforts on the farm, for farmers heading in new directions (for example becoming more ecological or organic), for business plans and templates, and could be applied more longitudinally to assess how farmer preferences have changed, and if there have been any changes over time in preferences and attitudes towards sustainability.

MCDA has potential applications in crops that have been affected by policy changes. For example, MCDA can aid in the mapping out of a strategy for the growing canola industry, which started to grow originally from the elimination of tariffs with the North American Free Trade Agreement in 1994 (NAFTA) and further with the United States-Mexico-Canada (USMCA) agreement.[275–277] Or, MCDA can aid in the mitigation of potential challenges introduced by the USMCA for dairy farmers, as they cede market share to US dairy imports and to declining domestic demand.[278] This method can also be used in the development of agricultural policy as it has been used in other settings such as health.[8,279–281]

Engagement at multiple levels of policy and action is necessary for creating the change necessary to produce heathy and sustainable agriculture systems. Consumers and individuals can educate themselves on the agriculture system and become more vocal to advocate for more sustainable food policies by contacting their representative politicians. Consumers can aim to purchase more sustainable foods at grocery stores. Understandably, some of these foods may be expensive and not everyone has the capacity to purchase their groceries in this way. However, advocating that the current food system has negative externalities not only on the environment, but also on our health (this needs to be framed as more than just the nutrition of food itself, but the impacts that the entire food system has on health from producers to consumers). Promotion of research, including CBA (or in the case of this thesis, MCDAs) goes a long way in understanding and developing the appropriate avenues to take towards sustainable and healthy systems.[230] Further MCDAs can be a tool used to structure farmer preferences and provide a methodology for their advocacy in policy.

Governments and organizations can promote locally grown and sustainably produced foods. They can develop healthier food policies, such as in school and work cafeterias. Governments can develop tools to help consumers buy more sustainable foods. Governments need to have multidisciplinary teams to implement these policies. They need to become more publicly transparent and comprehensive in their assessments of the agriculture food system, not only focusing on economic indicators, but environmental and health indicators as well.[230] MCDAs can be a tool used to great strength in these actions. Ultimately the goal of these policies should be that: agricultural systems must produce affordable, appropriate, and accessible food[4] in a way that is sustainable and in line with social justice,[5,6] and principles of food sovereignty.[7]

6.4 Strengths and Limitations of MCDA Applicability for Considering Agricultural Sustainability and Health

This thesis aimed to provide a tool for understanding how agricultural producers can and do take determinants of sustainability into consideration in their production decisions. However, it was determined that in some ways, MCDAs are limited in their application in connecting the concepts of sustainability of health in a concrete or obvious way. In other words, some conceptualization to connect health and sustainability had to be done. I do not believe that this thesis will tear down the conventional thinking that often keeps health and sustainability as separate concepts, but it does introduce a method for introducing this idea that they are connected, and that farmers make several trade-offs along certain competing categories or criteria.

Overall, this thesis provides evidence that MCDA in combination with a CBA (as a method for assessing overall effects) provides a feasible tool to understand the preferences of farmers, the constraints they face, and ultimately the trade-offs they make between their preferences and constraints along competing criteria that can ultimately help in the advocacy of the of sustainable and healthy agricultural systems. The farmers' "willingness to pay" (which is provoked by the CBA) to move towards their preferences (which is more ecological farming) can aid in evidence-based and farmer-informed policymaking.

This small-scale feasibility pilot study examining how agricultural producers consider health and sustainability in relation to other priorities could arguably also be considered as an example of how the preferences of other social and economic actors can be analyzed with regard to the influence of broader sets of social determinants. If this ambitious perspective was to be considered, however, it would be best to first examine the particular study setting of blueberry producers in greater depth and address the limitations of this pilot study that were raised in the text, to better validate the observations discussed above.

Finally, by conducting a bibliometric study of how tools of analysis have been applied in the scientific literature, I was able to situate the value of how such studies can contribute to filling gaps. In considering the value of a new application of a method, I also consider conducting such an analysis to be a strength of this study – and a valuable learning exercise.

7 Conclusions

This thesis examined the feasibility of a method to understand the preferences of farmers and how they are offset with competing constraints. Without the consideration of costs, farmers prefer to be more ecological, but once considering costs in a CBA, farmers choices are constrained towards more conventional methods. Although this thesis did not prove that MCDA, in this form, can unite the concepts of health and sustainability, this thesis introduces the idea that MCDAs can be used to aid in understanding these concepts as connected with similar, if not the same, goals and criteria. MCDA, specifically AHP, was implemented on farmers in the BC blueberry setting and elicited their preferences on agricultural production methods.

Furthermore, borrowing from MCDA practices learned from HTAs and health economics, a systematic bibliometric review determined that this thesis is a novel approach in agriculture in its application of MCDA where the aggregate scores of alternatives are divided by costs of production. The expertise, opinions, and attitudes of farmers were used to rank the most influential criteria in their decision-making, and ultimately the agricultural production method they prefer the most and the cost-benefit ratios once costs were considered in the CBA. The results of the study with and without costs provide interesting insights on the potential constraints and the potential "willingness to pay" that farmers must convince them to move towards more the expensive ecological farming methods. This "willingness to pay" can be aided through policies or other instruments that can help limit the constraints that farmers face in their choices. MCDAs have the potential to be used in many applications in agriculture, but most importantly, have the potential to better advocate for healthy and sustainable agricultural systems. To farmers, this means advocating for their preferences.

Farmers must balance competing criteria in their decision-making process that straddle the lines of environmental sustainability, economic sustainability, and social sustainability. This thesis argues that the determinants of health should be intrinsically considered in sustainability and need not be considered independently from one another – but would benefit from greater attention to considering the pathways where it may be considered relevant. In summary, this thesis identified preferences that drive decision-making in the context of constrained choice in BC blueberry farming – and how to potentially mitigate these constraints. For better advocacy of this process in policy, future MCDAs with CBA in the agricultural context, either in independent applications or complementary to other tools, should appreciate the overlapping goals of health and sustainability in agriculture.

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Appendices

Appendix 1 – Session 1 and Car Example

Some explanation of the MCDA method:

- Here is an example of an MCDA. The scenario is that you are going to be buying a sedan. Let's say I have asked you all to provide me a list of factors/criteria that you think are important when buying a sedan. The criteria that you determined are: Performance, Interior Features, Reliability, Safety, and Fuel Economy.
- Let's also say that you helped me define the criteria:

Definitions of Criteria	
Performance	Horsepower, speed, etc.
Interior	Seating and features (spacious, backup cameras, sunroof, heated seats, remote entry, connectivity, etc.)
Reliability (longevity)	Lifespan of car with minimal costs for breakdowns
Safety	5-star rating used: 5 star rating performs very well in crash tests and the least likelihood of injuries and fatalities, and exceeds on safety equipment and technologies
Fuel Economy	Miles per gallon used

1. Now that we have this list of criteria, there is also a list of sedan options – since this is hypothetical, they are named Car A, B, C, and D. Thus, the numbers (the performance measures) provided in the table are of course hypothetical as well.

Sedan Option	Performance	Interior	Reliability	Safety	Fuel Economy
Car A	8/10	7/10	8 years	3 Star	20
Car B	9/10	9/10	8 years	5 Star	30
Car C	7/10	9/10	8 years	5 Star	25
Car D	8/10	7/10	10 years	3 Star	25

Background

- International organizations such as the United Nations have proposed that agricultural systems meet the challenge of producing affordable, appropriate, and accessible food, in a way that is sustainable and in line with social justice
- Grower organizations (such as the BC Blueberry Council) have recognized the value of promoting sustainable options.

Purpose and objectives

- The purpose of this study is to develop and apply a method for considering how an optimal balance can be achieved between different criteria and economic factors, for different strategies of agricultural production, specifically in the context of blueberries in British Columbia.
- A multi-criteria decision analysis (MCDA) will be conducted to determine which agricultural production methods will provide the greatest overall weighted benefit for the goal of producing blueberries, considering multiple criteria/factors – not just yields and revenue, but other factors, such as sustainability and bio-security, particularly in relation to health
- This means that you will discuss which agricultural production method performs best in a MCDA according to your current practice

- The benefits of doing a MCDA are to help understand and arrive at decisions more transparently and comprehensively. This process will hopefully help you examine your decision-making process; in other words, why you make certain decision when it comes to your practice.
- Similarly, the other benefits are that I will also be gaining insight to your decision-making and preferences, and ultimately consider the degree to which MCDA is a useful method to get at understanding decision-making and preferences in agricultural production
- The results will be shared with the BC Blueberry Council, so that they can understand your decision-making process better and advocate for your preferences more
- MCDA can hopefully guide future decisions in agricultural production that are more representative of you
- We know that conventional methods are widely practiced, but if the results show that you prefer or are more interested in other agricultural methods, this method will help show your reasoning, and together we can then investigate under what conditions is it worth the associated cost to practice more towards your preferences. This can help for recommendations for not only future research, but agricultural policy and practice.
- If successful, this can be applied more in your context and other agricultural production settings as well, as this study is one part of a larger international study.

Example of MCDA method:

- The scenario is you are going to buy a sedan. Let's say I have asked you all to provide a list of factors/criteria that you think are important when buying a sedan. The criteria that you determined are: Performance, Interior Features, Reliability, Safety, and Fuel Economy.

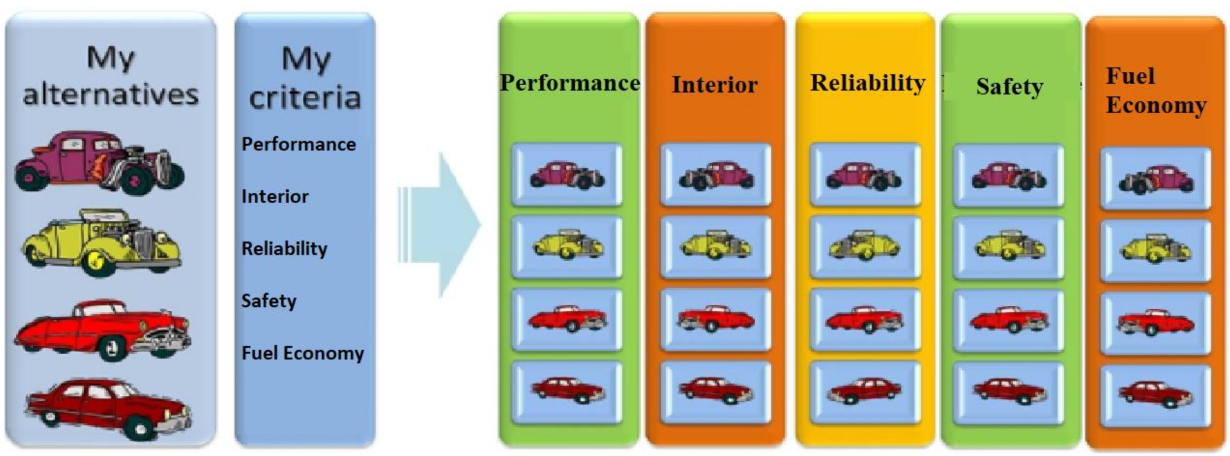
Definitions of Car Buying Criteria	
Performance	Horsepower, speed, etc.
Interior	Seating and features (spacious, backup cameras, sunroof, heated seats, remote entry, connectivity, etc.)
Reliability (longevity)	Lifespan of car with minimal costs for breakdowns
Safety	5 star rating used: 5 star rating performs very well in crash tests and the least likelihood of injuries and fatalities, and exceeds on safety equipment and technologies
Fuel Economy	Miles per gallon used

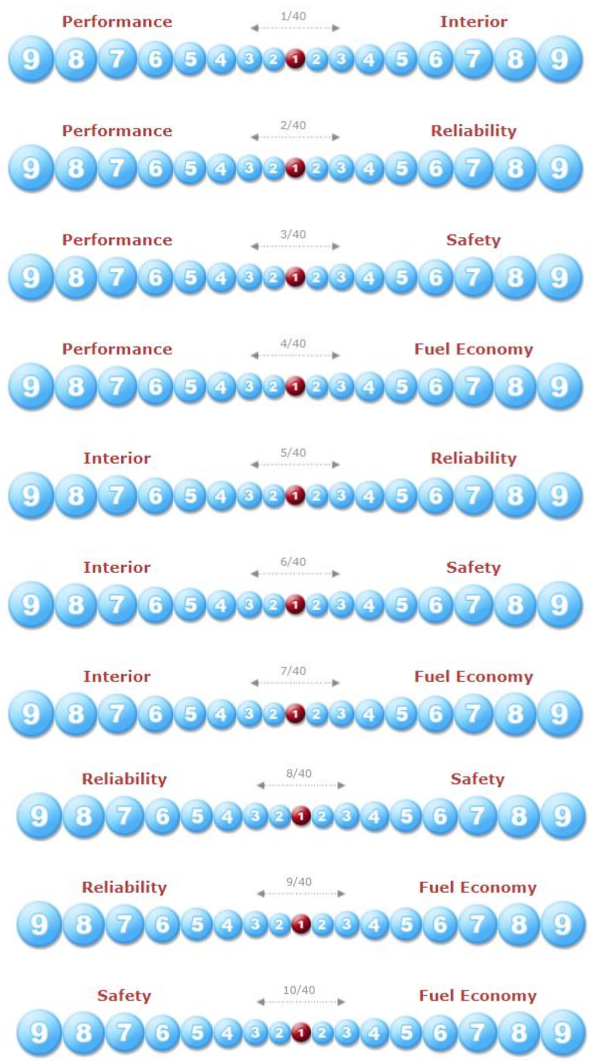
Sedan Option	Performance	Interior	Reliability	Safety	Fuel Economy
Car A	8/10	7/10	8 years	3 Star	20
Car B	9/10	9/10	8 years	5 Star	30
Car C	7/10	9/10	8 years	5 Star	25
Car D	8/10	7/10	10 years	3 Star	25

- You will first do the weighting of the criteria by comparing each criterion against another until all possible comparisons are made.
- Then you will decide how much, or the strength to which you prefer that criteria over the other.
- For this example, a scale of 1-9 will be used:

Scale	Definition	Explanation
1	Equal importance/preference	Two activities contribute equally to the objective
3	Moderate importance/preference of one criterion over another	Experience and judgement moderately favour one criterion over another
5	Essential or strong importance/preference	Experience and judgement strongly favour one criterion over another
7	Very strong importance/preference	Experience and judgement very strongly favour one criterion over another
9	Extreme importance/preference	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two judgements	When compromise is needed

Phase 1: Define alternatives and list of criteria	**Phase 2:** Weigh criteria	**Phase 3:** Score performance of each alternative (car) to the criteria





- Once that is complete, you will score the sedan options against each criterion, by putting the strength to which you think one measurement is better than another measurement. For example, how much do you think a measurement of 9/10 is better than 8/10.

criteria Performance

Use the scale to define importance of alternative by criteria Performance ,compared with the other alternative. Continue with comparisons.

Car A 11/40 Car B
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car A 12/40 Car C
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car A 13/40 Car D
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car B 14/40 Car C
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car B 15/40 Car D
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car C 16/40 Car D
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

criteria Interior

Use the scale to define importance of alternative by criteria Interior ,compared with the other alternative Continue with comparisons

Car A 17/40 Car B
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car A 18/40 Car C
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car A 19/40 Car D
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car B 20/40 Car C
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car B 21/40 Car D
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car C 22/40 Car D
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

criteria Reliability

Use the scale to define importance of alternative by criteria Reliability ,compared with the other alternative. Continue with comparisons.

Car A 23/40 Car B
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car A 24/40 Car C
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car A 25/40 Car D
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car B 26/40 Car C
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car B 27/40 Car D
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car C 28/40 Car D
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

criteria Safety

Use the scale to define importance of alternative by criteria Safety ,compared with the other alternative. Continue with comparisons.

Car A 29/40 Car B
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

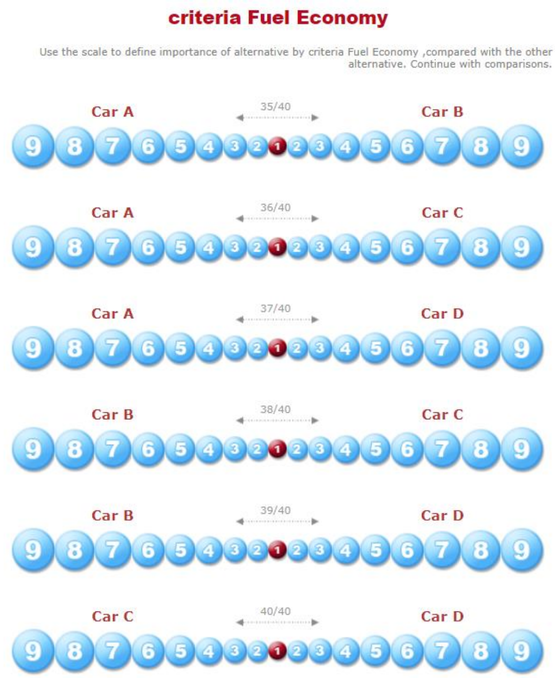
Car A 30/40 Car C
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car A 31/40 Car D
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car B 32/40 Car C
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car B 33/40 Car D
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9

Car C 34/40 Car D
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9



- Once this is complete it will provide you a weighted score, and the one with the highest score will be the choice for your sedan.

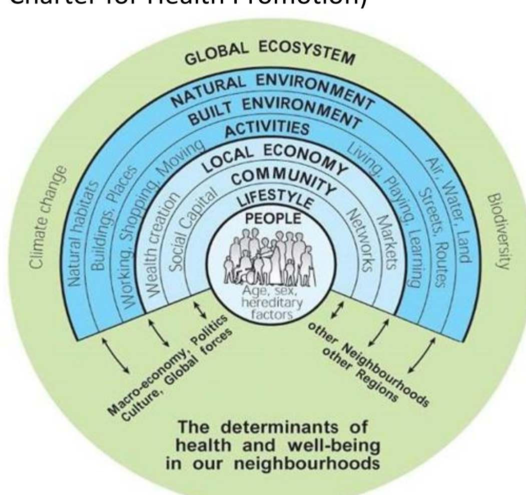
- This same process that will be done for our purposes. Only we will be comparing agricultural production methods against certain criteria that you come up with.
- Together we will decide which criteria are the most important to you and then score the performance of each option against that criteria.
- The idea is that MCDA can help by giving you evidence to help support your decision-making in a comprehensive and transparent process, and at the very least help you understand your current decisions.
- Today's session is the validation phase, where I will present to you the agricultural production options and specific criteria. By the end of this session, we will have the list of criteria decided upon, as well as the definitions of the options and criteria finalized.
- After this session, I will send emails to you all with the criteria and definitions to confirm with you where we left off. After that, I will schedule one-to-one meetings with each of you to weigh the criteria. You will also be asked some questions related to the established criteria in this meeting.
- Finally, after the weighting, a final one-to-one meeting will be set (likely on the phone) to score the agricultural production options against the criteria, and we will have an MCDA constructed to show you which method this process has led you to.
- I would like to remind you that everything is confidential, and that discussions should remain in this room. You will not be identified in any way in the results.

Agricultural Production Options

- I have provided some definitions for each option. Please read through these definitions and I will give you the opportunity to agree or disagree with the definitions, and also give you a chance to either change some of the definitions or provide your own until you agree on them.
- Also, provide some detail and specific examples of practice associated with each method (i.e. let's discuss specific techniques that you feel are presently being practiced – or you feel could be practiced (e.g. in relation to pest management, fertilization, pollination, etc.):
- **Conventional/Agro-industrial:** Monoculture agricultural systems (large as well as smaller scale) dependent on high inputs of synthetic fertilizers and pesticides to achieve and sustain high yields
- **Agro-ecological/Organic:** Practice of applying ecological concepts, principles and knowledge to design and management of sustainable farms; sometimes with organic certification
- **Integrated farming (mixed-methods):** Mixes both methods (ecological and conventional)

Criteria – Defining Health

- What is health to you?
- There are several factors or criteria that have relevance, consequence, or association with health – these are known as determinants
- Therefore, your decision-making is a process bringing together factors, each with a different degree of importance, that have health consequences
- Definitions:
    - "An ability to adapt and self-manage in the face of social, physical and emotional challenge" (Huber et al., (2011) How should we define health? *BMJ)*
    - *"*The states of health or disease are the expressions of the success or failure experienced by the organism in its efforts to respond adaptively to environmental challenges". (Rene Dubos (1965), Man Adapting)
    - Health appears on different scales (individual, community, sub-national, regional, national, global)
    - Includes physical, mental, socioeconomic, spiritual, environmental (including constructed environment), and social well-being, and not merely the absence of disease or infirmity – so not only the absence of disease or illness (WHO)
    - Also considers the ability to satisfy your needs, and change or cope with your environment (Ottawa Charter for Health Promotion)



- This is not different from criteria for sustainability… various factors/criteria in your decision-making inevitably affect your health. You may also notice these criteria are part of a broader definition of sustainability as well (sustainability of the environment, your yields and revenue (or economics), your own physical health, and the social networks required for you to have sustainable success

Criteria:

- Below are some criteria that I have found in my readings as possible attributes to consider in relation to how production activities are carried out.
- In future sessions, you will be comparing each agricultural production option to the criteria you determine, first by weighing the criteria according to your preferences, and then scoring the performance of each agricultural production method for each criterion to make up the final MCDA model.
- You may add or subtract any criteria that you think should or should not be there respectively.
- I invite you to agree with the definitions or provide your own.

Category	Criteria	Definitions
Environmental	**Agricultural Sustainability**	Ability to ensure that resources required to function optimally over time are maintained without deterioration (e.g. soil depletion; energy use)
	Adaptability	Ability to respond to changing conditions (also referred to as resilience)
	Biosecurity	Contamination of the environment (air pollution, water pollution, genetic contamination of crops, soil quality and erosion, wildlife protection)
Economic	**Crop Yield**	Volume of crops that are produced (pounds/acre)
	Net Revenue	Amount of money crop generates ($/acre)
Physical	**Health Effects**	Health issues as a result of exposure to toxic substances, work conditions, stress, etc.
Social	**Sovereignty**	Degree to which agricultural processes are within producer control, and the extent to which one can utilize own strategies (i.e. autonomy, self-reliance, and empowerment)
	Solidarity	Extent to which positive and healthy social networks are established or reinforced (e.g. with other producers, communities or consumers)
Other	**Food Safety**	Pesticide residue that remains on the blueberries is safe for consumption
	Nutrition	Health benefits from blueberry consumption (antioxidant properties)

Summary:

- This concludes our first session. To recap, today was the validation phase of this study, where first, I explained to you what an MCDA is and went through an example. You then provided me with a list of criteria as well as definitions for the agricultural production methods and criteria.
- If you remember from the sedan example, we weighted the criteria in order of your preferences (e.g. Performance, Interior Features, Reliability, Safety, and Fuel Economy).

- To do that for our study, we will take the list and definitions you provided me today and will weight the criteria in our next meeting. In other words, you will determine the order of importance or preference for the criteria we determined today.
- I will meet with each of you individually in order to weigh the criteria, and prior to the meeting I will send you all emails reminding you of where we got up to today. I will attach the definitions and list of criteria in the email so that you can provide any final feedback to them.
- Also, please come prepared for your one-to-one meeting to answer some questions with regards to costs and measures of each criterion that you have decided on today (I will remind you in the email).
- I will set up a time to meet with you one-on-one at that time as well.
- Finally, just to give you a look of what will happen even further ahead, we will meet one last time to measure the performance of each agricultural production against each criterion, and the MCDA will be constructed (as we did when we measured the performance of each sedan against each criterion).

Appendix 2 – Consent Form

Participant Information and Consent Form

Multi-criteria decision analysis (MCDA) comparing agricultural production methods: British Columbia (BC) blueberries case study

Part of the Food systems and health equity in an era of globalization: Think, Eat and Grow Green Globally (TEG3) Research Program

Study Team – Who is conducting the study?

Principal Investigator: Rami El-Sayegh, MSc. Candidate, BHSc.

Co-Investigator(s):

Dr. Jerry M. Spiegel, PhD

Dr. Craig Mitton, PhD

Sponsor – Who is funding this study?
This project is a component of a larger research program (*The food systems and health equity in an era of globalization: Think, Eat and Grow Green Globally (TEG3) Research Program)* funded by the Canadian Institutes of Health Research (CIHR).

Invitation and Study Purpose – Why are we doing this study?
This study is for a graduate thesis, and the purpose of the study is to examine different types of agricultural production methods to assess various criteria such as revenue, yields, sustainability and health effects in the context of blueberries in British Columbia. These criteria are the factors that you deem to be most important when making agricultural production decisions in your practice.

This work seeks to provide a case for a transparent and comprehensive process to decision-making that considers the multiple criteria/factors that you deem important in your farming practice – not just yields and revenue, but other factors, such as sustainability and bio-security, particularly in relation to health; and to assess and compare the performance of the agricultural methods against these criteria to the costs. This study seeks to also determine the usefulness of this method in the context of agricultural production (known as multi-criteria decision analysis (MCDA)).

Therefore, you are being invited to take part in this research study because we would like to learn more about the decision-making process of the wide range of production methods that you are representative of (conventional, agro-ecological/organic, and integrated farming/mixed-methods farms). Your participation will help us learn more about your perspectives, as well as the challenges and opportunities you face in the blueberry production industry.

Study Procedures – How is this study done?
By participating in the study, you will be interviewed through three one-to-one sessions by the co-investigator Rami El-Sayegh, in a process known as a MCDA. Each meeting should last about one hour to a maximum of two hours (for a total of three to six hours). In the first meeting, you will quickly learn what an MCDA before commencing the study. Then a list of criteria will be presented to you, and from your perspective, you will decide which criteria should or should not be on the list, and whether there are any additional criteria that should be included. This session will take 1-2 hours of participant time. This is followed by a one-to-two-hour one-to-one meeting to determine the criteria that are most important by weighing the criteria using a 1 to 9 scale. Finally, in the final meeting, you will be asked to score the performance measures of the agricultural production methods against each criterion. This final meeting will take approximately one hour. The final session can be arranged to be done over the phone. You will be asked questions during these sessions that will discuss your preferences and knowledge on your practice and agricultural production methods in general. Questions will also explore and compare the costs and benefits of the agricultural production methods and criteria (i.e. to consider under what conditions are increased benefits worth the associated cost), whether your decisions are constrained, and whether this methodology was helpful in understanding your decision making.

Results of the study:
The data may be used in research pertaining to a larger-long-term research project ("Food systems and health equity in an era of globalization: Think, Eat and Grow Green Globally (TEG3)") headed by Dr. Jerry M. Spiegel (principal investigator) of this study. Research results, publications or reports will be made available to all participants. If findings are shared via publications or conference presentations, no personal identifying information will be shared. Data will only be shared in aggregate form. The results of this study will also be used for the graduate thesis of Rami El-Sayegh.

Potential Risks – What are the risks of participating?
You should not be subject to any significant risk of any kind as a result of taking part in the study. Risks are minimal, no different to what one would experience in regular daily activities.

Some of the questions we ask may seem personal or sensitive. You do not have to answer any question if you do not want to.

Potential Benefits – What are the benefits of participating?
You will not receive any direct benefits as a result of your participation in this research. You will receive copies of the research report and will be involved in the process throughout the MCDA procedure. This will allow you to reflect on your decision-making process in a way that is comprehensive and transparent. Also, the results will be taken to the BC Blueberry Council, so that they can understand the producer decision-making process better and advocate for your preferences more and possibly guide future decisions in agricultural production, through MCDA.

Confidentiality:
Your confidentiality will be respected. Information that discloses your identity will not be released without your consent unless required by law. Subjects will not be identified by name in any reports of the completed study. Participant identity will be kept strictly confidential, as all documents related to participants will only be identified by a code number. This number will be used instead of participant names. All digital data (e.g. notes and audio recordings) will be saved on a password protected computer and password protected USB. All hard copies of data will be stored in a locked storage unit. Data will be securely kept on file for at least five years, as this study is part of a longer-term research project headed by Dr. Jerry M. Spiegel (principal investigator). At any point, if the participant wants their data to be destroyed, their request will be accommodated. The principal investigator and co-investigators will have access to this research, as well as any research assistants or translators hired. Confidentiality will be discussed with these individuals, and they will be required to sign a confidentiality agreement.

Audio recordings may be taken during interviews. As mentioned above, all recordings will be kept confidential and kept protected. These recordings are for the researcher to use shall he require access to discussions had with participants, strictly for use during data analysis and thesis write-up.

Contact for information about the study – who can you contact if you have questions about the study?
You are encouraged to raise any questions or concerns about the study, or your participation in the study to the co-investigator or principal investigator. You may contact the co-investigator or principal investigator in person, via email, or via phone (information listed at the top of the first page)

Contact for concerns about the rights of research subjects Who can you contact if you have complaints:
If you have any concerns or complaints about your rights as a research participant and/or your experiences while participating in this study, contact the Research Participant Complaint Line in the UBC Office of Research Ethics at 604-822-8598 or if long distance e-mail RSIL@ors.ubc.ca or call toll free 1-877-822-8598.

Consent:
Your participation in this study is entirely voluntary. You may decline to participate or withdraw from the study at any time without penalty.

Your signature below indicates that you have received a copy of this consent form for your own records.

Your signature indicates that you consent to participate in this study.

Your signature also indicates that you understand that you are agreeing to an audio recording of your participation in the interviews.

____

Participant Signature Date

____

Printed Name of the participant signing above

Appendix 3 – Redacted Email

Hello,

Hope all is well. This email is a follow-up to our conversation.

I wanted to start by reminding you of where we got to in our first session.

1. We went through a hypothetical scenario of a Multi-criteria decision analysis (MCDA), using a sedan purchase as the example.
2. You identified and agreed on definitions for the agricultural production options.
3. You identified and agreed on a list of criteria that are important to you.
4. You provided and agreed on definitions for the criteria

Attached in this email is a document with the definitions for the agricultural production options and the list of criteria. These definitions are based off responses from all growers participating in this study, including you. Therefore, I have aggregated your responses accordingly to be as reflective of each of your perspectives as possible.

Please review the document and provide any feedback in case something is highly inaccurate with the definitions or send me a confirmation that the definitions look fine to you. Keep in mind that this is meant to be a 'fine tuning' of the definitions that are reflective of the many different perspectives that growers hold.

Once I have received feedback from you all, I will schedule one-to-one meetings with each one of you to proceed to the next step: weighing the criteria.

Please be prepared to weigh these criteria and answer a few questions about them as well as questions about total costs.

If you have any questions or comments, please do not hesitate to contact me.

Rami

Attached table of terms and definitions for final feedback

Terms	Definitions
Alternatives	
Conventional	Agricultural, often monoculture, systems (large as well as small scale), that include inputs of synthetic fertilizers and pesticides to produce their crop and counteract pest and disease stresses
Organic/Ecological	Practice of applying ecological concepts, principles and knowledge to the design and management of sustainable farming to produce their crop and counteract and control pest and disease problems (organic certification required for farms using the term organic)
Integrated-Farming (Mixed-Methods)	Mixes both ecological and conventional methods (often including integrated pest-management approaches)
Criteria	
Ecological Sustainability	Capacity of ecosystems (e.g. land, water, etc.) to maintain their essential functions, processes, and biodiversity over time, without deterioration (e.g. soil depletion; diminished quality; pollination; energy use effects) or contamination (e.g. toxic effects), including the ability to respond to changing weather/climate conditions
Crop Yield	Volume of crops that are produced and harvested (pounds per hectare)
Net Revenue	Amount of money crop generates ($/hectare)
Health Effects	Health issues for you, family members, and other workers as a result of exposure to toxic substances, work conditions, stress, etc.
Empowerment & Autonomy	Degree to which your choice of agricultural practices is within your control; and with access to supportive social networks (e.g. other producers, communities, organizations, and consumers) to further develop self-reliance, including the ability to respond to changing market conditions
Food Safety & Nutrition	Provides health benefits from blueberry consumption (e.g. antioxidant properties) without negative effects of residue (e.g. pesticide, fungus, other contaminants) that remains on the blueberries
Sub-Criteria for Ecological Sustainability	
Ecosystem Processes	Capacity of ecosystems (e.g. land, water, etc.) to maintain their essential functions and processes over time without deterioration (e.g. soil depletion and diminished quality; pollination; and energy use effects)
Resilience	Ability to respond to changing conditions (e.g. change in weather conditions)
Biosecurity	Contamination of the environment from air pollution, water pollution, as well as, biodiversity, including the genetic contamination of crops (e.g. from new weed species, diseases, etc.)

Appendix 4 – Questionnaire Session 2: Weighting Phase

University of British Columbia

Research Program:
Food systems and health equity in an era of globalization: Think, Eat and Grow Green Globally (TEG3)

<u>Title of Study:</u>

Multi-criteria decision analysis (MCDA) comparing agricultural production methods: Protocol analyzing British Columbia blueberries

Research Investigators:

Co-Investigator	Rami El-Sayegh	UBC - SPPH
Co-Investigator	Jerry Spiegel	UBC - SPPH
Co-Investigator	Craig Mitton	UBC – SPPH

Description of Study:

The purpose of this study is to examine different types of agricultural production methods to assess various criteria in the context of blueberries in British Columbia. This study aims to understand the decision-making process of growers and determine the most important factors or criteria for growers when making decisions. The objective of this study is to also understand the constraints put on growers' decision-making, as well as what can be done to limit these constraints. This work seeks to provide a case for a transparent and comprehensive process to decision-making known as multi-criteria decision analysis (MCDA), which has the potential to better advocate for grower preferences and perspectives to guide agricultural production policy.

Description of Questionnaire

This questionnaire is a component of the final two phases of this study. In the first phase we determined the criteria/factors that the participants of the study (the growers) determined to be most important in their decision-making process. These criteria/factors will be weighed in order to determine a ranking for their importance. This is followed by the scoring of each agricultural method (conventional, ecological/organic, and mixed-methods) against each criterion.

After discussing with all the growers participating in this study, by aggregate, the criteria that were determined to be the most important are: ecological sustainability, crop yield, gross revenue, health effects (to growers, workers, family, and community), empowerment and autonomy, and food safety and nutrition (for consumers).

In this questionnaire, you will be doing pairwise comparisons (i.e. comparing every criterion pair once on a scale of 1-9) to determine the ranking of importance. You will then answer specific questions related to each criterion so that we can get measurements and values in order for you to score the agricultural production methods against each criterion in the final phase.

Breakdown of Questionnaire

This survey consists of four parts:

1) Answering general questions related to you and your farm
    a. About you
    b. About the farm
2) Weighing of the criteria through pairwise comparisons using a scale of 1-9
3) Answering questions related to your farming practices and the criteria determined in phase 1 of this study
4) Answering questions related to costs

Participant #: __________

Part 1: General Questions

Part 1A: General questions about you

Age	
Sex	
Years on farm	
Years in blueberry farming	
Role	Owner / Operator / Manager / Worker / Other / All

Part 1B: General questions about farm

1) What land tenure system applies to your farm?
   1. Own (mortgage paid)
   2. Own (with mortgage)
   3. Share
   4. Lease
   5. Other

2) Total acreage of property?
   2.1. 2017: _______
   2.2. 2016: _______
   2.3. 2015: _______

3) How many acres of blueberries?
   3.1. 2017: _______
   3.2. 2016: _______
   3.3. 2015: _______

4) Type of blueberry
   a) What blueberry variety do you grow?
   0=DOES NOT GROW; 1=GROWS
   4.1. Aurora
   4.2. Bluecrop
   4.3. Brigitta
   4.4. Duke
   4.5. Draper
   4.6. Elliot
   4.7. Hardyblue
   4.8. Liberty
   4.9. Northland
   4.10. Rancocas
   4.11. Reka
   4.12. Spartan
   4.13. Other: _______

b) Why?

5) Type of farming? What Type of farming do you practice?

1. Conventional
2. Mixed-methods
3. Ecological or Organic

a) Is this your preference? YES NO

6) Can you explain your method (i.e. pest-management strategy)?

7) Crop picking strategy

a) What percentage do you employ the following crop picking strategies?

7a.1 Handpicking: _______

7a.2 Machine picking: ________

b) Is this your preference? YES NO

8) What third-party certifications do you have, if any?

9) How many people work on the farm?

9.1. Year-round full-time:
9.2. Year-round part-time:
9.3. Seasonal full-time:
9.4. Seasonal part-time:
9.5. Seasonal Agricultural Worker Program (SAWP):
9.6. Family labour:
9.7. Volunteers:

10) What are your [owner/operator] work hours per week?

11) Hiring

a) Do you have difficulty hiring employees? YES NO

b) Why or why not?

12) Other employment

a) Do you work another job? YES NO

b) Is this for necessity to support farm, or desire?

1. Necessity (support farm)
2. Desire
3. Necessity & Desire

13) Other Comments

Part 2: Weighing of Criteria

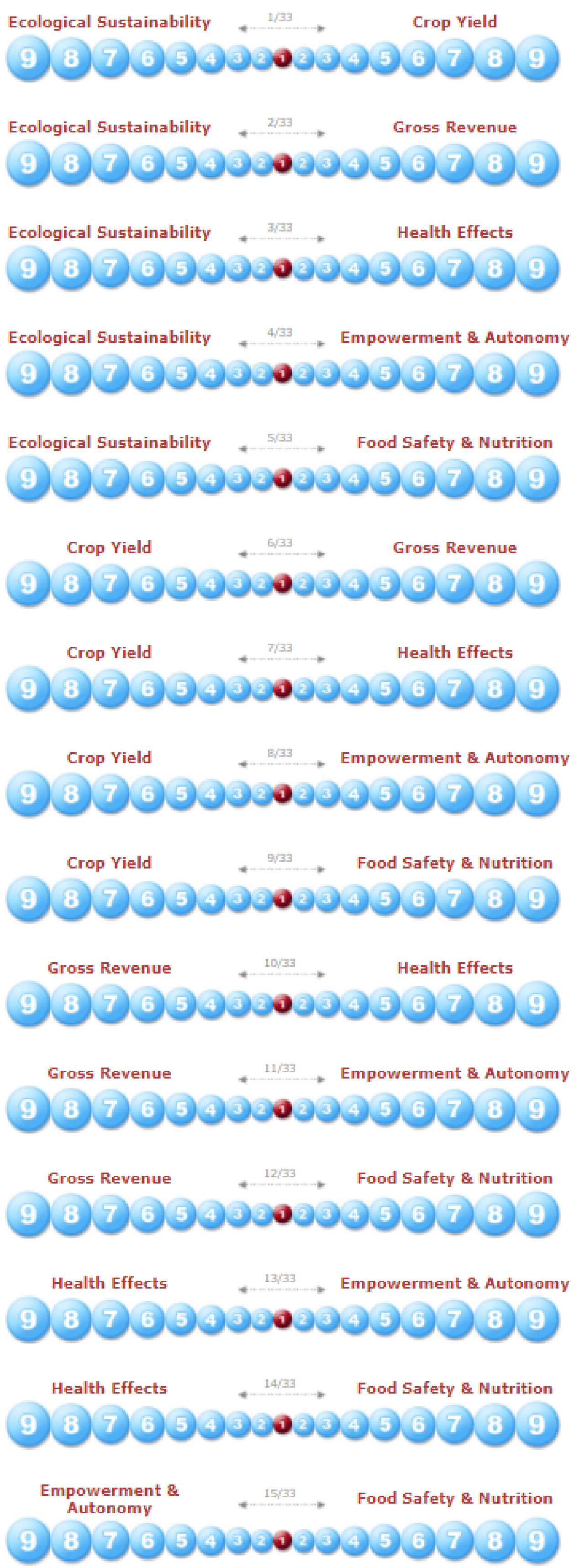
Part 2A: Criteria Preferences/Importance Ranking

In this section you will determine, through pairwise comparisons, which criteria are the most important to you. For each comparison, you will pick the one that is most important to you and rate the degree of its comparative importance on a scale of 1-9. See below for guidance on the rating scale.

Degree of Importance	Definition
1	Equally important
3	Moderately important
5	Strongly important
7	Very strongly important
9	As important as possible
2, 4, 6, 8	Intermediate values

A table of definitions for each criterion is provided below. These definitions were developed from discussions with study participants in the study's first phase.

Criteria	Definitions
Ecological Sustainability	Capacity of ecosystems (e.g. land, water, etc.) to maintain their essential functions, processes, and bio-diversity over time, without deterioration (e.g. soil depletion; diminished quality; pollination; energy use effects) or contamination (e.g. toxic effects), including the ability to respond to changing weather/climate conditions
Crop Yield	Volume of crops that are produced and harvested (pounds per acre)
Gross Revenue	Amount of money crop generates ($ per acre)
Health Effects	Health issues for you, family members, and other workers as a result of exposure to toxic substances, work conditions, stress, etc.
Empowerment & Autonomy	Degree to which your choice of agricultural practices is within your control; and with access to supportive social networks (e.g. other producers, communities, organizations, and consumers) to further develop self-reliance, including the ability to respond to changing market conditions
Food Safety & Nutrition	Provision of health benefits from blueberry consumption (e.g. antioxidant properties) without negative effects from production practices, handling, preparation and storage of food, in ways that prevent food-borne illness (e.g. from pesticide, fungus, other contaminants)


Ecological Sustainability
1/33
Crop Yield
Ecological Sustainability
2/33
Gross Revenue
Ecological Sustainability
3/33
Health Effects
Ecological Sustainability
4/33
Empowerment & Autonomy
Ecological Sustainability
5/33
Food Safety & Nutrition
Crop Yield
6/33
Gross Revenue
Crop Yield
7/33
Health Effects
Crop Yield
8/33
Empowerment & Autonomy
Crop Yield
9/33
Food Safety & Nutrition
Gross Revenue
10/33
Health Effects
Gross Revenue
11/33
Empowerment & Autonomy
Gross Revenue
12/33
Food Safety & Nutrition
Health Effects
13/33
Empowerment & Autonomy
Health Effects
14/33
Food Safety & Nutrition
Empowerment & Autonomy
15/33
Food Safety & Nutrition

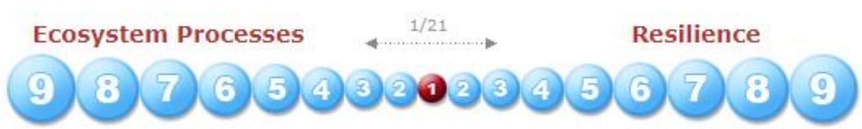
Part 2B: Ranking of Sub-criteria for Ecological Sustainability

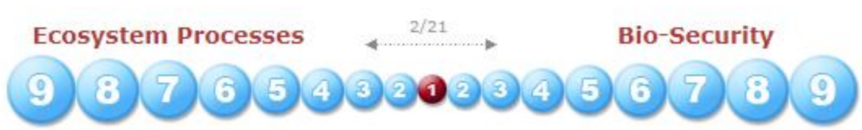
In this section you will determine, through pairwise comparisons, which elements of ecological sustainability are most important to you. For each comparison, you will pick the one that is most important to you and rate the degree of its comparative importance on a scale of 1-9. The same rating scale as above is going to be used (shown again below).

Degree of Importance	Definition
1	Equally important
3	Moderately important
5	Strongly important
7	Very strongly important
9	As important as possible
2, 4, 6, 8	Intermediate values

A table of definitions for each sub-criterion for ecological sustainability is provided below. These definitions were developed from discussion with study participants in the study's first phase.

Criteria	Definition
Ecosystem Processes	Capacity of ecosystems (e.g. land, water, etc.) to maintain their essential functions and processes over time without deterioration (e.g. soil depletion and diminished quality; pollination; and energy use effects)
Resilience	Ability to respond beneficially to changing conditions (e.g. change in weather conditions)
Bio-Security	Management practices designed to reduce the introduction of pests onto a farm and to minimize their spread within the farm and beyond





<u>Part 3: Questions Related to Criteria</u>

Part 3A: Ecological Sustainability

Ecosystem Processes

1) Satisfaction that the practices you apply contribute to ecological sustainability

1. Very Dissatisfied
2. Dissatisfied
3. Satisfied
4. Very Satisfied

2) Do you use the following practices related to soil quality (i.e. soil fertility, restoration, erosion, etc.)? And to what extent do you employ these (for each) (frequency)?

Practice	Extent				Comments
	Regularly (at least every year) (3)	Some of the time (every few years) (2)	Not usually (1)	N/A (99)	
2a. Compost green waste					
2b. Plant N-fixing legumes					
2c. Crop rotation					
2d. Intercropping					
2e. Green manures/plough-ins					
2f. Windbreaks or Shelterbelts					
2g. Buffer zone or strip					
2h. Mulching					
2i. Other: ___________					

3) Soil nutrient levels:

a) Do you know what the nutrient levels in the soil are (N and P)?

1. Do NOT know
2. Know

b) What are the nutrient levels in the soil (N and P)?

4) IPM techniques:

a) To what degree do you use IPM techniques?

1. Never
2. Seldomly
3. Sometimes
4. Often
5. Always
6. Not applicable

b) Techniques : __________________

5) How often do you apply synthetic pesticides?

1. Frequent or liberal
2. Somewhat frequent (following the instructions)
3. As needed sparingly in minimal concentrations
4. Only as last resort
5. Never

6) How often do you apply organic control methods?

1. Frequent or liberal
2. Somewhat frequent (following the instructions)
3. As needed sparingly in minimal concentrations
4. Only as last resort
5. Never

7) How many kg per acre of pesticides do you apply? _________

8) Do you perceive there is pesticide resistance, which requires a heavier dosage or has cause a lack of efficacy of pesticides over time?

1. Much worse
2. Somewhat worse
3. About the same
4. Somewhat better
5. Much better

Resilience

1) **Measures of landscape diversity, vegetation cover, or other adaptation measures**
   a) **Do you apply methods or have unmanaged land (e.g. forests or pastures) on or adjacent to your land that provide protection against bad weather?**
      1. Not at all
      2. Not much
      3. More or less
      4. A bit
      5. A lot
   b) **Identify any: _________________**

2) **How concerned are you that changes in climate and weather will cause you to modify your agricultural practices?**
      1. Not at all
      2. Not much
      3. More or less
      4. A bit
      5. A lot

Biosecurity

1) Perception of biodiversity change over time

	A lot Higher (5)	Higher (4)	About the Same (3)	Lower (2)	A lot Lower (1)	Comments
1a. Bird Species						
1b. Insects						
1c. Animals						
1d. Bees/pollinators						
1e. Plants						

2) Perception of contamination

	A lot Higher	Higher	About the Same	A lot Lower	Lower	Comments/Cause of Contamination
2a. Water Contamination						
2b. Air contamination/ pollution						

3) Diversity in crops

a) How many other different crop species do you grow?

1. 1 crop
2. 2-3 crops
3. 4 or more crops

b) Please list and provide proportion of total crop

4) Other Comments for all Ecological sustainability sub-criteria

Part 3B: Crop Yield

1) **How many blueberries did you yield last year and the last three years (in pounds)?**

	2017	**2016**	**2015**
1.1. Harvested			
1.2. Harvested but wasted			
1.3. Total produced including not harvested			
1.4. Harvested but rejected			
1.5. TOTAL Produced			

2) **Satisfaction with your yields?**
    1. Very Dissatisfied
    2. Dissatisfied
    3. Satisfied
    4. Very Satisfied

3) **Other comments about yields (are trends of last three years in line with your perception of trends (i.e. how you see your yields)**

Part 3C: Gross Revenue

1) **How much money did your blueberry crop produce in revenue last year and the last 3 years?**
    1.1. 2017: ______
    1.2. 2016: ______
    1.3. 2015: ______

2) **Satisfaction with your revenue**
    1. Very Dissatisfied
    2. Dissatisfied
    3. Satisfied
    4. Very Satisfied

3) **What proportion of your income is achieved through agriculture? _________**

4) ***For organic growers:* what is your perception of price premiums contributing to your revenues?**
    1. Very inadequate
    2. Inadequate
    3. About right
    4. Somewhat Adequate
    5. Very Adequate
    99. Not Applicable (NA)

5) ***For conventional and mixed-method growers* – what is your perception of the price premiums in place for organically grown blueberries**
    1. Very inadequate
    2. Inadequate
    3. About right
    4. Somewhat Adequate
    5. Very Adequate
    99. Not Applicable (NA)

6) **Other comments about gross revenue (are trends of last three years in line with your perception of trends (i.e. how you see your gross revenue)**

Part 3D: Health Effects

1) **In general, how would you rate your physical health?**
    1. Poor
    2. Fair
    3. Good
    4. Very Good
    5. Excellent

2) **In general, how would you rate your emotional/mental health?**
    1. Poor
    2. Fair
    3. Good
    4. Very Good
    5. Excellent

3) **Do you or others on the farm have any of the following conditions:**
    a) **Asthma, diabetes, arthritis, hearing impairments, ulcers, foot problems, high blood pressure, heart disease, kidney disease, allergies, tuberculosis, UTI, CVD, stroke, migraines/headaches, hip fracture, other?**
        1. Not at all
        2. Some
        3. A lot
    b) **Specify: ___________**

4) **Pain or discomfort**
    a) **Do you or others on your farm experience pain/discomfort regularly that you think may be related to the work (e.g. working conditions, exposures, tasks)?**
        1. Not at all
        2. Some
        3. A lot
    b) **Describe:**

5) **Contamination/exposure health concerns [consumption]**
    a) **To your knowledge, have there been any cases where you, family, or workers have had any health concerns related to contamination/exposure to agro-chemicals, including through consumption of food and water?**
        - YES (1)   NO (0)
    b) **Approximately how many?**
    c) **Describe:**

6) **Work-related health and safety concerns**
   a) **To your knowledge, have there been any cases where you, family, or workers have had any injuries, or other health or safety concerns related to work on the farm?**
      - YES (1) NO (0)
   b) **Approximately how many?**
   c) **Describe:**

7) **How many days did employees miss on average per year due to pain/injury/illness?**
      - Approximate number of days:

8) **Do you and those working on your farm have access and training for Personal Protective Equipment?**
      1. No
      2. Provide
      3. Provide and train

9) **Working condition health satisfaction**
   a) **How satisfied are you with the healthiness of working conditions at your farm?**
      1. Very Dissatisfied
      2. Dissatisfied
      3. Satisfied
      4. Very Satisfied
   b) **What concerns? (if any)**

10) **Job satisfaction**
   a) **How satisfied are you with your job?**
      1. Very Dissatisfied
      2. Dissatisfied
      3. Satisfied
      4. Very Satisfied
   b) **What aspects?**

11) **Other comments about health effects?**

Part 3E: Autonomy & Empowerment

1) What is your level of satisfaction with your lifestyle, particularly with your family on the farm?

1. Very Dissatisfied
2. Dissatisfied
3. Satisfied
4. Very Satisfied

2) What is your level of perceived self-exploitation?

1. None
2. Very Low
3. Low
4. Medium
5. High
6. Very High

3) Financial assistance

a) Do you receive any financial assistance for production of crops?

1. Not receiving support (Adequate support not available)
2. Receiving some support (Support available not fully adequate)
3. Receiving support (Adequate)
4. Not receiving support (Adequate support available)

b) If so, from who? ___________________

c) If so, what kind? (e.g. grant, credit, infrastructure/tools, support/training, other)

4) Processor access

a) Do you have ADEQUATE access to processors (i.e. through contracts)?

1. Not at all
2. Could be better
3. Adequate
4. Marginally so
5. Very Much so

b) How satisfied are you with your sense of control with this arrangement?

1. Very Dissatisfied
2. Dissatisfied
3. Satisfied
4. Very Satisfied

5) **Knowledge/technical/information access**
   a) **How adequate is the access to knowledge/technical/information assistance from any organization?**
      1. Not at all
      2. Could be better
      3. Adequate
      4. Marginally so
      5. Very Much so
   b) **What organizations? ______________**

6) **How adequate is the passing down of social/cultural knowledge and practices for farming to the next generation?**
      1. Not at all
      2. Could be better
      3. Adequate
      4. Marginally so
      5. Very Much so

7) **Organizational support**
   a) **Do you feel that you have good support from organizations such as BC Blueberry Council and the Ministry?**
      1. Not at all
      2. Could be better
      3. Adequate
      4. Marginally so
      5. Very Much so
   b) **Why or why not?**

   c) **Do you feel excluded?**
      - YES (1)   NO (0)

8) **To what degree do you participate in activities dealing with issues relevant to you & your farm (e.g. with BC Blueberry Council and Ministry of Agriculture)?**
      1. None
      2. Very Low
      3. Low
      4. Medium
      5. High
      6. Very High

9) **Give an example of your participation**

10) How valuable to you is this participation?

1. None
2. Very Low
3. Low
4. Medium
5. High
6. Very High

11) Market access

a) What markets do you have access to? How do the proportions reflect your preferences?

Market type	**Proportion of Sales (%)**	**A lot less (1)**	**Little Less (2)**	**About right (3)**	**Little more (4)**	**A lot more (5)**
Internationally, through distributor						
Locally, direct to consumer						
Locally, direct to retailer						
Locally, through distributor						
Wholesaler						
Directly to packer/processor						
Other: ______________						

b) Why (e.g. better price, more reliable market, easier transport, other (specify))?

12) To what degree do you feel adequately empowered?

1. None
2. Very Low
3. Low
4. Medium
5. High
6. Very High

13) What is your perception of your connection with consumers?

1. Very Dissatisfied
2. Dissatisfied
3. Satisfied
4. Very Satisfied

14) Other comments about autonomy and empowerment

Part 3F: Food Safety & Nutrition

1) **How concerned are you about the traceability of products (e.g. from pesticides, fungus, etc.) and the adequacy of a formal traceability scheme (i.e. ability to trace product back to the place of origin with possible food safety issues)?**
    1. No Concern (system inadequate)
    2. No Concern (not aware)
    3. Concern (not aware)
    4. Concern (system inadequate)
    5. No Concern (system adequate)

2) **What percentage of your crop is rejected due to pesticide residue, fungus, or pests?**

	Percent Rejected
Pesticide Residue	
Fungus	
Pests	
Other	

3) **How important do you think the nutrition of blueberries is to your business model?**
    1. Very Unimportant
    2. Unimportant
    3. Important
    4. Very Important

4) **Other Comments about food safety and nutrition?**

Part 4: Questions Related to Costs

1) Costs

<table>
<tr><th>Cost Type</th><th>Cost Amount on average per year ($)</th></tr>
<tr><td>Land</td><td></td></tr>
<tr><td>Labour</td><td></td></tr>
<tr><td>Inputs (i.e. agrotoxins)</td><td>
<table>
<tr><th>Input</th><th>Cost Amount on average per year ($)</th></tr>
<tr><td>Pesticides</td><td></td></tr>
<tr><td>Fungicides</td><td></td></tr>
<tr><td>Fertilizers</td><td></td></tr>
<tr><td>Machinery</td><td></td></tr>
<tr><td>Equipment</td><td></td></tr>
<tr><td>Other</td><td></td></tr>
</table>
</td></tr>
<tr><td>Certifications</td><td></td></tr>
<tr><td>Transportation (selling/shipping product)</td><td></td></tr>
<tr><td>Marketing</td><td></td></tr>
<tr><td>Health care and insurance for yourself and employees?</td><td></td></tr>
<tr><td>Safety and protection</td><td></td></tr>
<tr><td>Administration</td><td></td></tr>
<tr><td>Depreciation</td><td></td></tr>
<tr><td>Waste management</td><td></td></tr>
<tr><td>Other</td><td></td></tr>
</table>

2) Other comments about costs

Appendix 5 – Questionnaire – Session 3

University of British Columbia

Research Program:
Food systems and health equity in an era of globalization: Think, Eat and Grow Green Globally (TEG3)

Title of Study:

Multi-criteria decision analysis (MCDA) comparing agricultural production methods: Protocol analyzing British Columbia blueberries

Research Investigators:

Co-Investigator	Rami El-Sayegh	UBC - SPPH
Co-Investigator	Jerry Spiegel	UBC - SPPH
Co-Investigator	Craig Mitton	UBC – SPPH

Description of Study:

The purpose of this study is to examine different types of agricultural production methods to assess various criteria in the context of blueberries in British Columbia. This study aims to understand the decision-making process of growers and determine what the most important factors or criteria for growers when making decisions. The objective of this study is to also understand the constraints put on growers' decision-making, as well as what can be done to limit these constraints. This work seeks to provide a case for a transparent and comprehensive process to decision-making known as multi-criteria decision analysis (MCDA), which has the potential to better advocate for grower preferences and perspectives to guide agricultural production policy.

Description of Questionnaire

This questionnaire is the final of the three phases of this study. In the first phase we determined the criteria/factors that the participants of the study (the growers) determined to be most important in their decision-making process. In the second phase, these criteria/factors were weighed through pairwise comparisons to determine a ranking of their importance. Six criteria, and three sub-criteria were determined to be the most important: ecological sustainability (sub-criteria: ecological processes, resilience, bio-security), crop yield, gross revenue, health effects (to growers, workers, family, and community), empowerment and autonomy, and food safety and nutrition (for consumers).

In this final phase, you will be scoring your farming method based on a rating scale of 0 to 3. In other words, 'how would you rate the performance of your farming method for each criterion on the 0 to 3 scale provided'? This score, along with the criteria weights established in the previous phase, will provide aggregate scores that will be compared against the costs that were provided in the previous phase.

This will reveal which method aligns with your *preferences*. Lastly, you will be asked some additional questions about your practice considering these results, costs and other constraints, ideas on how to limit these constraints to allow you to practice more to your preferences, and the feasibility of MCDA in agricultural policy.

Breakdown of Questionnaire

Before this session:

- Defined the criteria and alternatives (Phase 1)
- Conducted pairwise comparisons of criteria to provide weights for the criteria (Phase 2)
- Conducted pairwise comparisons of sub-criteria of Ecological Sustainability to provide weights for the sub-criteria (Phase 2)
- Provided costs associated with your farming practice (Phase 2)
- Pairwise comparisons provided an order of importance for the criteria (weighted out of 100%) (Phase 2)

During this session:

- Score your farming method (conventional, mixed-methods, organic/ecological) on the rating scale (from 0 to 3) for each criterion
- Aggregate the weighted scores from all participants and construct a 'cost-benefit ratio' which is calculated from the aggregate scores over the costs provided in previous phase

Next and final session:

- You will be told of these results, and you will provide me with final feedback with regards to your thoughts on the results (i.e. is it reflective of your preferences)
- Questions about policy or other instruments to get you to practice more towards your preferences
- Questions about study feasability (i.e. how can methodology of study be improved)

Participant #: __________

Refresh of Definitions

Terms	Definitions
Alternatives	
Conventional	Agricultural, often monoculture, systems (large as well as small scale), that include inputs of synthetic fertilizers and pesticides to produce their crop and counteract pest and disease stresses
Organic/Ecological	Practice of applying ecological concepts, principles and knowledge to the design and management of sustainable farming to produce their crop and counteract and control pest and disease problems (*organic certification required for farms using the term organic*)
Mixed-methods	Mixes both ecological and conventional methods (often including integrated pest-management approaches)
Criteria	
Ecological Sustainability	Capacity of ecosystems (e.g. land, water, etc.) to maintain their essential functions, processes, and bio-diversity over time, without deterioration (e.g. soil depletion; diminished quality; pollination; energy use effects) or contamination (e.g. toxic effects), including the ability to respond to changing weather/climate conditions
Crop Yield	Volume of crops that are produced and harvested (pounds per acre)
Gross Revenue	Amount of money crop generates ($ per acre)
Health Effects	Health issues for you, family members, and other workers as a result of exposure to toxic substances, work conditions, stress, etc.
Empowerment & Autonomy	Degree to which your choice of agricultural practices is within your control; and with access to supportive social networks (e.g. other producers, communities, organizations, and consumers) to further develop self-reliance, including the ability to respond to changing market conditions
Food Safety & Nutrition	Provision of health benefits from blueberry consumption (e.g. antioxidant properties) without negative effects from production practices, handling, preparation and storage of food, in ways that prevent food-borne illness (e.g. from pesticide, fungus, other contaminants)
Sub-Criteria for Ecological Sustainability	
Ecosystem process	Capacity of ecosystems (e.g. land, water, etc.) to maintain their essential functions and processes over time without deterioration (e.g. soil depletion and diminished quality; pollination; and energy use effects)
Resilience	Ability to respond beneficially to changing conditions (e.g. change in weather conditions)
Biosecurity	Management practices designed to reduce the introduction of pests onto a farm and to minimize their spread within the farm and beyond

Results of session 2 – Criteria Weights

Criteria	Criteria Weights	Criteria Weights (%)
Gross Revenue	0.2677	26.77%
Crop Yield	0.2464	24.64%
Food Safety & Nutrition	0.1692	16.92%
Health Effects	0.1579	15.79%
Ecological Sustainability	0.0874	8.74%
Ecosystem Processes	0.0437	4.37%
Resilience	0.0247	2.47%
Biosecurity	0.0189	1.89%
Empowerment & Autonomy	0.0713	7.13%

Instructions for this Session – Role of Participants

- For each criterion, you will provide a number between 0 and 3 based on the rating scale. This number is the score for your production method for the criterion being assessed (i.e. how would you rate the performance of your farming method for each criterion on the 0-3 scale provided?)
- Provide any reasoning or comments if you see fit for your score selections

CRITERIA	DEFINITION	WEIGHT	RATING				Notes on interpretation		
			0	1	2	3		Raw Score	Weighted Score
Ecological Sustainability	Capacity of ecosystems (e.g. land, water, etc.) to maintain their essential functions, processes, and bio-diversity over time, without deterioration (e.g. soil depletion; diminished quality; pollination; energy use effects) or contamination (e.g. toxic effects), including the ability to respond to changing weather/climate conditions	0.0874							
Ecosystem Processes	Capacity of ecosystems (e.g. land, water, etc.) to maintain their essential functions and processes over time without deterioration (e.g. soil function, abundance of beneficial organisms, and energy use effects)	0.0437	Concerned with deterioration - concern that ecosystems have **deteriorated** (i.e. reduced soil quality and reduced beneficial organisms, and **heavy** reliance on inputs)	Maintained with attention - ecosystems have begun to show **signs of deterioration** (i.e. reduced soil quality and beneficial organisms, and **moderate** reliance on inputs)	Sustainabily maintained - ecosystems have **remained the same** over time due to farming practices (i.e. stable soil quality, and **some** reliance on inputs)	Enhance - ecosystems have been **enhanced** over time due to farming practices (i.e. enhanced soil quality, and **little to no** reliance on inputs)		0	0
Resilience	Ability to respond beneficially to changing conditions (e.g. change in weather conditions)	0.0247	Not confident - Your farm **does not have** the qualities needed to respond or adapt to changing climate & weather conditions	Not very confident - Your farm has **some** of the qualities needed to **adequately/sufficiently** respond or adapt to changing climate & weather conditions	Fairly condifent - your farm has the qualities needed to **adequately/sufficiently** respond or adapt to changing climate & weather conditions	Very confident - your farm has the qualities needed to **superbly** respond or adapt to changing climate & weather conditions		0	0
Bio-Security	Management practices designed to reduce the introduction of pests onto a farm and to minimize their spread within the farm and beyond	0.0189	**A lot of concern** that invasive pests could be introduced and spread within the farm and beyond (*and that* ***a lot of*** *toxic effects and uncertainties are being introduced to maintain pests and soil fertility*)	**Some concern** that invasive pests could be introduced and spread within the farm and beyond (*and that* ***moderate*** *toxic effects and uncertainties are being introduced to maintain pests and soil fertility*)	**Lower concern** that invasive pests could be introduced and spread within the farm and beyond (*and that* ***some*** *toxic effects or uncertainties are being introduced to maintain pests or soil fertility*)	**No concern at all** that invasive pests could be introduced and spread within the farm and beyond (*and* ***minimal*** *toxic effects or uncertainties are being introduced to maintain pests or soil fertility*)	Maintaining natural processes without introducing toxic effects that may be associated with degrees of harm or potentially toxic effects that bring uncertainty Address this question as if you were to assess farmers in general in your farming method	0	0
Crop Yield	Volume of crops that are produced and harvested (pounds per acre)	0.2464	<3,000	3,000 to 6,000	6,000 to 9,000	>9,000		0	0
Gross Revenue	Amount of money crop generates ($ per acre)	0.2677	<3,000	3,000 to 6,000	6,000 to 9,000	>9,000		0	0
Health Effects	Health issues for you, family members, and other workers as a result of exposure to toxic substances, work conditions, stress, etc.	0.1579	**Poor** - Self-rated health (physical, mental, etc.) is poor	**Fair** - Self-rated health (physical, mental, etc.) is fair	**Good** - Self-rated health (physical, mental, etc.) is good	**Excellent** - Self-rated health (physical, mental, etc.) is excellent		0	0
Empowerment & Autonomy	Degree to which your choice of agricultural practices is within your control; and with access to supportive social networks (e.g. other producers, communities, organizations, and consumers) to further develop self-reliance, including the ability to respond to changing market conditions	0.0713	**Very low** sense of control, **very little** access to supportive networks, **very high** degree of dependence	**Low** sense of control, **little** access to supportive networks, **high** degree of dependence	**High - High** sense of control, **high** access to supportive networks, **low** degree of dependence	**Very High - Very high** sense of control, **very high** access to supportive networks, **very low** degree of dependence		0	0
Food Safety & Nutrition	Provision of health benefits from blueberry consumption (e.g. antioxidant properties) without negative effects from production practices, handling, preparation and storage of food, in ways that prevent food-borne illness (e.g. from pesticide, fungus, other contaminants)	0.1692	**Very Dissatisfied** with food safety standards and nutrition of your product relative to blueberries grown in different production methods	**Dissatisfied** with food safety standards and nutrition of your product relative to blueberries grown in different production methods	**Satisfied** with food safety standards and nutrition of your product relative to blueberries grown in different production methods	**Very Satisfied** with food safety standards and nutrition of your product relative to blueberries grown in different production methods		0	0
									0

Appendix 6 – Concluding Session

University of British Columbia

Research Program:
Food systems and health equity in an era of globalization: Think, Eat and Grow Green Globally (TEG3)

Title of Study:

Multi-criteria decision analysis (MCDA) comparing agricultural production methods: Protocol analyzing British Columbia blueberries

Research Investigators:

Co-Investigator	Rami El-Sayegh	UBC - SPPH
Co-Investigator	Jerry Spiegel	UBC - SPPH
Co-Investigator	Craig Mitton	UBC – SPPH

Description of Study:

The purpose of this study is to examine different types of agricultural production methods to assess various criteria in the context of blueberries in British Columbia. This study aims to understand the decision-making process of growers and determine what the most important factors or criteria for growers when making decisions. The objective of this study is to also understand the constraints put on growers' decision-making, as well as what can be done to limit these constraints. This work seeks to provide a case for a transparent and comprehensive process to decision-making known as multi-criteria decision analysis (MCDA), which has the potential to better advocate for grower preferences and perspectives to guide agricultural production policy.

Description of Questionnaire

This is the conclusion of the data collection. In the first phase we determined the criteria/factors that the participants of the study (the growers) determined to be most important in their decision-making process. In the second phase, these criteria/factors were weighed through pairwise comparisons to determine a ranking of their importance. Six criteria, and three sub-criteria were determined to be the most important: ecological sustainability (sub-criteria: ecological processes, resilience, bio-security), crop yield, gross revenue, health effects (to growers, workers, family, and community), empowerment and autonomy, and food safety and nutrition (for consumers). In the final phase, you scored the performance of your farming method based on a rating scale of 0 to 3. This score, along with the criteria weights established in the second phase, provided aggregate scores that I then compared against the costs that were provided in the previous phase.

Therefore, in line with his, I am now revealing these results and will ask you some concluding questions about any final feedback from you with regards to these results and the study as a whole.

Breakdown of Questionnaire

This survey consists of two parts:

1) Revealing of results
    a. Recall: Criteria Weights
    b. Aggregate weights
    c. Average costs per acre
    d. Cost-benefit ratios
2) Concluding questions
    a. About the results
    b. About the study methodology

Participant #: ___________

Part 1: Results of Study

Table 1A: Recall Priority Weights of Criteria

Criteria	Criteria Weights
Gross Revenue	0.2677
Crop Yield	0.2464
Food Safety & Nutrition	0.1692
Health Effects	0.1579
Ecological Sustainability	0.0874
Ecosystem Processes	0.0437
Resilience	0.0247
Bio-Security	0.0189
Empowerment & Autonomy	0.0713

Recall: The criteria were weighted using pairwise comparisons and the order of importance of the criteria in the above table. These weights were used to calculate the aggregate weights (scores) of your farming method using a rating

Table 1B: Aggregate weights

Farming Method	Aggregate Weights (Score)
Organic	2.281
Mixed-Methods	2.617
Conventional	1.795

Mixed-methods has the highest aggregate weight, followed by organic/ecological, and then conventional. This means that based off results of the rating scale exercise in the previous session (i.e. your scoring of your farming methods performance, on a scale of 0-3, multiplied by the criteria weights, as seen in Table 1A), mixed-methods 'performs' the best followed by organic and then conventional.

Table 1C: Average Costs per Acre

Farming Method	Cost per acre (with land)	Cost per acre (without land)	Cost per acre (without Other*)	Cost per acre (without Other* and Land)
Organic	$10,833	$10,327	$9,882.07	$9,377.02
Mixed-Methods	$10,872	$9,846	$9,533.12	$8,507.48
Conventional	$6,681	$6,251	$5,096.48	$4,666.67

**Other: Certifications, transportation, marketing, health care and insurance, safety and protection, administration, depreciation, waste management, other*

Mixed-methods has the highest cost per acre, slightly higher than organic. However, organic has the highest cost per acre when subtracting land, other (as defined in table 1B), and other & land.

Table 1D: Cost-benefit ratios

Farming Method	Cost-benefit ratio (with land)	Cost-benefit ratio (without land)	Cost-benefit Ratio (without Other*)	Cost-benefit Ratio (without Other* and Land)
Organic	0.000211	0.000221	0.000231	0.000243
Mixed-Methods	0.000241	0.000266	0.000275	0.000308
Conventional	0.000269	0.000287	0.000352	0.000385

**Other: Certifications, transportation, marketing, health care and insurance, safety and protection, administration, depreciation, waste management, other*

After considering costs, the farming method with the best cost-benefit ratio is conventional, followed by mixed-methods, and then organic/ecological. This means that conventional is the 'preferred' farming method.

Remember, this was a feasibility study, so the number of growers interviewed was not high enough to generalize the results. That said, based on 8 growers (3 organic, 2 mixed-methods, and 3 conventional), these are the results. For example, one of the participants labour costs was eight times the cost of other growers in their growing method. By adjusting the labour cost, the results show that organic is the most preferred method. This demonstrates how sensitive the results are when there are so few participants.

One of the biggest objectives of this study is to see if multi-criteria decision analyses (MCDA) is feasible in agricultural settings. This introduces MCDA as a comprehensive and transparent tool to better advocate for patient preferences and perspectives in agricultural policymaking.

Finally, I ask you to answer a few questions to elaborate on these results and the MCDA methodology.

Part 2: Concluding Questions

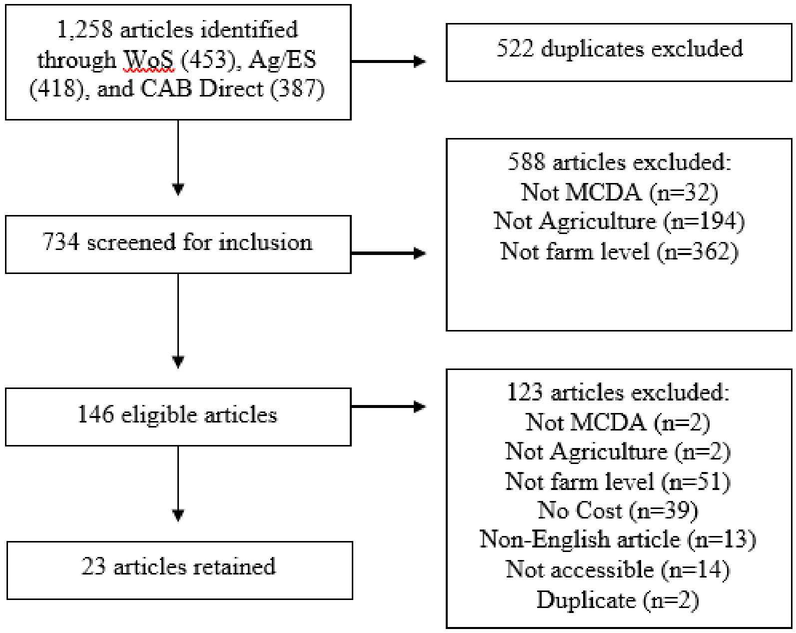
Concluding questions regarding results:

1) Do the results of the study reflect your preferences accurately?
2) Are you surprised by these results?
    a. Considering without costs, mixed-methods and organic are preferred over conventional?
    b. Considering with costs, conventional is rated higher than mixed-methods and organic?
3) What are the biggest constraints preventing you from practicing towards your preferences?
4) Do you feel that this tool has good potential to better reflect your preferences and perspectives in policy?
5) What policies, instruments, or tools do you think will help you practice more towards your preferences if you aren't already.
    a. Additionally, do you feel like the new trade agreement (re. NAFTA) has had an impact – this was a major concern for many of you at the beginning of this study.

Concluding questions about study and methodology?

6) How can this methodology be improved?
7) Do you feel that this tool has good potential to be applied more broadly for considering options that might suggest policy changes such as ways to support the meeting of certain criteria that are identified as important?
8) Final comments or suggestions…

Appendix 7 – PRISMA Diagram



Appendix 8 – Article Summary List

Author(s)/Year	Journal	Country	MCDA Technique	Decision/Application Area	Crop/Intervention	Cost Application	Health Considered
Bogdanović et al (2019)[208]	Ekonomika poljoprivrede	Serbia	AHP-NPV	Competitive Analysis	Maize, wheat, soybean, walnut, hazelnut, apple	CEA; NPV	No
Devatha et al (2019)[219]	Journal of the Saudi Society of Agricultural Sciences	India	SAW; WPM; TOPSIS; PROMETHEE	Crop Management	Mustard	Production/operation costs	No
Rocchi et al (2019)[227]	Journal of Cleaner Production	Italy	PROMETHEE	System sustainability	Poultry	Criteria	Yes
Troiano et al (2019)[209]	Ecological Indicators	Italy	MAVT	System Sustainability	Wild Rocket	Profitability; Production/operation costs	Indirectly
Crncan et al (2018)[210]	Spanish Journal of Agricultural Research	Croatia	AHP	System Sustainability	Table Eggs	Profitability	Indirectly
De Luca et al (2018)*[148]	International Society of Horticulture Science	Italy	AHP	Soil Management	Olives	NR	NR
Król et al (2018)[211]	Sustainability	Poland	PROMETHEE	System Sustainability	Maize	Profitability; Net income/Gross Margin	No
Ndwandwe et al (2018)[220]	Sustainability	Swaziland	AHP; SWOT	Competitive Analysis	Pig	Production/operation costs	Yes
Tran et al (2018)[212]	Agricultural Water Management	Vietnam	AHP	System Sustainability	Rice, vegetables, aquaculture	Profitability	No
Rozman et al (2017)[207]	Erwerbsobstbau	Western Balkans	DEXi	Crop Variety Selection	Plum	CEA; NPV; Production/operation costs	No

Azizi et al (2016)[221]	Socio-economic problems and the state	Iran	AHP	System Sustainability	Poplar	Production/operation costs	No
Emamzadeh et al (2016)[213]	Information processing in agriculture	Iran	AHP	System Sustainability	Cucumber	Net income/Gross Margin	No
Olveira et al (2016)[156]	Journal of Environmental Accounting and Management	Brazil	AHP	System Sustainability	Dairy	Production/operation costs	Yes
Palash et al (2016)[222]	Open Agriculture	Bangladesh	PROMETHEE	Crop Management	Rice, fish	Production/operation costs	No
Cobuloglu et al 2015[223]	Expert Systems with Applications	USA	SAHP	System Sustainability	Biomass	Production/operation costs	No
Carmona-Torres et al (2014)[224]	Agricultural Systems	Spain	ANP	Crop Management	Olives	Production/operation costs	No
Rozman et al (2013)[159]	Erwerbsobstbau	Slovenia	AHP	Pesticide Strategies	Apples	CBA	Indirectly
Chavez et al (2012)[214]	Thesis-Wageningen University	Netherlands	AHP	Diversification	Tobacco	Net income/gross margin	Indirectly
Rezaei-Moghaddam et al (2008)[217]	Environment, Development, and Sustainability	Iran	AHP	System Sustainability	Sustainable Agriculture Techniques/models	Profitability	Yes
van Calker et al (2008)[215]	Ecological Economics	Netherlands	MAUT; Linear Programming Model	System Sustainability	Dairy	Net income/gross margin; Production/operating costs	Yes
Masuda et al (2007)[216]	Thesis – University of Hawaii	USA	Multi-objective programming	System Sustainability	Coffee	Net income/gross margin;	Yes

						Production/operating costs	
Rozman et al (2006)[206]	Journal of Sustainable Agriculture	Slovenia	AHP	Competitive Analysis	Spelt Wheat	CEA	No
van Calker et al (2006)[218]	Ecological Economics	Netherlands	MAUT	System Sustainability	Dairy	Profitability	No