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Multi-Criteria Decision Analysis (MCDA) for Agricultural Sustainability Assessment

By

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DISSERTATION

Submitted to the Department of Geography, Faculty of Arts
in partial fulfillment of the requirements for
Doctor of Philosophy in Environmental Resource Management
Wilfrid Laurier University

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Originality statement

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Abstract

Multi Attribute Utility Theory (MAUT), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) and Elimination methods of Multi-Criteria Decision analysis (MCDA) are tested to assess and compare the sustainability of different agricultural systems. Indicators and composite indicators are derived from data gathered using the agricultural sustainability categories of Productivity, Stability, Efficiency, Durability, Compatibility and Equity (PSEDCE).

Agricultural systems around the world face challenges from current agricultural practices, over-exploitation of natural resources, population growth and climate change. As a result, understanding agricultural sustainability has become a global issue. Assessment is a first step in benchmarking and tracking agricultural sustainability and can support related policy and programmes. This thesis applied the PSEDCE categories to understand more about the complexities inherent to agricultural sustainability assessment.

Agricultural sustainability assessment (ASA) requires a wide variety of ecological, economic and social information with various methods. In the first part of this thesis, a systematic analysis of the scientific soundness and user-friendliness of eight ASA approaches revealed that MCDA based ASA is the preferred holistic method. MCDA can take into account both qualitative and quantitative indicators of all dimensions of sustainability and analyze them to draw a comprehensive picture. As a multifaceted, complex issue, agricultural sustainability assessment is well-suited to MCDA, which is able to handle large data sets including stakeholders' perspectives. Given that it is a relatively new analysis procedure in the study of agriculture, only a few researchers have applied this technique to measure sustainability. Considering these findings, three MCDA methods, MAUT, PROMETHEE and Elimination, were tested to measure the relative sustainability of five agricultural systems in coastal Bangladesh.

To investigate the performance of MAUT, PROMETHEE, and Elimination, a total of 50 indicators from agricultural sustainability categories of PSEDCE were tested. From these 50 indicators, 15 composite indicators were developed through proportionate normalization and hybrid aggregation rules of arithmetic mean and geometric mean. The 15 composite indicators were used in MAUT and PROMETHEE analysis, and the 50 indicators were used in Elimination analysis.

The analyses show that MAUT is able to aggregate diverse information and stakeholders' perspectives to generate a robust score that enables a comparison of sustainability across the different agricultural systems. PROMETHEE is a non-compensatory approach that can also accommodate a variety of information and provide thresholds for ranking relative agricultural sustainability for each of the five agricultural systems. Elimination ranks the sustainability of agricultural systems through a set of straightforward decision rules expressed in the form of "if … then …" conditions. Elimination appears to be quick and less complex, whereas MAUT and PROMETHEE are regarded as fairly complicated and require software to find potential solutions.

Overall, the study shows that MAUT, PROMETHEE and Elimination can handle multidimensional data and can be applied for relative assessment of sustainability of agricultural systems. However, selection of the appropriate criteria, stakeholders' perspectives and the purpose of the assessment are very important and must be considered carefully for inclusion in MCDA methods for agricultural sustainability assessment. The results of the case studies also demonstrate that these approaches have the potential to become a useful framework for agricultural sustainability assessment and related policy development and decision-making.

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I am eternally grateful to my supervisor, Dr. Alison Blay-Palmer, Associate Professor, Department of Geography and Environmental Studies, Wilfrid Laurier University. My thesis is the output of my perfect relationship with my supervisor. I can honestly say that Dr. Blay-Palmer has the best personality for generous, thoughtful, and dedicated mentoring that I have ever encountered in my life. She has been supportive in all stages of my research both technically and personally. She has allowed me to make independent decisions about my research and then given me a lot of feedback so that I can become a better independent researcher. I am grateful to her for providing me with the opportunity to have this rewarding research experience. I could not have completed my PhD without her encouragement, help, support and flexibility. I appreciate that I could share my doubts and problems about the research with her.

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I could not have completed this thesis without continuous love, affection and motivation from my family. I owe a debt to my parents, Partual Chandra Talukder and Milan Roy, and to my brothers and sisters. I would like to thank my great family for their unconditional support and encouragement throughout my studies. Most importantly, this research work is for two very special persons, my wife Soma Karmaker and daughter Purnata Talukder Tuli, who always inspired me with their ever-encouraging emotional support, cooperation and empathy. Thank you.

Byomkesh Talukder

Dedication

This dissertation is dedicated to my respected and loving elder brother, Dr. Talukder Prafulla Kumar, who was my childhood inspiration and motivational hero. From him I learned all the important life lessons and "we shall overcome" attitude. He has motivated me throughout my life to reach this stage. I also appreciate my parents' good wishes and good lessons for life. Their love and inspiration have motivated me to always work hard. I also appreciate the patience and understanding of my wife, Soma Karmaker, and my daughter, Purnata Talukder Tuli.

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Abbreviation

ADB	=	Asian Development Bank
ASA	=	Agricultural sustainability assessment
CBA	=	Cost Benefit Analysis
DFID	=	Department for International Development-UK
EC	=	European Commission
EESC	=	European Economic and Social Committee
EIA	=	Environmental Impact Assessment
EPI	=	Environmental Performance Index
FAO	=	Food and Agriculture Organization
FGD	=	Focus group discussions
GDP	=	Gross Domestic Product
GEM	=	Gender Empowerment Measure
GHG	=	Greenhouse gas
GIZ	=	Gesellschaft für Internationale Zusammenarbeit (German Federal Ministry for Economic Cooperation and Development)
HDI	=	Human Development Index
I	=	Prawn, rice and vegetable based-integrated agriculture systems
IAASTD	=	International Assessment of Agricultural Knowledge, Science and Technology for Development
IDEA	=	The IDEA Method
IFPRI	=	International Food Policy Research Institute
IPCC	=	Intergovernmental Panel on Climate Change
LCA	=	Life Cycle Analysis
MAUT	=	Multi-Attribute Utility Theory
MCDA	=	Multi Criteria Decision Analysis
MDG	=	Millennium Development Goals
MEA	=	Millennium Ecosystem Assessment
MESMIS	=	The MESMIS Program
MOTIFS	=	Monitoring Tool for Integrated Farm Sustainability
NGO	=	Non-Government Organization
OECD	=	Organisation for Economic Co-operation and Development
PROMETHEE	=	Preference Ranking Organization Method for Enrichment Evaluations
PSEDCE	=	Productivity-Stability-Efficiency-Durability-Compatibility-Equity
R	=	Improved methods based-rice systems (R)
RISE	=	Response-Inducing Sustainability Evaluation model
S	=	Shrimp-based agricultural systems
SAFA	=	Sustainability Assessment of Food and Agriculture Systems
SAFE	=	Sustainability Assessment of Farming and the Environment
SDG	=	Sustainable Development Goal

SEAMLESS	=	Integrated Assessment of Agricultural Systems: A Component-Based Framework for the European Union
SOS	=	Systems of Systems
SR	=	Shrimp and rice-based agricultural systems
T	=	Traditional methods based-agricultural systems (T)
TUG	=	TriUniversity (University of Guelph, University of Waterloo and Wilfrid Laurier University) Group of Libraries
UN	=	United Nations
UNDP	=	United Nations Development Programme
UNEP	=	United Nations Environment Programme
UNFCC	=	United Nations Framework Convention on Climate Change
UNSCD	=	United Nations Conference on Sustainable Development
USAID	=	United States Agency for International Development
WCED	=	World Commission on Environment and Development
WDR	=	World Development Report
WEF	=	World Economic Forum
WTO	=	World Trade Organization

Chapter One: Introduction

1.0 Introduction

This chapter outlines the purpose and rationale for this dissertation, followed by a conceptual overview of sustainability in general and agricultural sustainability specifically. After establishing the meaning of agricultural sustainability, the complexities in interpreting the concept of agricultural sustainability are described. Next, we explore the importance of agricultural sustainability assessment and the need for a holistic approach to capture the complexities of sustainable agriculture. The chapter concludes with a statement of research objectives.

1.1 Purpose and rationale

Agriculture began around 13,000 BC, when early humans started domesticating plants and animals to produce food (Diamond, 2002; Gupta, 2004). In preindustrial times, agriculture could not produce enough food. In this period, famine often occurred due to crop failure (WIT, 2008), such as in the case of the 1845-1849 potato famine in Ireland caused mainly by potato blight, the 1850-1873 famine in China partly caused by drought and the 1866 famine in India caused by limited rainfall. Between 1800-2000, food production increased (Federico, 2005). In the 1960s, an unprecedented increase in production of wheat, rice and other crops started in many parts of the world as part of a "Green Revolution" whose core features included high-yielding varieties and hybrids, the use of chemical fertilizers, pest control, heavy irrigation, and the application of improved agronomic practices (Conway & Barbier, 2013; Evenson & Gollin, 2003; Khush, 2001; Pretty, 2008; Sebby, 2010; Tilman et al., 2002).

People of the present world are better fed than in the past (Conway & Barbier, 2013; Federico, 2005). "World average per capita availability of food for direct human consumption, after allowing for waste, animal-feed and non-food uses, improved to 2,770 kcal/person/day in 2005/2007" (Alexandratos & Bruinsma, 2012:1). Despite this achievement, continuing vulnerability to food shortages (Huang et al., 2002) due to uneven productivity across crops and regions (Evenson & Gollin, 2003), loss or waste[1] of up to half of all grown food (Parfitt et al., 2010), uneven distribution, lack of access to land and poverty (Shapouri & Rosen, 1999) is still a common problem. Across the globe, there are differences in availability of an adequate, nutritious and culturally appropriate diet especially among resource-poor women, infants and children (Welch & Graham, 2000). "The latest available estimates indicate that about 795 million people in the world – just over one in nine – were undernourished in 2014–16" (FAO et al., 2015:8). Apart from this, periodic natural calamities and anthropogenic factors (i.e., war, politics and lack of logistics support) disrupt agriculture and distribution of food and result in famine and starvation in many parts of the globe (Barrett, 2010; Cribb, 2010; Sheu, 2007; vanLoon et al., 2005).

Agriculture was a critical component in the successful attainment of the Millennium Development Goals (MDGs)[2] (Rosegrant et al., 2006), specifically the first goal to reduce extreme poverty and hunger (FAO, 2010). Now, agriculture is also related to many Sustainable Development Goals (SDGs), such as ending poverty, zero hunger, sustainable consumption and production, and combating climate change. Sustainable agriculture is the main strategy to achieve agriculture-related SDGs (FAO, 2015). As a source of livelihood for an estimated 86% of rural people (WDR, 2008), agriculture is one of the largest and most important economic activities and has a significant impact on Gross Domestic Product (GDP) growth in developing countries (Asenso-Okyere et al.,

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[1] The amount of food lost or wasted is equivalent to more than half of the world's annual cereal crops. In 2009/2010 total 2.3 billion tonnes cereal was produced (Gustavsson et al., 2011).

[2] Millennium Development Goals: 1. Eradicate extreme poverty and hunger; 2. Achieve universal primary education; 3. Promote gender equality and empower women; 4. Reduce child mortality; 5. Improve maternal health; 6. Combat HIV/AIDS, malaria and other diseases; 7. Ensure environmental sustainability; 8. Develop a Global Partnership for Development (UN, 2013a)

2008). GDP growth from agriculture generates at least twice as much poverty reduction as any other sector (WDR, 2008). For example, a DFID (2005) study indicates that labour-intensive small-scale farming supports poverty reduction. According to the FAO (2012), the agriculture sector can play an essential role in a nation's resilience against global economic and financial turmoil, and it is often more effective in facing economic crisis than other sectors.

Agricultural systems are shaped by accumulated knowledge, technology (Byerlee et al., 2009; Sigrimis et al., 2001), integrated value chains, institutional innovations (Byerlee et al., 2009), globalization (Von Braun & Diaz-Bonilla, 2008) and physical, biological and cultural environments (Vasey, 2002). In return, agriculture has impacts on ecosystems as a result of land clearing, habitat fragmentation, alteration of ecosystems, desertification, soil erosion, eutrophication, and loss of biodiversity (Conway & Barbier, 2013; Dirzo & Raven, 2003; Fan et al., 2012; Federico, 2005; Rosset et al., 2000; Tilman et al., 2002; Vitousek et al., 1997). It pollutes ecosystems (Conway & Pretty, 2013; Diaz & Rosenberg., 2008) and affects human health (WHO, 1996) through agrochemicals, especially pesticides and fertilizers. About 70% of global fresh water is used in agriculture (WWAP, 2012). The agricultural sector contributes to climate change by producing up to 31% of global greenhouse gas (GHG) emissions (Burney et al., 2010; IPCC, 2007) and is also subject to climate change impacts in terms of its extent and productivity across the globe (Battisti & Naylor, 2009; Turral et al., 2011). However, agriculture also helps ecosystems through "regulation of soil and water quality, carbon sequestration and support for biodiversity" (Power, 2010:2959), and it can support cultural services and diversity (IAASTD, 2009; Power, 2010), local knowledge, traditional technologies, international trade and tourism (IAASTD, 2009).

Whatever the negative and positive impacts, agriculture will have to ensure a sufficient food supply for the present and future (vanLoon et al., 2005). Global crop production[3] needs to be doubled by 2050 in order to feed the growing population (Ray et al., 2013; Tilman et al., 2002) and tackle demand for biofuels[4] (Ray et al., 2013; Beddington, 2010). However, according to Maletta (2014), there is enough food and agricultural land in the world, so more land will not be required to grow more food. Crop production has to be sustainable (Horlings & Marsden, 2011; Tester & Langridge, 2010) to address climate change impacts (FAO, 2009; Hajkowicz et al., 2012), water scarcity (Fereres & Soriano, 2007; Giovannucci et al., 2012; Vorosmarty et al., 2000) and other challenges. Some improved techniques, including some versions of publically-funded cross-breed technology[5] (Huang et al., 2002) for drought (Hu & Xiong, 2014) and saline (Apse & Blumwald, 2002) tolerant crops, resilient and diverse production systems (Hajkowicz et al., 2012) and policy changes (Tilman et al., 2001), may increase production. However, ecosystems will remain impacted (Godfray et al., 2010), leaving the social, institutional and ecological components of agriculture vulnerable (Ericksen, 2008). The need for sustainable agriculture has been noted in many international meetings; for example, Agenda 21[6] (UN, 1992), the Rome Declaration on World Food Security[7] (1996), the Johannesburg Plan of Implementation[8] (2002) and RIO+20[9] (2012) address the significance of sustainable agriculture. The EU (2012) opined that sustainable agriculture

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[3] Nearly 2.5 billion tonnes of grain were produced around the world in 2013 (FAO, 2014).

[4] "From a sustainability perspective, biofuels offer both advantages (energy security, GHG reductions, reduced air pollution) and risks (intensive use of resources, monocultures, reduced biodiversity, and even higher GHGs through land use change)" (Elbehri et al, 2013: XIV). So, it can be argued that it should be food first and that land should not be used for biofuels.

[5] Here, cross-bred crops by improved technology are considered genetically engineered crops. The country that improves cross-breeding technology to create drought and saline tolerant crops will be the patent holder of the crops and the local communities of the country will benefit from this invention.

[6] Agenda 21 is an action of United Nations for sustainable development. It is non-binding and voluntary (UN, 1992).

[7] The main purpose of the World Food Summit of 1996 was to make a declaration to reduce the number of hungry people in the world by half in twenty years (FAO, 1998).

[8] The Johannesburg Plan of Implementation called for practical modalities and programmes of work on sustainable development (UN, 2003).

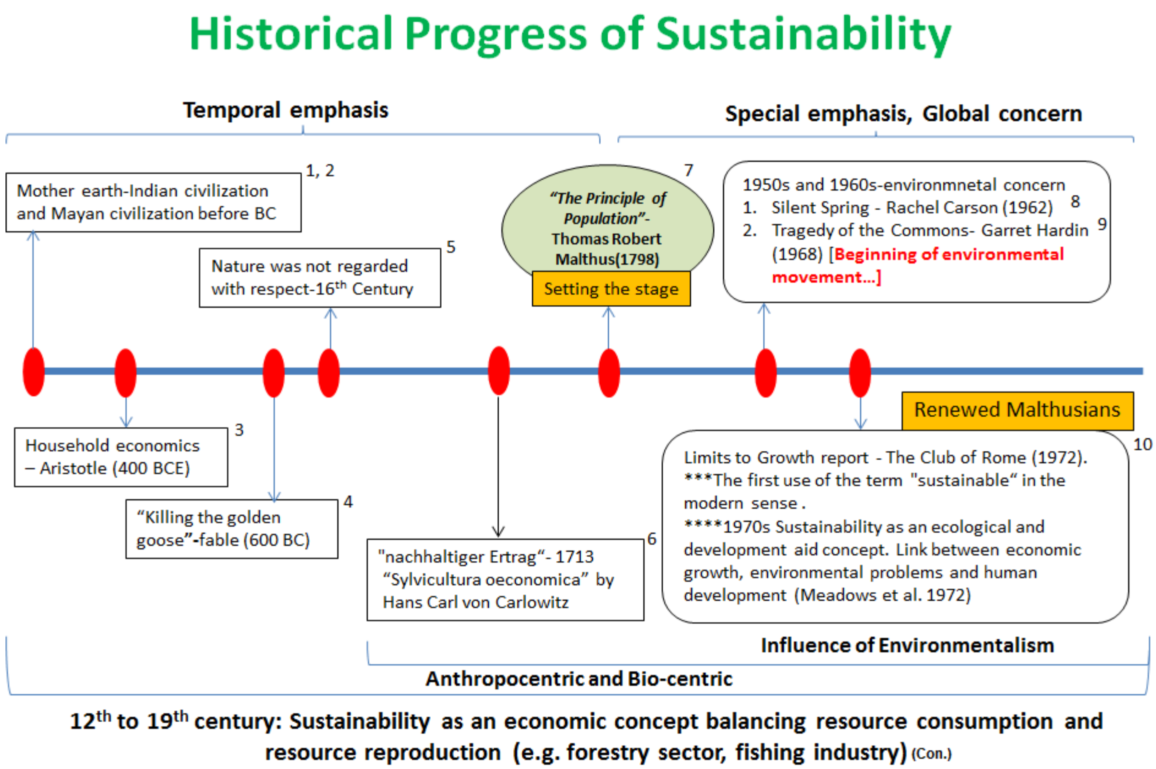
[9] Rio+20 is the third international conference on sustainable development aimed at reconciling the economic and environmental goals of the global community (UN, 2012).

combining environmental, economic and social issues can make a vital contribution to reducing poverty and ensuring food security.

Given the changing climate and environmental pressures, more widespread sustainable food systems approaches are needed (Pretty, 2008). Therefore, a key question is whether current agricultural practices can feed the growing population equitably, healthily and sustainably (Beddington, 2010). Important questions include: How can current and future agricultural practices be improved to make them more sustainable? What types of agricultural systems are sustainable? Can agriculture support a good life for producers and consumers? Can agriculture support sound ecosystems? These complex issues require equally complex and comprehensive responses (Godfray et al., 2010; Von Braun et al., 2008). Assessing agricultural sustainability at multiple scales, including at the farm, regional and national levels, is one of these responses.

1.2 What is sustainability?

Sustainability has become a leading concern among scholars, nations and international organizations (Drexhage & Murphy, 2010). A clear idea of the concept of sustainability is necessary to understand the issues of sustainability. The concept of sustainability began to appear in the 1960s after the publication of Rachel Carson's (1962) *Silent Spring* and Garrett Hardin's (1968) *The Tragedy of the Commons* (UNEP, 2002) as well as the occurrence of the UN Conference on Human Environment in Stockholm in 1972 (UN, 2009). The concept of sustainability has evolved into its present form influenced by many events related to environmental and human well-being. The key ideas, application of these ideas and events that have shaped the present form of the concept of sustainability are presented in Figure 1.1.



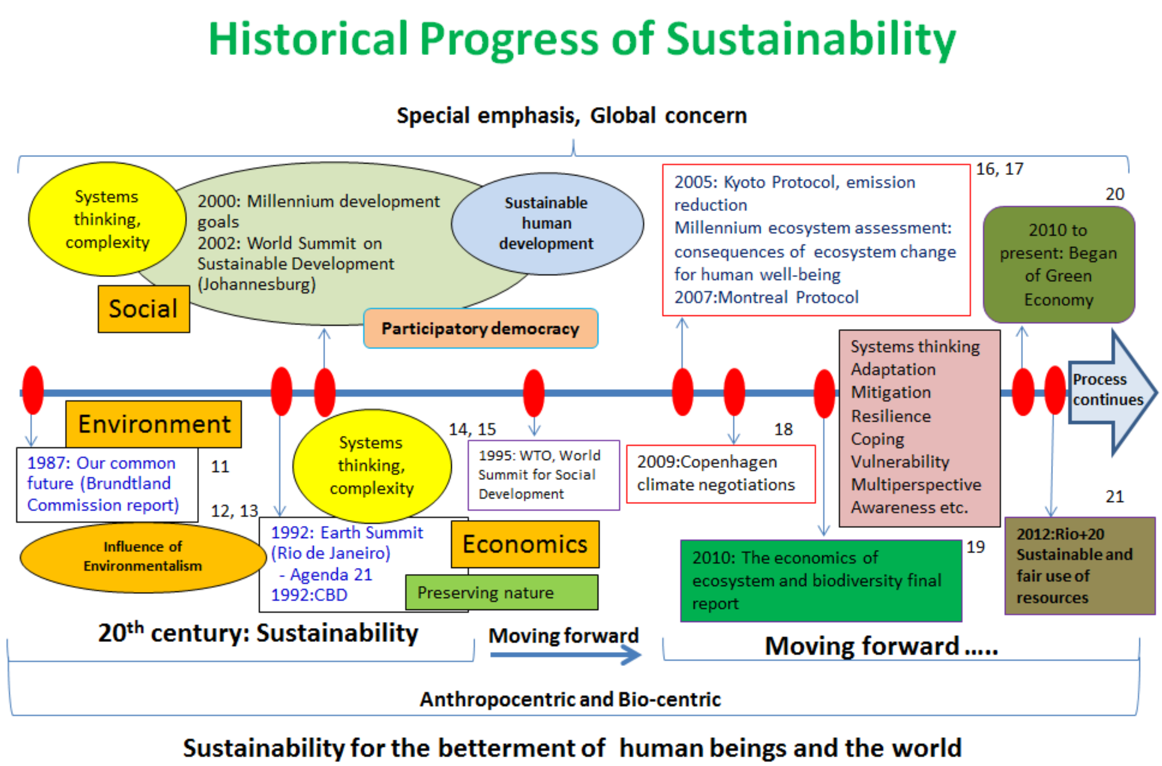


Figure 1.1: A brief overview of some factors influencing sustainability theory. Source: Adapted from [1]UN, 1992; [2]Carson, 1962; [3]EU, 2010; [4]Fash, 1994; [5]Gordon, 1993; [6]Grober, 2007; [7]Haigh, 2010; [8]Hardin, 1968; [9]Malthus, 1798; [10]Meadows et al., 1972; [11]Palme, 2011; [12]Pattberg, 2007; [13]UN, 1992b; [14]UN, 1995; [15]UN, 2013a; [16]UNSCD, 2012; [17]UNEP, 2007; [18]UNEP, 2011; [19]UNFCC, 2005; [20]UNFCC, 2009; [21]WCED, 1987; [22]WTO, 2011.

Sustainability can be defined as "development that meets the needs of current generations without compromising the ability of future generations to meet their needs" (WCED, 1987:43). This definition highlights the necessity of meeting the needs of both present and future generations within the scope of the present environment, technology and social organization (WCED, 1987). This concept leads us to think of the world as a system connected through space (van Zeijl-Rozema, 2011) and time (Sen, 2013; van Zeijl-Rozema, 2011). Although the essence of the concept is clear enough, the interpretation of sustainability has caused strong debates (Ciegis et al., 2009). For example, sustainability is explicitly considered anthropocentric because of its major focus on intergenerational equity (Kates et al., 2005) for ensuring the survival and comfort of humans now and in the future. It is also criticized as a political or normative rather than scientific concept (van Zeijl-Rozema, 2011) and there are divergent viewpoints (Aguirre, 2002) about how to apply it in practice (Sathaye et al., 2007). Based on the WCED's definition, many scholars and organizations have defined sustainability from different perspectives. For example, according to Briassoulis (2001:410), "sustainability can be conceptualized as a state of dynamic equilibrium between societal demand for a preferred development path and the supply of environmental and economic goods and services to meet this demand." The WCED (1987:46) described sustainability as "a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations."

Sustainability necessarily involves a comprehensive and integrated approach to economic, social, and environmental processes for well-being (Sathaye et al., 2007; Stevens, 2005; Tracey & Anne, 2008) and requires the participation of diverse stakeholders and perspectives to develop a mutual action plan for development (Kates et al., 2005). For some, this idea of sustainability suggests a need to adopt an integrated vision of social, economic and environmental development. Many other people argue that the whole “development” agenda is part of the problem and we need to think about things like “degrowth” (Jackson, 2011). Current sustainability initiatives consider how to integrate escalating public and governmental concerns about the environment, economics, climate change, the earth’s carrying capacity, industrial pollution, food security and safety, demographic issues, social inequality and other issues (Lubin & Esty, 2010; UN, 2012a). Sustainability includes the “principles of protecting nature, thinking long-term, understanding socio-ecological systems, recognizing limits, practicing fairness, and embracing creativity” (Susarla & Nazareth, 2007:10). Sustainability also maintains “adaptive capability” (Holling, 2001:390). It is a multi-dimensional concept encompassing environmental integrity, human rights and well-being, a resilient economy and transparent governance (FAO, 2013; Gibson, 2006). The integrative idea of sustainability combines a variety of sciences, interests and challenges (Gibson, 2006; Glomsaker, 2012). The actions needed to achieve sustainability vary depending on the challenges, goals and methods to achieve the goals and their connections with socio-ecological systems. Sustainability uses different theories/approaches depending on the situation to improve human well-being. Some of the influential theories and approaches are presented in Table 1.1.

Table 1.1: Theories/approaches to achieve sustainability

SP	Theory/Approach	Main Points/Issues	Timeline
Environmental sustainability	Resilience[11]	Adaptation and transformation of ecosystem	1990s-2000s
	Environmental Impact Assessment[17]	"Identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals" (IAIA, 1999:1)	1970s
	Risk Assessment[28]	Ecosystem change, biodiversity degradation, pollution	1990s
	Environmental Management System[27]	Developing, implementing and maintaining policy for environmental protection	1990s
	Life-Cycle Assessment[23]	"Material extraction and processing, manufacturing, distribution, use, repair and maintenance, disposal/recycling"	1960s
	Ecological Footprint[20]	Human demand on ecosystem, natural capital, ecological capacity	1990s
	Carbon Foot Printing[9]	Total greenhouse gas emissions, organization, event, product and person	1990s
	Water Foot Printing[9]	Production, water use, community, organization, agriculture	1990s
	Protection Area[7]	Natural, ecological and/or cultural values, biodiversity, ecosystem services	1960s
	Biodiversity Conservation[12]	Species protection, human development, environmental soundness, ecological process	1980s
	Millennium Ecosystem Assessment[16]	State of the Earth's ecosystems, functions, services, guidelines for decision-makers	2000s
	Pollution Control[29]	Contaminants, natural environment, adverse change (started after the ban on burning of sea-coal)	1970s
	Waste Management[10]	Environment, protection of environment, waste control, processing, reuse	1750s
Economic sustainability	Neoclassical Resource Economics[2]	Provides a variety of appropriate economic instruments for environmental protection	1970s
	Ecological Economics[6]	Addresses the interdependence and coevolution of human economies and natural ecosystems over time and space through various disciplines	1980s
	Capital Stock[14]	Natural capital and human-made capital, productivity	1990s
	Well-being[15]	Consumption, market goods and services, income, household and environmental services, non-market outcomes (such as social connectedness)	1990s-2000s
	Effectiveness of Market[15]	Price discrimination, welfare programs, government intervention, property rights	2000s
	Innovativeness[15]	Entrepreneurship	1990s-2000s
	Competitiveness[19]	Performance of a firm, sale and supply of goods and services, market	1990s
	Efficiency[18]	Use of resources, maximize the production of goods and services	1980s
	Network Economics[26]	Business economics that benefit from the network effect increase the value of a good or service	2000s
	Capability[25]	Capability of individuals related with political freedoms/civil rights, economic facilities, social opportunities, transparency guarantees and protective security	2000s
Social sustainability	Equity and Human Rights[1,24]	Poverty studies, unequal development and access to internationally defined rights	1980s
	Capital Stock[21,4]	Social capital, environmental capital equity	1980s
	Institutional Theory and Governance[3,5]	Participation and stakeholder analysis	1990s
	Business and Corporate Studies[8]	Triple bottom line, corporate social responsibility	1990s
	Behavioural and Social Sciences[13]	Well-being, health and happiness perspective	1990s
	Transition Theory[22]	Changes in nature, social institutions, social behaviours, social relations	2000s

Legend: SP = Sustainability pillars, Source: [1]Anand & Sen, 2000; [2]Baumol & Oates, 1971; [3]Chambers, 1992; [4]Colantonio, 2011; [5]Colantonio & Dixon, 2008; [6]Costanza, 2003; [7]Eagles et al., 2002; [8]Elkington, 2004; [9]Ercin & Hoekstra, 2012; [10]Herbert, 2009; [11]Holling, 1973; [12]IUCN, 1980; [13]Layard, 2005 & 2010; [14]Lerch & Nutzinger, 2002; [15]Markulev & Long, 2013; [16]MEA, 2005; [17]Ogola, 2007; [18]Pezzey & Toman, 2002; [19]Rennings, 2000; [20]Rees & Wackernagel, 1992; [21]Rees, 1996; [22]Rotmans et al., 2001; [23]SAIC & Curran, 2006:1; [24]Sen, 1985; [25]Sen, 1999; [26]Shapiro et al., 2004; [27]Tibor & Feldman, 1996; [28]UN, 1992; [29]Urbinato, 1994.

The idea of resilience offers a valuable balancing viewpoint for sustainability. “A resilience approach is that it develops adaptive capacity and/or robustness into the system so that the system can gracefully weather the inevitable, but unspecified, system shocks and stressors. Sustainability prioritizes outcomes; resilience prioritizes process” (Redman, 2014:37). Resilience was initially presented to define the perseverance of natural systems in the face of changes in ecosystem variables due to natural or anthropogenic causes (Holling, 1973). Different studies show the relationship between resilience and sustainability (Carpenter et al., 2001; Charles, 2004; Derissen et al., 2009; Folke et al., 2002; Holling & Walker, 2003; Perrings, 2006; Pisano, 2012; Tainter, 2006). According to Derissen et al. (2009) and Perrings (2006), the path of sustainability will not last long if it is not resilient. Folke et al. (2002) recognize resilience as an additional criterion for sustainability. In the literature, resilience is often observed in relation to “vulnerability, adaptation, adaptive capacity, transformability, and robustness” (Martin-Breen & Anderies, 2011:14).

Various models have been proposed for sustainability. Daly (1990) combines the 3E’s (Environment, Equity and Economy) into a sustainability model to simultaneously consider economic development, the conservation and restoration of the natural environment and enabling social equity. The popular model shown in Figure 1.2 includes the interaction among the three pillars of sustainability and recognizes the interdependence of environmental, economic and social systems (Spies, 2003). This model is a useful starting point to guide an assessment of sustainability concepts.

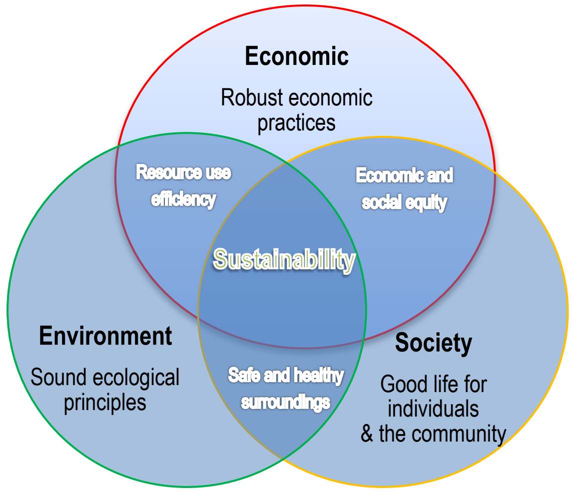


Figure 1.2: The sustainability tripod, showing interrelations between the components of environment, economy and society. Source: Adapted from vanLoon et al., 2005.

1.3 Agricultural sustainability

Since the 1960s, agriculture has been a central concern in sustainability because of its impacts on food production, its pervasive use of natural resources, and its effects on the environment (Bell & Morse, 2008). This concern led to the development of the idea of sustainable agriculture that first focused on the environmental dimensions and later expanded to include economic and broader social and political dimensions (DFID, 2003). Many studies (Allen et al., 1991; DFID, 2004; Godfray et al., 2010; Horrigan et al., 2002; Pretty et al., 2003; Pretty et al., 2006; Robertson & Swinton, 2005; Thrupp, 2000; Tilman et al., 2002; UNCSD, 2011; FAO, 2013) show that sustainable agriculture is able to meet present and future food demands through initiatives like reduced tillage (Lal, 1991), integrated pest management (IPM; Gurr et al., 2003), crop rotation (Caporali & Onnis, 1992), water management (Tilman et al., 2002), nutrient management, wild habitat enhancement, enhanced genetic resistance, diversification of farm enterprises, and improving community well-being (Jackson-Smith, 2010).

Agricultural sustainability includes the consideration of economic, social and environmental issues associated with agriculture (Nedea, 2012, Altieri, 1995; FAO, 1992; GIZ, 2012; Jackson-Smith, 2010; Pretty & Hine, 2001; Ross, 1995). Economic sustainability is related to the capacity of farmers to produce enough food to maintain the economic viability of agriculture and feed themselves and their community (Jackson-Smith, 2010; Pretty & Hine, 2001; Van Calker et al., 2008). Social sustainability refers to equity and quality of life for farmers, consumers, and members of the community (Jackson-Smith, 2010; Sydorovych & Wossink, 2007). Environmental sustainability includes the enhancement of the environmental quality of the landscape and natural resource base (Jackson-Smith, 2010; Pretty & Hine, 2001; Sydorovych & Wossink, 2007). Defining agricultural sustainability is an essential first step in setting out a broad vision[10] of its assessment and guides questions of sustainability (Jackson-Smith, 2010; Smith & McDonald, 1998; vanLoon et al., 2005; Van Cauwenbergh et al., 2007). With this in mind, agricultural sustainability is defined in this thesis as:

> Human activities to produce food and fiber in a manner that ensures the well-being of present and future communities without diminishing the surrounding ecosystems' capacity and ensuring environmental integrity, social well-being, resilient local economies and effective governance (FAO, 2013; Jackson-Smith, 2010; vanLoon et al., 2005).

1.4 Complexities in interpreting the concept of agricultural sustainability

Agricultural sustainability is a complex and dynamic concept (Blay-Palmer, 2010; Jackson-Smith, 2010) that is specific to time (Gomez-Limon & Riesgo, 2010) and space (Amekawa, 2010; Gomez-Limon & Riesgo, 2010), so its application is constantly being developed and enriched (Nedea,

[10] A broad vision of sustainability of any activities is necessary because of the intrinsically multifaceted, normative, subjective and unclear nature of sustainability (Kasemir et al., 2003).

2012). Achieving and maintaining environmental, economic and social sustainability simultaneously is not easy as different stakeholders emphasize different goals of sustainability (Jackson-Smith, 2010; Nedea, 2012) and there are different pathways to reach different goals (FAO, 2013). Agricultural sustainability depends on the interaction and robustness of these systems to be adaptive, keep evolving, remain functional, be resilient to stress (Darnhofer et al., 2010; Jackson-Smith, 2010), be productive, use resources efficiently and balance sustainability goals across all scales (Jackson-Smith, 2010). In this respect, systems thinking[11] is essential to understanding agricultural sustainability because it facilitates apprehending the consequences and interconnectedness of the different aspects of agricultural sustainability for both humans and nature (Levy et al., 1998; Lutteken & Hagedorn, 1999; Nedea, 2012; Schiere et al., 2004).

Various issues are involved with agricultural sustainability at both the macro and micro scales. Macro sustainability issues include "consumption of resources at national and global levels" (vanLoon et al., 2005:43), greenhouse gas production/sequestering (Paustian et al., 2006), international trade and environmental regulations (Gonzalez, 2004), loss of genetic diversity and regulatory legislation (Esquinas-Alcazar, 2005), "equity in food supplies between nations and preserving environmental and social values in rural society" (vanLoon et al., 2005:43). Micro scale sustainability issues include the productivity of individual farmers (FAO, 2012a), "availability of financial and physical resources, financial viability for farmers, ability to grow crops in a safe manner, equity within the local and national community" (vanLoon et al., 2005:43), maintaining

[11] "Systems thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static 'snapshots'" (Senge, 1990:68). Systems thinking is considered highly relevant for dealing with complex systems and problems (Richmond, 1993). Orr (2010:53) defined systems thinking as "relationships among things instead of on the things themselves. The approach draws attention to the 'whole', rather than the parts. Systems thinking is integrative" (cited in Morawiecki, 2011:29).

human nutrition, innovation and the availability of diverse technologies, reducing food waste (Giovannucci, et al., 2012) and adaptation to climate change (IPCC, 2007).

1.5 Complexities in applying the concept of agricultural sustainability at local to global scales

The application of agricultural sustainability concepts is very complex in terms of local, national and global issues. Broadly speaking, eight concerns can be distinguished in applying these concepts: (1) integration of capitals; (2) maintaining resilience, adaptation and transformation; (3) ensuring systems performance; (4) involving stakeholders; (5) mixing interdisciplinary views; (6) integration of scales; and (7) practicing good governance (Dasgupta & Roy, 2011; Galford et al., 2013; IAASTD, 2009; Jackson-Smith, 2010; Pretty, 2008; USAID, 2012; vanLoon et al., 2005;). Each of these is now considered very briefly.

1.5.1 Integration of capitals

Natural, human, social, financial and physical capitals (Pretty, 2008; vanLoon et al., 2005; Van Cauwenbergh et al., 2007) are needed to manage agricultural sustainability (see Table 1.2). They are also required for agricultural intensification[12] (Scoones, 1998) and diversification[13] (Theodore et al., 2001). While there are varying views about what components of these capitals are required to ensure agricultural sustainability in any given situation, in all cases there is a robust requirement about the availability of a range of different types of capitals/resources (Pretty, 2008; vanLoon et al., 2005). Natural capitals involve various functions of ecosystems (Ekins et al., 2003). Human (skill) capitals ensure agricultural sustainability by innovation (Pretty, 2008). Social capitals such as social/political institutions and traditional knowledge (Berkes & Folke, 1994) capture the idea of

[12] "Agricultural intensification - increased agricultural output per unit area of existing croplands" (Smith et al., 2014:1).
[13] "The sustainability of diversified farms was found to be significantly higher than non-diversified farms" (Theodore et al., 2001:1)

social bonds and norms for ensuring sustainability (Pretty, 2003a). Financial capitals determine the nature, quality and quantity of inputs and management of the gaps, for example, between planting and harvest (UNDP, 2012). Physical capitals like roads, means of communication, infrastructure and machinery create opportunities (vanLoon et al., 2005). The practices of agricultural sustainability must therefore take into account each type of capital (Saunders et al., 2010; vanLoon et al., 2005).

Table 1.2: Various capitals for agricultural sustainability

Natural capital	*Financial capital*
▪ Soil conservation ▪ Ecosystem services (pollination, recreation and leisure) ▪ Biological pest control ▪ Water harvesting, water management ▪ Composting, manuring ▪ Diverse systems (many types) ▪ Conserving genetic resources	▪ Stable markets ▪ Subsidiary activities ▪ Readily available credit ▪ Post-harvest technological opportunities ▪ Value-added activities ▪ Welfare payments ▪ Grants
Social capital	*Human capital*
▪ Cooperatives ▪ Extension work: government, NGO and private ▪ Farmer self-help and research activities ▪ Social values and systems (norms, values, trust, reciprocity and obligations; and common rules and sanctions) ▪ Cultural values, for example gathering and harvesting food from the land and water	▪ Stock of knowledge, skills ▪ Improved nutrition ▪ Education ▪ Health ▪ Leadership and organizational skills
Physical capital	
▪ Improved tools, machinery ▪ Precision agriculture methods ▪ Low-dose spraying ▪ Improved crop varieties	▪ Transportation systems (roads, bridges) ▪ Processing plants ▪ Communications ▪ Energy

Source: Based on Scoones, 1998; Pretty, 1999:256 & 2008:452, CCA, 2014.

1.5.2 Addressing resilience, adaptation and transformation

Agriculture is often disturbed by various physical and anthropogenic shocks and stresses such as floods, drought, salinity fluctuations, water shortages, agricultural inputs (e.g., fertilizer, seeds, irrigation), and economic crisis. Agriculture needs the capacity to withstand and adapt to these disruptions in order to be viable into the future. This capacity is referred to as agricultural resilience and is defined by USAID as "the ability of people, households, communities, countries, and systems to mitigate, adapt to, and recover from shocks and stresses in a manner that reduces chronic vulnerability and facilitates inclusive growth" (USAID 2012:5 see also ADB & IFPRI, 2009; Mann et al., 2009; Darnhofer, 2010; USAID, 2012; WEF, 2013). Various internal and external factors determine the resilience of an agricultural system (Figure 1.3). Resilience is not an isolated process; rather, it works in an interlinked structure (WEF, 2013). The absence of resilience may lead toward a gradual decline of agricultural productivity and can ultimately result in collapse (EESC, 2013), making resilience an essential attribute of agricultural sustainability (Berardi et al., 2011).

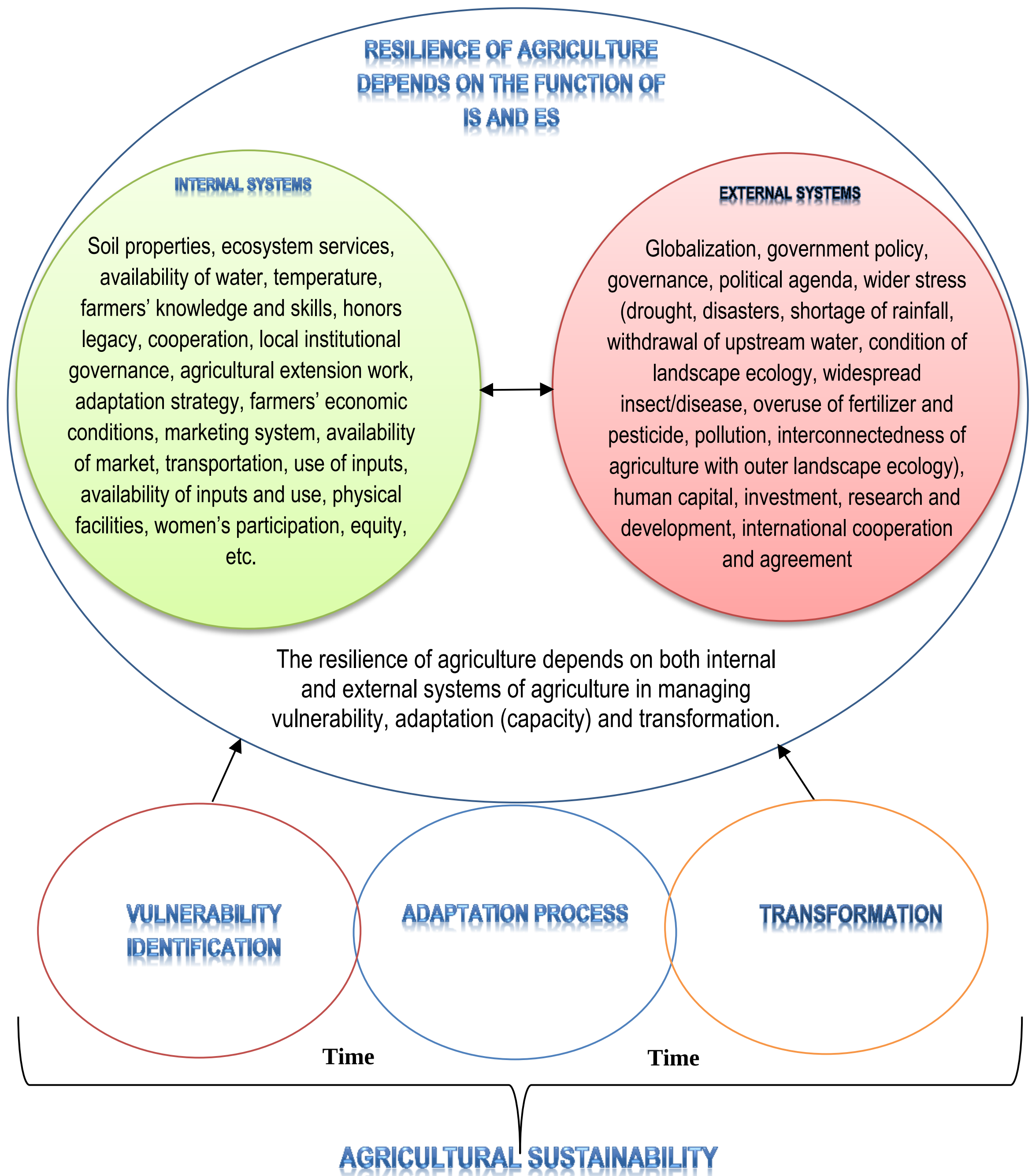


Figure 1.3: Possible factors affecting resilience and sustainability of agricultural systems. Source: Based on ADB & IFPRI, 2009:27; Cabell & Oelofse, 2012:18; Jackson-Smith, 2010; Rodrigues et al., 2009; Swanson et al., 2009. Note: "Vulnerability is the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt" (Adger, 2006:268). Vulnerability needs to be identified for adaptation. Adaptation manages risks associate with the vulnerability. Identification of vulnerability guides the adaptation process (Downing & Patwardhan, 2005). Through adaptation process transformation takes place. Without transformation adaptation will not sustain (Dinshaw, 2014). Vulnerability identification, adaptation and transformation take place over time.

Different capitals within agricultural systems are sensitive or vulnerable to different drivers and pressures (such as demand, market) and shocks and stress, but at the same time the capitals create opportunities and coping capacity for agricultural sustainability (Figure 1.4). To increase the resilience of an agricultural system in light of sustainability, farmers do a lot of experimentation to adapt and transform, creating short- and long-term learning opportunities and innovations that will increase the resilience of agriculture. Resilience, adaptability and transformability are also interrelated across multiple scales as supports at one scale; for example, a national policy can support or impede programs at the farm or regional scale (Folke et al., 2010).

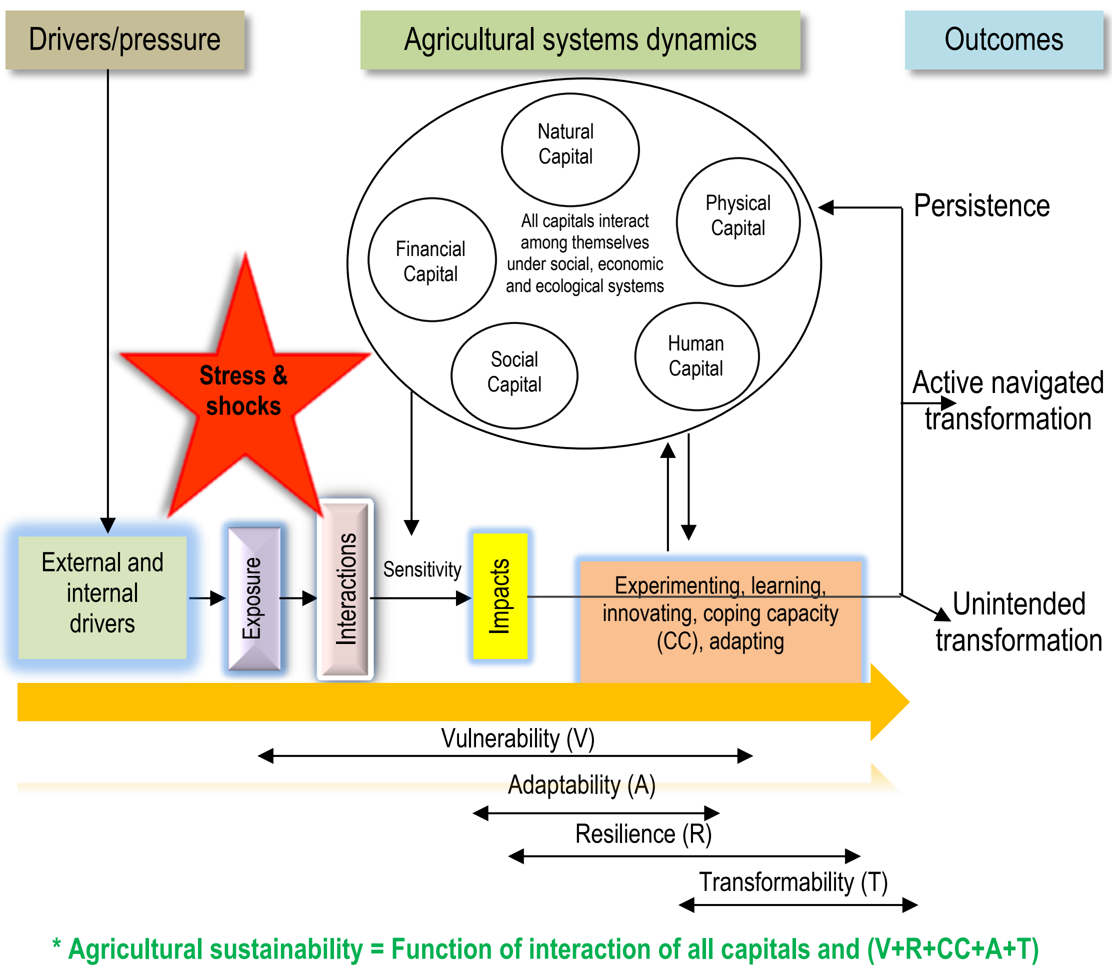


Figure 1.4: Complexity in resilience of agricultural systems. Source: Adapted and modified from Chapin et al., 2010; Pretty, 1999:256 & 2008:452; ADB & IFPRI, 2009:27; Cabell & Oelofse, 2012:18; Jackson-Smith, 2010; Rodrigues et al., 2009; Swanson et al., 2009.

1.5.3 Ensure systems integrity

Agricultural systems consist of social, economic and environmental systems of systems (SOS; Francis et al., 2003, IAASTD, 2009) that create agricultural system resilience through adaptation and interaction among themselves (Darnhofer et al., 2010). The relationship of SOS agriculture is non-linear (Figure 1.5), with diverse and complex relationships. Each system needs inputs from other systems to be productive because in isolation the system cannot produce anything (Lutteken & Hagedorn, 1999). An agricultural system is sustainable when it protects and helps to improve the economic, social and environmental systems of agriculture in a circular way. To maintain agricultural sustainability, a robust system is necessary that synergizes and balances trade-offs among SOS (Jackson-Smith, 2010).

Figure 1.5: A generalized illustrative figure of the complexity of the integrated agricultural systems (rice, shrimp and vegetable in the same field throughout the year) of coastal Bangladesh. The agricultural systems consist of complex ecological, economic and social systems which are interconnected to produce food and other socio-ecological services for the actors of the systems. The actors of the systems work to achieve specified agricultural objectives. This figure demonstrates in a general way the interactions among the three components of sustainability and the three levels of systems of systems within the agricultural systems. Sustainability assessment of these agricultural systems requires a comprehensive method that can handle multidimensional indicators from the systems of systems of agriculture to cover the complexity of the agricultural systems. This illustration is developed based on field observations and interviews with farmers and key informants in 2011.

1.5.4 Involving stakeholders

Stakeholders[14] have different perspectives about agricultural sustainability (Sydorovych & Wossink, 2008) and place different emphases on the various goals of sustainability. For example, it is observed during field study that in integrated agricultural systems of coastal Bangladesh women play an important role in agricultural diversification and production. Agriculture is largely dependent on stakeholders' demands and activities. Hence, agricultural sustainability largely depends on stakeholders' perspectives and policies. Various forms and intensities of stakeholder participation must come together for quality agricultural improvement (Galford et al., 2013; Neef & Neubert, 2011). Stakeholders other than farmers, like governments, local and international businesses, NGOs, experts, scientists, and social advocacy groups, all influence the direction of activities that lead to more or less agricultural sustainability (Poppe et al., 2009).

1.5.5 Mixing interdisciplinary views

Integrating interdisciplinary concepts (biophysical, social and economic), ideas and methodologies is essential for understanding agricultural sustainability because of the fundamental interconnectedness of natural and socioeconomic aspects of sustainability (Schoolman et al., 2012). Interdisciplinary research contributes to the development of sustainable farming systems by generating knowledge to develop and expand agricultural management systems (Jackson-Smith, 2010). For example, interdisciplinary efforts involving private and public organizations provide unique opportunities to integrate markets for the purpose of ensuring agricultural sustainability (Schoolman et al., 2012).

[14] "Stakeholders include interests groups who are affected by the issue or those whose activities strongly affect the issue; those who possess information, resources and expertise needed for strategy formulation and implementation; and those who control the implementation of the various responses" (FAO, 2007:1).

1.5.6 Integration of scales

Issues of agricultural sustainability can be considered across a spectrum of scales: individual, local, national and global (vanLoon et al., 2005). Integration of spatial and time scales[15] of social, economic, and environmental domains is essential (Weaver & Rotmans, 2006) for agricultural sustainability. For example, transboundary water and pollution problems, regional biodiversity degradation, vulnerability in extreme events like floods, drought and cyclone, over-fishing, and so forth must be taken care of at different scales to achieve regional agricultural sustainability. Many policies, management programs and assessments for human-environment systems fail because they do not appropriately address scales and cross-scales (MEA, 2005). Integrating different scales can produce a holistic picture of sustainability.

1.5.7 Practicing good governance

Governance plays a significant role in ensuring productivity, efficiency and equity in agricultural systems (Dasgupta & Roy, 2011). The effective functioning of national and international institutions and NGOs, application of technology and scientific innovations, implementation of policies, adherence to acts and regulations, international cooperation and active participation of all involved stakeholders are essential for effective agricultural governance (Dasgupta & Roy, 2011). Good governance deals with “uncertainty, a diffuse responsibility of impacts, complexity at systemic level and among actors and sectors, large temporal and spatial scales, and possible irreversibility of processes” (van Zeijl-Rozema, 2011:16).

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[15] “‘Scale’ [is] the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon, and ‘levels’ [are] the units of analysis that are located at different positions on a scale” (Cash et al., 2006:8).

1.6 Agricultural sustainability assessment

Effective and comprehensive assessment methods can reconcile the complex concepts involved in interpreting and applying agricultural sustainability at different scales from local to global in a way that fosters increased attention to social, ecological and economic resilience and good governance in agricultural systems. Sustainability assessment rests on concerns for human and ecological well-being and the kinds of responses required for maintaining sustainability and also aims to increase integrated attention and progress toward sustainability (Astier et al., 2012; Gibson, 2012). One must evaluate existing or proposed policy, plans, programmes, projects and pieces of legislation as well as current practices and activities through the lens of sustainability (Pope et al., 2004).

The complexity of agricultural sustainability requires holistic assessments in order to understand the dynamic interactions between agriculture, economy, society and environment. Achieving this insight helps to monitor the progress of agricultural sustainability toward its goals (Guijt & Moiseev, 2001; Vaidya & Mayer, 2013), suggests what actions to take in response to past activities (Gibson, 2012) and facilitates comparisons of the performance of various agricultural systems (von Wiren-Lehr, 2001). Understanding the relationship across scales is important for better planning for agricultural sustainability (Devuyst, 2001) because all the scales are interconnected, and the information, policies and actions associated with each scale affect sustainability issues at other scales (vanLoon et al., 2005). Assessment provides appropriate information for all scales, which is essential to take into account in order to make appropriate shifts with respect to policy and programme. Assessment can assist with reviews of the state of knowledge of farming practices, technologies and management systems and also helps to identify the views of different stakeholders about agricultural systems and factors related to agricultral productivity, efficiency, vulnerability, resiliency, adaptive capacity and tranformability (Jackson-Smith, 2010; Marie et al., 2009; Pope, 2006).

There are many methods for agricultural sustainability assessment. Existing holistic methods have some limitations such as generating aggregated results, not considering stakeholders' opinions, structuring complex agricultural systems and often failing to account for system dynamics including the interconnections and interdependencies of agricultural systems. Therefore, there is an opportunity to identify a framework that helps to integrate indicators of system dynamics and interconnections and interdependencies to generate scores in order to compare overall sustainability as well as sustainability of environmental, social and economic systems. Multi Criteria Decision Analysis[16] (MCDA) is a technique which can be helpful in this regard.

MCDA is a well-known branch of Decision Theory[17] (Triantaphyllou, 2000) that helps decision makers evaluate, prioritize and select options given many conflicting choices and criteria (Alencar & Almeida, 2010; Jeon et al., 2010; Koksalan et al., 2011). MCDA methods are widely used for real-world problems like environmental management (Khalili & Duecker, 2013; Mendoza & Martins, 2006), forest management (Wolfslehner & Seidl, 2010), protection of natural areas (Geneletti & van Duren, 2008), biodiversity conservation planning (Moffett & Sarkar, 2006), water management (Hajkowicz & Collins, 2007), wetland management (Herath, 2004), management of contaminated sediments (Linkov et al., 2006), integrated catchment management (Prato & Herath, 2007), agricultural resource management (Hayashi, 2000), farm management (Sadok et al., 2009), tourist farm service (Rozman et al., 2009), and energy sector issues (Diakoulaki et al., 2005).

[16]Multiple Criteria Decision Analysis (MCDA) is also known as Multiple Criteria Decision Making (MCDM), Multi Criteria Decision Aiding (MCDA), Multi-Attribute Decision Analysis (MADA), Multiple Objective Decision Analysis (MODA), Single Participant-Multiple Criteria Decision Making (SPMC) (Hipel, 2013).

[17] "Decision theory provides a rational framework for choosing between alternative courses of action when the consequences resulting from this choice are imperfectly known. Two streams of thought serve as the foundations: utility theory and the inductive use of probability theory" (North, 1968:200).

In MCDA, a decision maker finds the optimum scenario that suits the ultimate goal among a set of alternatives (Figueira et al., 2005). In MCDA terminology, the way to obtain decision results by applying MCDA techniques is known as the problematic (Figueira et al., 2005). Figure 1.6 shows the four primary types of problematics when considering a discrete decision making problem: choice problematic, sorting problematic, ranking problematic and description problematic (Doumpos & Zopounidis, 2002; Figueira et al., 2005). Belton and Stewart (2002) gave a detailed analysis of the theoretical foundations of different MCDA methods.

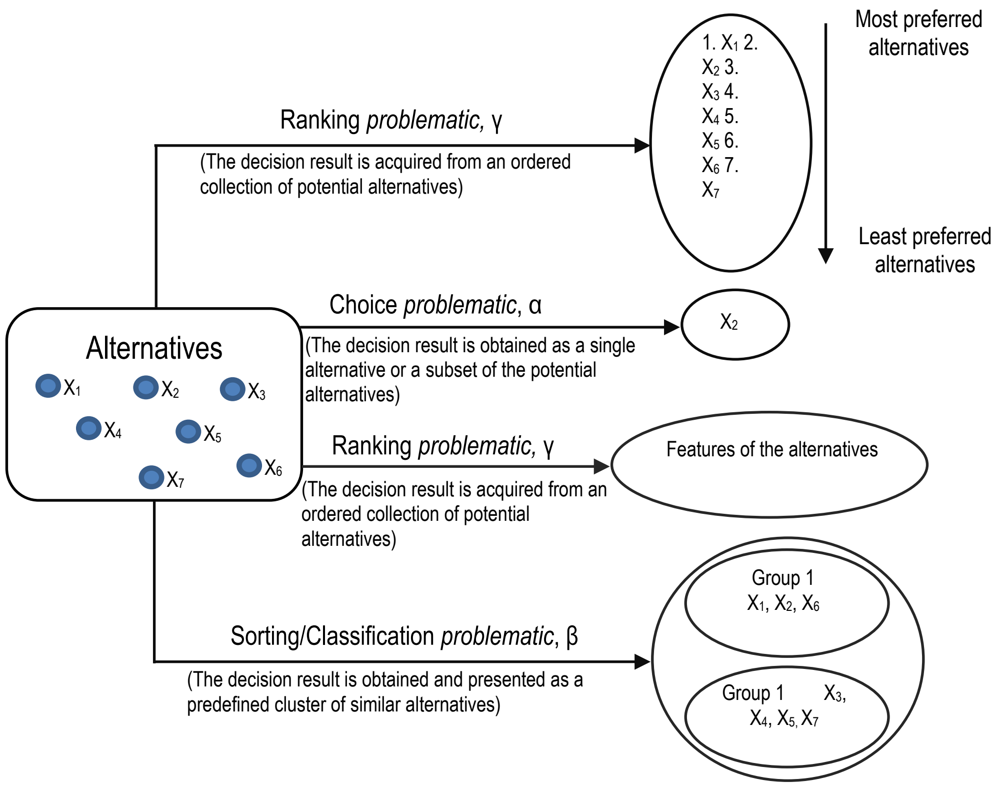

Figure 1.6: Decision-making problematics with definitions. Source: Adapted and modified from Doumpos & Zopounidis, 2002:2; Figueira et al, 2005.

MCDA may be carried out using various methods along with computer software. Generally, MCDA follows several phases. It starts by defining objectives, after which the criteria are chosen to measure the objectives and alternatives are then specified. Once the criteria and alternatives are fixed, the criteria of different scales are transformed into commensurable units and weights are assigned to reflect the relative importance of the criteria. In the last phase, mathematical algorithms are selected and applied for ranking or choosing an alternative (Herath & Parato, 2006).

The comparative strengths and weaknesses of different MCDA methods are presented in Belton and Stewart (2002). MCDA depends on accurate information (Diakoulaki & Grafakos, 2004) to offer a process that leads to rational, justifiable, and explainable decisions that can serve as a focus for discussion (Belton & Stewart, 2002). MCDA techniques can take into account a wide range of contrary but relevant criteria (Belton & Stewart, 2002; Zietsman et al., 2003).

The techniques of MCDA belong to different "axiomatic groups" and "schools of thought" (Herath & Parato, 2006:5). MCDA can also be classified as continuous or discrete[18] (Hajkowicz et al., 2000). However, MCDA methods are generally divided into (1) multi-objective decision making (MODM), for decision problems with a continuous and multiobjective decision space, and (2) multi-attribute decision making (MADM) for selecting the "best alternatives among a finite number of predetermined alternatives" (Stanujkic et al., 2012:141).

1.7 MCDA in agricultural sustainability assessment

Agricultural sustainability assessment is increasingly regarded as a typical decision-making problem (Sadok et al., 2009) and requires a tool that provides data integration ability, transparency, robust analysis, the opinions of engaged stakeholders and improved learning. Hence, MCDA methods can be applied to agricultural sustainability assessment because the methods are structured and transparent, can break down complex problems, facilitate discussion and can produce a systematic and visual presentation of the perspectives of diverse stakeholders (Linkov &

[18] MCDA concentrates on problems with a discrete decision space (Triantaphyllou, 2000). "Discrete methods can be further subdivided into weighting methods and ranking methods. Weighting and ranking methods can be further distinguished in terms of being qualitative/quantitative, mixed or quantitative. Qualitative methods use only ordinal performance measures. Mixed qualitative and quantitative methods apply different decision rules based on the type of data that are encountered. Quantitative methods require the data to be measured in cardinal or ratio terms" (Herath & Prato, 2006:5).

Moberg, 2011; Tsoutsos et al., 2009; Wood et al., 2012). MCDA is also appropriate for assessing complex agricultural sustainability problems because it can integrate the interests and objectives of the sustainability pillars through criteria and weight factors (Loken, 2007; Tsoutsos et al., 2009).

Not all MCDA methods are suitable for agricultural sustainability assessment. All the MCDA methods have advantages and disadvantages, with some methods better fitted to certain situations. All the MCDA methods have the capacity to deal with mixed information and manage uncertain weights and criteria to different extents. Among all the methods, Multi-Attribute Utility Theory (MAUT) has the advantage that it obtains robust results, the Preference Ranking Organization Method for Enrichment Evaluations **(**PROMETHEE) has the advantage of ranking re-evaluation (Cinelli et al., 2013) and the Elimination method can "handle both qualitative and quantitative criteria, uses prioritization of criteria instead of quantitative weights and has a simple decision rule for ranking alternatives" (Hipel, 2013:27). Given these parameters, each of these three MCDA methods can be applied in agricultural sustainability assessment.

Given the complexity of agricultural systems, the dependence of agricultural SOS on various capitals and the interrelatedness of the resilience, adaptability and transformability of agricultural systems, a framework that allows for systems thinking would be helpful for better understanding agricultural sustainability. A content-based framework like Productivity-Stability-Efficiency-Durability-Compatibility-Equity (PSEDCE) can be very helpful to generate multidimensional indicators and indexes (vanLoon et al., 2005). PSEDCE is considered a good framework for gathering information related to agricultural sustainability through a top-down and bottom-up approach. The framework itself and its approach to data collection are discussed in the literature review chapter.

1.8 Research goal and objectives

The broader goal of this research is to develop and test Multi-Criteria Decision Analysis method-based assessment tools for holistically assessing the sustainability of agricultural systems. More specifically, the objectives of this research are to gain a better understanding of the conceptual and methodological frameworks of MAUT, PROMETHEE and Elimination for use in agricultural sustainability assessment. The specific research objectives that guide this study are to:

1. Develop MCDA techniques: Methodological frameworks for agricultural sustainability assessment based on Multi-Attribute Utility Theory (MAUT), the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), and Elimination will be applied to assess the sustainability of coastal agriculture systems in Bangladesh.
2. Design representative composite indicators for assessing agricultural sustainability with application to coastal agriculture in Bangladesh.
3. Employ Multi-Criteria Decision Analysis (MCDA) techniques: MAUT, PROMETHEE, and Elimination will be applied in combination with composite indicators and indicators to compare different agricultural systems with respect to different categories of sustainability.
4. Compare sustainability assessment results from the application of MAUT, PROMETHEE and Elimination methods to identify the best MCDA options for agricultural sustainability assessment.

1.9 Research design and methods

To assess agricultural sustainability by using MAUT, PROMETHEE and Elimination, data were taken from Talukder (2012). The collected data represent various sustainability issues of five different agricultural systems of coastal Bangladesh: shrimp-based agricultural systems (S), shrimp and rice-based agricultural systems (SR), improved methods based-rice systems (R), prawn, rice and vegetable based-integrated agriculture systems (I), and traditional methods based-agricultural systems (T). The data set and the agricultural systems are described in more detail in Chapter Three: Methodology.

In order to meet the research goal and to answer the research questions, MAUT and PROMETHEE were tested through a set of composite indicators and Elimination was tested by a set of individual indicators. The composite indicators were developed from the indicators of Talukder (2012). Comprehensive methods were followed for data collection in Talukder (2012).The data set for the sustainability indicators was designed to capture a holistic view of coastal agricultural sustainability of Bangladesh.

Chapter Three provides a detailed explanation of the methods that are used for developing the composite indicators. Chapter Four gives a detailed description and presents and discusses the results of the conceptual framework of MAUT, PROMETHEE and Elimination, which are applied to the composite indicators and indicators for sustainability assessment to answer the research goals and objectives. Chapter Five provides the overall conclusions and presents the contributions of the thesis as well as further recommendations for future research.

1.10 Structure of the thesis

The structure of the thesis is presented in Figure 1.7. This will help to follow the thesis chapters.

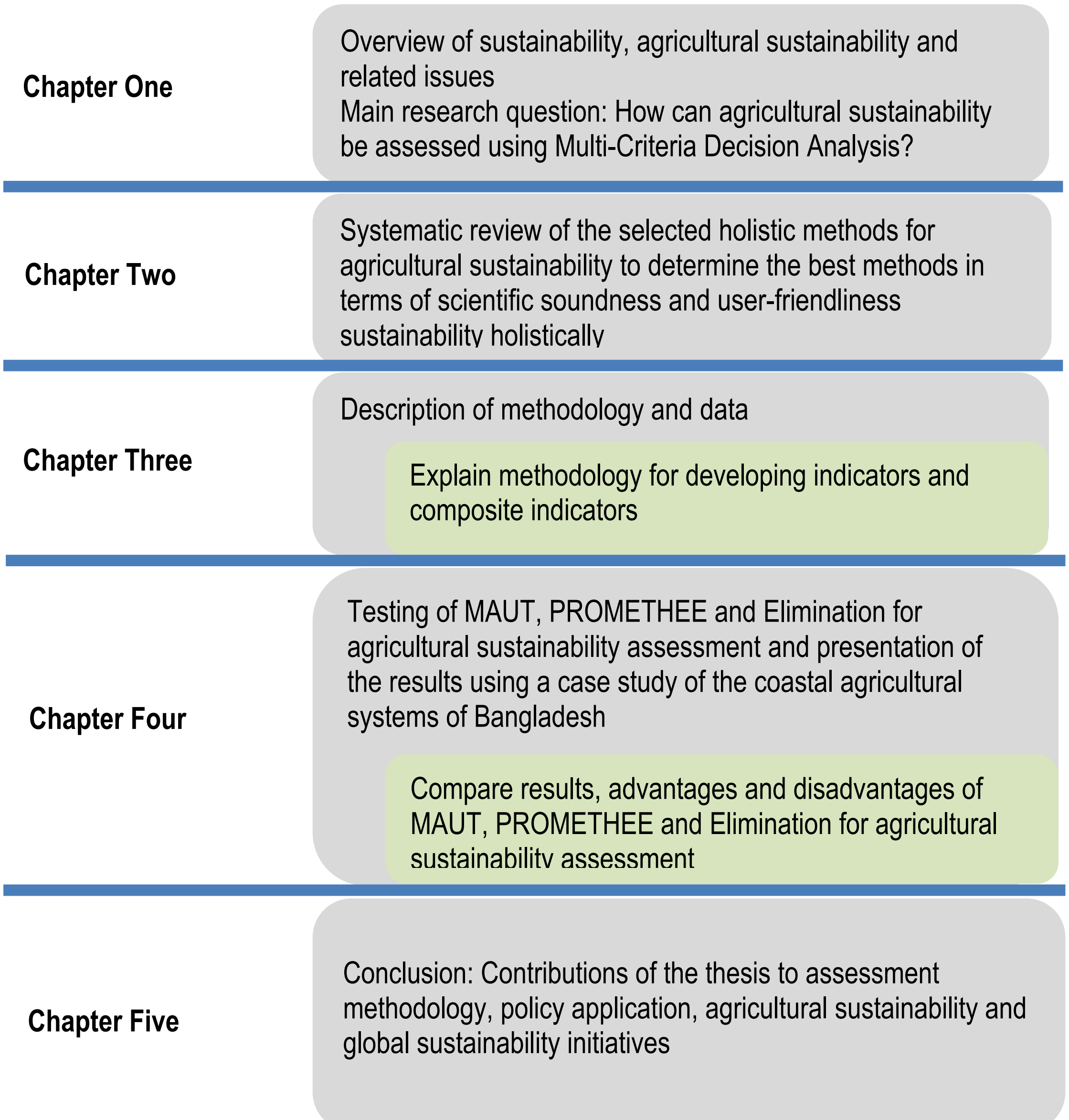

Figure 1.7: Structure of the thesis

Chapter Two: Review of Agricultural Sustainability Assessment Methods

2.0 Introduction

Agricultural sustainability assessment (ASA) frameworks and methods are reviewed and compared in this chapter. Eight especially prominent ASA methods are reviewed systematically to compare and determine the scope of the methods and to see what gaps can be filled by Multi-Criteria Decision Analysis in agricultural sustainability assessment.

2.1 Methods for ASA

A wide variety of assessment methods have been developed to assess agricultural sustainability (i.e., Binder & Feola, 2013; Bockstaller et al., 2009; Ness et al., 2007; Sadok et al., 2009; Van der Werf & Petit, 2002). These methods are continuously evolving. Binder and Feola (2013:33) classified assessment methods into three categories: “(i) top-down farm assessments, which focus on field or farm assessment; (ii) top-down regional assessments, which assess the on-farm and the regional effects; and (iii) bottom-up, integrated participatory or transdisciplinary approaches, which focus on a regional scale.”

In a broader sense, assessment methods can be classified into two categories: non-holistic and holistic[1]. Non-holistic assessment methods are mostly designed to address individual aspects of sustainability, while holistic methods take all aspects of sustainability into consideration in combination.

[1] "Holism is the idea that all the properties of a given system (biological, chemical, social, economic, mental, lingustic, etc.) cannot be determined or explained by the sum of its component parts alone. Instead, the systems as a whole determine in an important way how the parts behave” (Valdez et al., 2008:4).

2.1.1 Non-holistic methods for ASA

Cost Benefit Analysis (CBA; Rahman & Roy, 2006), Contingent Valuation Method (CVM; Rasul, 2009), Carbon Footprint (CF; Dubey & Lal, 2009), Water Footprint (WF; Mekonnen & Hoekstra, 2012), Ecological Footprint Analysis (EFA; Anielski & Wilson, 2010), Environmental Risk Mapping (ERM; Delbaere & Serradilla, 2004), Environmental Impact Assessment[2] (EIA; Payraudeau & van der Werf, 2005), Life Cycle Analysis (LCA; Brentrup et al., 2004), and the Simulation Tool to Assess Ecological Sustainability of Agricultural Production (Eriksson et al., 2005) can be considered non-holistic methods because they only assess one aspect of sustainability. Among these non-holistic methods, only CBA, EIA and LCA are discussed here because they are prominent in the literature.

CBA only considers the economic aspect of sustainability and is very effective in terms of the monetary assessment of the sustainability of agricultural systems. CBA has been used to evaluate input-output. For example, Rahman and Roy (2006) used CBA to examine potentials of rice intensification by comparing input costs with income from yield.

EIA is used to assess environmental impacts of agricultural activities (Rodrigues et al., 2003). In general EIA is a predictive exercise to foresee environmental and related socio-economic impacts of development (Duffy, 1998). One of the limitations of EIA is that not all EIA processes inherently consider the triple-bottom-line of sustainability; nevertheless, it has been considered to be among the most promising methods for the application of sustainability-based criteria (Pope et al., 2004).

Brentrup et al. (2004) used LCA to assess the environmental impacts of agricultural production systems considering environmental effects (land use, climate change, toxicity, depletion of abiotic

[2]Traditionally EIA can consider social, economic and environmental aspect but Rodrigues et al. (2003) used EIA to assess environmental aspect of agriculture. So it is considered as a reductionist method for this analysis.

resources, eutrophication etc.) on crop production. However, LCA follows a series of complicated computations and lacks credibility as an impartial tool. It does not "address localised impacts and is generally a steady state approach rather than a dynamic one" (Muthu, 2014:125). It is based on linear modelling, which limits a true understanding of complex sustainability issues (Heller & Keoleian, 2006).

Non-holistic approaches are important in helping farmers and planners understand specific economic or environmental impacts of agricultural sustainability and, except for LCA, can generate information rapidly (Payraudeau & Van der Werf, 2005). Almost all the non-holistic approaches can be applied to assess the environmental sustainability of past and present agricultural activities. The result of non-holistic approaches can be presented numerically and normatively. Table 2.1 compares the most commonly used non-holistic approaches: CBA, EIA and LCA.

Table 2.1: Overview of the selected non-holistic approaches

Categories	Methods	Target group	Dimension of Sustainability	Indicators selection process				Application at spatial level
				Approach	Selection method	Validation	Source of reference values	
Non-holistic Approaches	CBA[7]	Policy makers, farmers, researchers	Economic	Top-down	Expert appraisal	Comparison	Relative reference	Farm level
	EIA[9]	Policy makers, farmers, researchers	Environmental	Top-down	Expert appraisal	Expert appraisal	Referring to thresholds	Farm level
	LCA[2]	Policy makers, farmers, researchers	Ecological	Top-down	Expert appraisal	Expert appraisal	Referring to thresholds	Farm level

Source: [2]Brentrup et al., 2004; [7]Rahman & Roy, 2006; [9]Rodrigues et al., 2003.

2.1.2 Holistic methods for ASA

Environmental, economic and social aspects of sustainability need to be considered in ASA, and so holistic approaches that address different dimensions and objectives of sustainability are important (Gafsi et al., 2006; Van de Fliert & Braun, 2002). The following methods are considered holistic approaches because they consider all three dimensions of sustainability in assessment: Integrative Assessment of Risk in Agriculture System (IARAS) (Su et al., 2011); Sustainability

Assessment of Farming and the Environment (SAFE) (Van Cauwenbergh et al., 2007); Response-Inducing Sustainability Evaluation model (RISE) (Hani et al., 2003); Multi-Criteria Decision Analysis (MCDA) (Dantsis et al., 2010); On-Farm Assessment Tool (OFAT) (Bylin et al., 2004); Sustainability Assessment of Food and Agriculture Systems (SAFA) (FAO, 2012b); Empirical Evaluation of Agricultural Sustainability (EVAS) (Gomez-Limon & Sanchez-Fernandez, 2010); the IDEA Method (IDEA) (Zahm et al., 2008); the Monitoring Tool for Integrated Farm Sustainability (MOTIFS) (Meul et al., 2008); Sustainability Solution Space (SSP) (Binder et al., 2010); Integrated Assessment of Agricultural Systems: A Component-Based Framework for the European Union (SEAMLESS) (Van Ittersum et al., 2008); Multi-scale Methodological Framework (MMF) (Lopez-Ridaura et al., 2005); the MESMIS[3] Program (Astier et al., 2012); Multi-Agent System (MAS) (Payraudeau & van der Werf, 2005); and, Multilevel Sustainability Assessment of Farming Systems: A Practical Approach (MSAFA:APA) (Van Passel & Meul, 2010). These methods are diverse in terms of their application and development. In order to appreciate the benefits and drawbacks for ASA, the following section compares the most commonly used eight holistic methods. The main features of the methods are shown in Table 2.2.

[3] Spanish acronym for Indicator-based sustainability assessment framework

Table 2.2: Selected holistic methods and their main features

Methods	Brief description	Number of indicators
RISE[1, 2]	Developed and refined since 2000 in cooperation with Swiss and international partners and clients from scientific, societal, public administration and food and agro-industry sectors. It includes ecological, economic and social aspects of agriculture.	12
SAFE[3]	Developed in a hierarchical and structured way according to a wide-ranging framework of principles, criteria, indicators and reference values.	
IDEA[4]	Based on research conducted since 1998 in France. It gives practical expression to the concept of sustainable farms and provides an operational tool for sustainability assessment.	41
MOTIFS[5, 6]	Based on the equal importance of the social, ecological and economic dimensions of sustainability. This method allows a detailed study of sustainability by choosing the most appropriate sustainability indicators.	47
SEAMLESS[7, 8]	"System for Environmental and Agricultural Modelling; Linking European Science and Society (SEAMLESS) brings together over 100 scientists from a broad range of disciplines and 15 countries. It aims to develop a framework to underpin integrated assessment of agricultural systems at multiple scales (from field, farm, region to EU and global)".	9
MCDA[9, 10]	MCDA in sustainability assessment provides a simple and cheap but holistic tool to evaluate the degree of sustainability of agricultural systems. Multi-attribute utility theory (MAUT) is used to amalgamate the indicators to generate a score representing overall sustainability. The number of indicators varies in this technique.	16[9], 12[10]
MESMIS[11, 12]	MESMIS was developed in Mexico and tested in different Latin American countries. The approach is based on a field-tested operational framework. The concepts received feedback from a number of case studies. It is examined in a contrasting set of socio-ecological contexts.	11
SAFA[13]	SAFA was developed to bring together various sustainability approaches into coherent systems through an open and participatory process under FAO guidelines guiding sustainability assessment. It can be used as a self-evaluation tool for producers and food manufacturers.	118

Source: [1]Häni et al., 2003; [2]Grenz et al., 2011; [3]Van Cauwenbergh et al., 2007; [4]Zahm et al., 2008; [5]Meul et al., 2008; [6]Van Passel & Meul, 2010; [7]van Ittersum et al., 2008:152; [8]van Ittersum & Brouwer, 2010; [9]van Calker et al., 2005; [10]Dantsis etal., 2010; [11]Lopez-Ridaura et al., 2002; [12]Astier et al., 2012; [13]FAO, 2012b.

2.2 Systematic review of selected holistic ASA methods

The following objectives are tackled in this section:

1. What standard criteria can be used to compare the effectiveness of ASA methods?
2. What are the differences and similarities of the selected ASA methods in terms of these standard criteria?
3. Is there an ASA method that emerges as the most effective in terms of these criteria?

It should be reiterated here that ASA methods are developed using stakeholders' input, so their characteristics vary depending on which stakeholders are involved. However, as we are concerned with effectiveness, our aim is to see how many standard criteria are covered by each method. First, the selected methods are analyzed in relation to the identified criteria for effectiveness. The methods are then compared in terms of their effectiveness and, finally, further development options are proposed.

The comparison of effectiveness was completed in four phases. In the first phase, a set of selected criteria are used to identify ASA methods. Methods that were developed after 1990 by national and international organizations to address the three aspects of sustainability and that applied multi-criteria assessment in a holistic manner were identified through a search of the literature during 2012 to 2014 using the database of the TriUniversity (University of Guelph, University of Waterloo and Wilfrid Laurier University) Group of Libraries (TUG). This database contains more than 7 million items (WLU, 2014). Methods that were developed after 1990 were considered because agricultural sustainability has gained momentum since the Rio Conference held in 1990. In addition to the TriUniversity database, Google Scholar was used to flag and review agricultural journals and these were scanned for additional approaches. In the second phase, ASA effectiveness criteria were identified based on the literature review. These criteria were then clustered into two dimensions: scientific soundness and user-friendliness. Scientific soundness draws on the criteria for strong scientific and conceptual bases in terms of input data and calculation methods (Cinelli et al., 2014; Niemeijer & de Groot, 2008) described in the OECD report on environmental indicators (Bockstaller et al., 2009; OECD, 1999). Scientific soundness reflects whether the methods are based on the procedures of sustainability science and take into consideration the most relevant aspects of agricultural sustainability assessment (Perry, 2010). User-friendliness is taken from De

Mey et al. (2011) and is defined as being easy to understand based on software support, videos, guidelines and results presentation (Cinelli et al., 2014). In the third phase, the scores for each criterion were calculated for each method (Table 2.3). Finally, in the fourth phase, effectiveness scores were summed for each method. A higher score indicates a better method as the method fulfils more criteria.

2.2.1 Selection and justification of the criteria

The following criteria were chosen to assess the effectiveness of the selected methods. The justifications for the selection of the criteria are discussed below by main criteria and the associated sub-criteria.

Under the dimension of scientific soundness, twelve sub-criteria were considered. These are described in order:

1. Sustainability Concept: The concept of sustainability needs to be well-defined for sustainability assessment (Pope et al., 2004; Zahm et al., 2008) and is usually based on the Triple Bottom Line approach (UN, 1987) or a principles-based approach (Gibson, 2006; Pinter et al., 2012; vanLoon et al., 2005). Due to many inherent limitations of the triple-bottom-line approach including ambiguity, principles-based approaches are more appropriate for concept development because they avoid these limitations (Pope et al., 2004). A well-defined concept of agricultural sustainability provides a strong basis for defining which indicators are needed for assessment (Sathaye et al., 2007; vanLoon et al., 2005). Assessment based on a well-defined concept can support the development of robust agricultural policy that in turn supports sustainability (Van Pham & Smith, 2014).
2. Methodological paradigms for the development of indicators: Agricultural sustainability indicators can be developed under two broad methodological paradigms: top-down

(expert-led) and bottom-up (community/stakeholders-based) approaches (Roy & Chan, 2012). In a top-down approach, experts select the set of indicators based on their expertise (Bossel, 1999), whereas in a bottom-up approach, the opinion of the stakeholders/community are considered in developing representative indicators of systems (Reed et al., 2006). Indicators can also be developed by involving both stakeholders and experts. In terms of indicator development, the approach that gets input from both stakeholders and experts is the most effective (Fraser et al., 2006; Reed et al., 2006).

3. Justification of indicator selection: It is important to understand the justification for the selection of the indicators in order to understand and link them with agricultural sustainability. It is also important for transparency and replicability reasons (vanLoon et al., 2005).
4. Data sources for indicators: Agricultural sustainability indicators can be developed based on both primary and secondary data sources (Dantsis et al., 2010). These need to be technically sound, generate acceptable guidelines and standards and be subject to peer review (UN, 2014). Indicators that are developed based on primary data and validated by secondary information are most sound.
5. Use of qualitative and quantitative data to develop indicators: In agricultural sustainability there are many considerations such as good governance, labour rights and so forth that can be measured using qualitative indicators (FAO, 2012). An assessment system that can handle both qualitative and quantitative information is appropriate for sustainability assessment.
6. Ability to consider sustainability issues across scales in developing indicators: As agricultural sustainability is influenced by different issues across a spectrum of scales, including local, national and global (vanLoon et al., 2005), it is important to consider the

issues of the integration across scales and over time. Many policies, management programs and assessments for human-environment systems fail because they do not appropriately address issues across scales (MEA, 2005). Integrating different issues across spatial and temporal scales (one year or a series of years) can help to produce a more holistic picture of sustainability. This is different from the spatial applicability of the methodology as stated in criterion 12. This is related with sustainability issues across scale whereas criterion 12 is related with the applicability of assessment methods in different spatial scale (e.g., farm, local, nation and regional agricultural systems).

7. Validation of indicators: "An indicator will be validated if it is scientifically designed, if the information it supplies is relevant" (Bockstaller & Girardin, 2003:641). Validation helps to identify transparent indicators of ASA.
8. Reference values of indicators: Reference values describe the desired level of sustainability for each indicator (van Cauwenbergh et al., 2007). They can be based on legislative norms, scientific norms, or observations in the study areas (Sauvenier et al., 2006) and/or defined by stakeholders and experts. Reference values can also be applied to compare sustainability levels (Acosta-Alba & Van der Werf, 2011). "Reference values help to interpret the indicator value and may guide the evolution of a system towards an acceptable level defined in the objectives of the study. Reference values are requested by users, because they help to interpret the method's results" (Acosta-Alba & Van der Werf, 2011:425). A reference value can act as a threshold value (Hrebicek et al., 2013).
9. Data normalization: Data normalization brings different indicator values into the same scale and facilitates comparison (Benini, 2012). "Whenever indicators in a dataset are incommensurate with each other, and/or have different measurement units, it is necessary

to bring these indicators to the same unit, to avoid adding up apples and pears and to help avoid dependence on the choice of measurement units" (Nardo et al., 2005:11).

10. Data aggregation: Aggregated indicators lead to an integrated and holistic approach to sustainability considering different dimensions of agricultural sustainability (Van Passel & Meul, 2012). Usually, the meaningful components and indicators are identified from each dimension of sustainability, then a single scoring system is applied to add indicators and to aggregate sustainability measures (Gafsi & Favreau, 2010).
11. Sensitivity analysis: Sensitivity analysis is "used to determine how different values of an independent variable will impact a particular dependent variable under a given set of assumptions" (Akasie, 2010:253). Sensitivity and uncertainty analysis play a fundamental role in increasing the quality and robustness of the answer provided by a sustainability assessment (Ciuffo et al., 2012:18). "Sensitivity analysis is performed for two reasons: robustness analysis, and 'what-if' analysis. Both approaches use perturbation of input values. 'What-if' analysis aims at pinpointing those inputs that affect output the most" (Information Resources Management Association, 2014:176). Sensitivity analysis helps decision makers formulate agricultural policy by assessing potential scenarios (Information Resources Management Association, 2014).
12. Spatial applicability: Spatial applicability is important to the extent that the method can be applied across scales (i.e., farm, local and regional). It will be much more appealing to policymakers and stakeholders if it can be applied in diverse agricultural systems across scales.

The main criterion of user-friendliness captures the extent to which the ASA method is flexible and easy to use. It includes graphic design, calculation (automation) and ease of assessment (De Mey et al., 2011). The following five sub-criteria were used to assess user-friendliness:

1. Learning dimension: The application of an ASA method itself is a learning experience since it deals with many issues (vanLoon et al., 2005). It is important that the method focuses on filling the gap in sustainability assessment and shows the steps towards utilization of the research findings.
2. Presentation of results: Results presented in a clear and multi-perspective manner (both graphical and numerical) are more attractive to users and stakeholders. Van Passel and Meul (2012) observed that results presented using visual tools are helpful and appropriate for farmers to understand farm sustainability, whereas policy makers benefited most from the numerical integration tools applied at farm to regional levels.
3. Available as software with video tutorials and with free access: Availability and free access to software and video help stakeholders implement the method, manage and analyze data, present the results and demonstrate how to use the methods. Software allows for fast, automatic calculation of huge data sets. It also allows various stakeholders to use the method. Availability of software can improve communication among wider stakeholders and policy makers.
4. Guidelines: User guidelines allow stakeholders to use the methods effectively, help in indicator development and aid in analysis and generation as well as the communication of results. Guidelines should clearly describe or lay out all the procedures for the method.
5. Certification procedure or advisory tool: ASA can be used for certification or as an advisory tool. If used for certification, it will test the fulfilment of certain criteria, whereas an advisory

tool will suggest how to improve agricultural systems through an analysis of management weaknesses (Hrebicek et al., 2013). Knowing whether it is a certification procedure or advisory tool aids in communicating the results.

These two main criteria and their associated sub-criteria are now applied to test eight methods that can be applied to ASA.

2.2.2 Scoring system

A scoring system was developed to assign values for each criterion and sub-criterion. This allows for the ranking and then comparison of methods with respect to their performance against the selected effectiveness criteria. A purposeful, simple, linear scoring system (for example, 0 = does not exist, 1 = exists, 2 = strongly exists) is assigned to rate the performance for each criterion. Decision rules for the scoring systems to assess the effectiveness of the ASA methods are presented in Table 2.3. Validity and reliability, the two basic statistical qualities of the scoring systems, are taken into consideration (Golafshani, 2003) when assigning scores against criteria. Validity refers to whether the statement can answer the questions raised by the criterion or not. Reliability tests measure the consistency of the scoring. The scoring system that is used here is binary and could be improved on, but is adequate for the purposes of this thesis.

Table 2.3: Scoring system to assess the effectiveness of the ASA methods

Main criteria	Sub criteria	Decision rules for the score of the criteria
Scientific Soundness	Sustainability concept	3 = Concept of agricultural sustainability uses principles-based approaches 2 = Concept of agricultural sustainability uses Triple Bottom Line approach 1 = Concept of agricultural sustainability is not well defined 0 = Concept of agricultural sustainability is not defined
	Methodological paradigms for development of indicators	2 = Both top-down (expert-led) and bottom-up (community/stakeholders-based) paradigms 1 = Either top-down (expert-led) or bottom-up (community/stakeholders-based) paradigms 0 = No paradigm
	Justification of indicator selection	1 = Justifications for the selection of the indicators are documented 0 = Justifications for the selection of the indicators are not documented
	Data sources for indicators	2 = Indicators are based on both primary and secondary data sources 1 = Indicators are based on either primary or secondary data sources
	Use qualitative and quantitative data	2 = Can use both qualitative and quantitative data to develop indicators 1 = Can use only qualitative or quantitative data to develop indicators
	Ability to consider sustainability issues across scales in developing indicators	1 = Integrates information related to sustainability issues across scales 0 = Does not integrate information related to sustainability issues across scales
	Validation of indicators	3 = Validation of the indicators is based on comparison, expert appraisal and stakeholder appraisal 2 = Validation of the indicators is based on any two appraisals 1 = Validation of the indicators is based on only one appraisal 0 = No validation
	Reference values of indicators	1 = Reference values are used to interpret indicators 0 = No reference values are used to interpret indicators
	Data normalization	1 = Data are normalized 0 = Data are not normalized
	Data aggregation	1 = Capable of aggregating data 0 = Not capable of aggregating data
	Sensitivity analysis	1 = Supports implementation of sensitivity analysis 0 = Sensitivity analysis is not possible
	Spatial applicability	3 = Applied at field, farm, landscape and national levels 2 = Applied at two spatial levels 1 = Applied at one spatial level
User-friendliness	Learning dimension	1 = Focus on filling the gap in agricultural sustainability assessment and show the steps toward utilization of the research findings 0 = No focus on filling the gap in agricultural sustainability assessment and does not show the steps toward utilization of the research findings
	Presentation of results	2 = Results can be presented through numerical values and graphs 1 = Results can be presented by only one method 0 = Results cannot be presented by any method
	Available as software and video and free access	2 = Software available and free access with demonstration video 1 = Software available without free access/demonstration video 0 = No software or demonstration video are available
	Guidelines	1 = Has documented guidelines 0 = No documented guidelines
	Certification procedure or advisory / education / planning tool	2 = Provides both certification and advisory/education/planning tool 1 = Provides either certification or advisory/education/planning tool 0 = Does not provide any certification or advisory/education/planning tool

Note: Spatial applicability can also be called geographical scope.

2.3 Effectiveness of ASA methods

The effectiveness of the selected criteria for each of the methods was determined using the criteria in Table 2.3 and is reported in Table 2.4. In Table 2.5, the effectiveness scores of the sub criteria are proportionately normalized (Table 2.5), and then summed. The proportionate normalization process (Dailey, 2000; Pomerol & Barba-Romero; 2012) is carried out by the following formula:

$$N_{ias} = \frac{C_i}{\sum_i C_i} \quad 0 < N_{ias} < 1$$

Where N_{ias} = Proportionate normalization,

C_i = Criteria value,

$\sum_i C_i$ = Sum of the criteria values.

Table 2.4: Matrix of the criteria of effectiveness for selected methods

Main criteria	Criteria	Selected methods								Total
		RISE	SAFE	IDEA	MOTIFS	MCDA	SEAMLESS	MESMIS	SAFA	
Scientific soundness	Sustainability concept	3	2	3	2	2	2	2	3	19
	Methodological paradigms for development of indicators	1	1	1	1	2	2	1	2	11
	Justification of indicator selection	1	1	1	1	1	1	1	1	8
	Data sources for indicators	2	2	1	2	2	2	1	2	14
	Use qualitative and quantitative data	2	2	2	2	2	2	2	2	16
	Ability to consider sustainability issues across scales in developing indicators	0	1	0	0	1	1	0	1	11
	Validation of indicators	1	1	2	1	1	1	2	2	4
	Reference values of indicators	0	1	0	1	1	0	1	0	4
	Data normalization	1	0	0	1	1	0	0	0	1
	Data aggregation	0	0	1	0	1	0	0	0	3
	Sensitivity analysis	0	0	0	0	1	0	0	0	2
	Spatial applicability	2	3	1	2	2	2	2	2	16
User-friendliness	Learning dimension	1	1	1	1	1	1	1	1	8
	Presentation of results	2	1	2	2	2	2	2	2	15
	Available as software and video and free access	2	0	0	0	1	1	1	1	6
	Guidelines	1	0	0	1	0	1	1	1	5
	Certification procedure or advisory / education / planning tool	2	1	1	1	1	1	1	1	9

Source: RISE (Hani et al., 2003; Porsche et al., 2004); SAFE (Van Cauwenbergh et al.,2007; Sauvenier et al., 2006); IDEA (Zahm et al., 2008; Galan et al., 2007); MOTIFS (Meul et al., 2008; Van Passel & Meul, 2010); MCDA (Dantsis et al., 2010; van Calker et al., 2006); SEAMLESS (van Ittersuma et al., 2008; van Ittersum & Brouwer, 2010); MESMIS (Lopez-Ridaura et al., 2002; Astier et al., 2012); SAFA (FAO, 2012).

Table 2.5: Normalization of the criteria of effectiveness for selected methods

Main criteria	Sub-criteria	Selected methods							
		RISE	SAFE	IDEA	MOTIFS	MCDA	SEAMLESS	MESMIS	SAFA
Scientific soundness	Sustainability concept	0.16	0.11	0.16	0.11	0.11	0.11	0.11	0.16
	Methodological paradigms for development of indicators	0.09	0.09	0.09	0.09	0.18	0.18	0.09	0.18
	Justification of indicator selection	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
	Data sources for indicators	0.14	0.14	0.07	0.14	0.14	0.14	0.07	0.14
	Use qualitative and quantitative data	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
	Validation of indicators	0.09	0.09	0.18	0.09	0.09	0.09	0.18	0.18
	Reference values of indicators	0.00	0.25	0.00	0.25	0.25	0.00	0.25	0.00
	Ability to consider sustainability issues across scales in developing indicators	0.00	0.25	0.00	0.00	0.25	0.25	0.00	0.25
	Sensitivity analysis	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
	Data normalization	0.33	0.00	0.00	0.33	0.33	0.00	0.00	0.00
	Data aggregation	0.00	0.00	0.50	0.00	0.50	0.00	0.00	0.00
	Spatial applicability	0.13	0.19	0.06	0.13	0.13	0.13	0.13	0.13
	Total	1.19	1.37	1.31	1.39	3.23	1.15	1.07	1.29
User-friendliness	Learning dimension	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
	Presentation of results	0.13	0.07	0.13	0.13	0.13	0.13	0.13	0.13
	Available as software and video and free access	0.33	0.00	0.00	0.00	0.17	0.17	0.17	0.17
	Guidelines	0.20	0.00	0.00	0.20	0.00	0.20	0.20	0.20
	Certification procedure or advisory / education / planning tool	0.22	0.11	0.11	0.11	0.11	0.11	0.11	0.11
	Total	0.76	0.11	0.11	0.31	0.28	0.48	0.48	0.48
Total of scientific soundness and user-friendliness		1.95	1.48	1.43	1.70	3.51	1.62	1.55	1.77

Source: RISE (Hani et al., 2003; Porsche et al., 2004); SAFE (Van Cauwenbergh et al.,2007; Sauvenier et al., 2006); IDEA (Zahm et al., 2008; Galan et al., 2007); MOTIFS (Meul et al., 2008; Van Passel & Meul, 2010); MCDA (Dantsis et al., 2010; van Calker et al., 2006); SEAMLESS (van Ittersuma et al., 2008; van Ittersum & Brouwer, 2010); MESMIS (Lopez-Ridaura et al., 2002; Astier et al., 2012); SAFA (FAO, 2012).

2.3.1 Results of the tests of effectiveness of the selected criteria of ASA methods

The scores of effectiveness based on the selected critera for each method are shown in Figure 2.1 and Table 2.5. These scores are presented in table and figure form to help readers understand the procedures of the calculation of effectiveness. The next sections provide the decision rationale for each set of main criteria, along with the sub-criteria (please note, the sub-criteria are italicized).

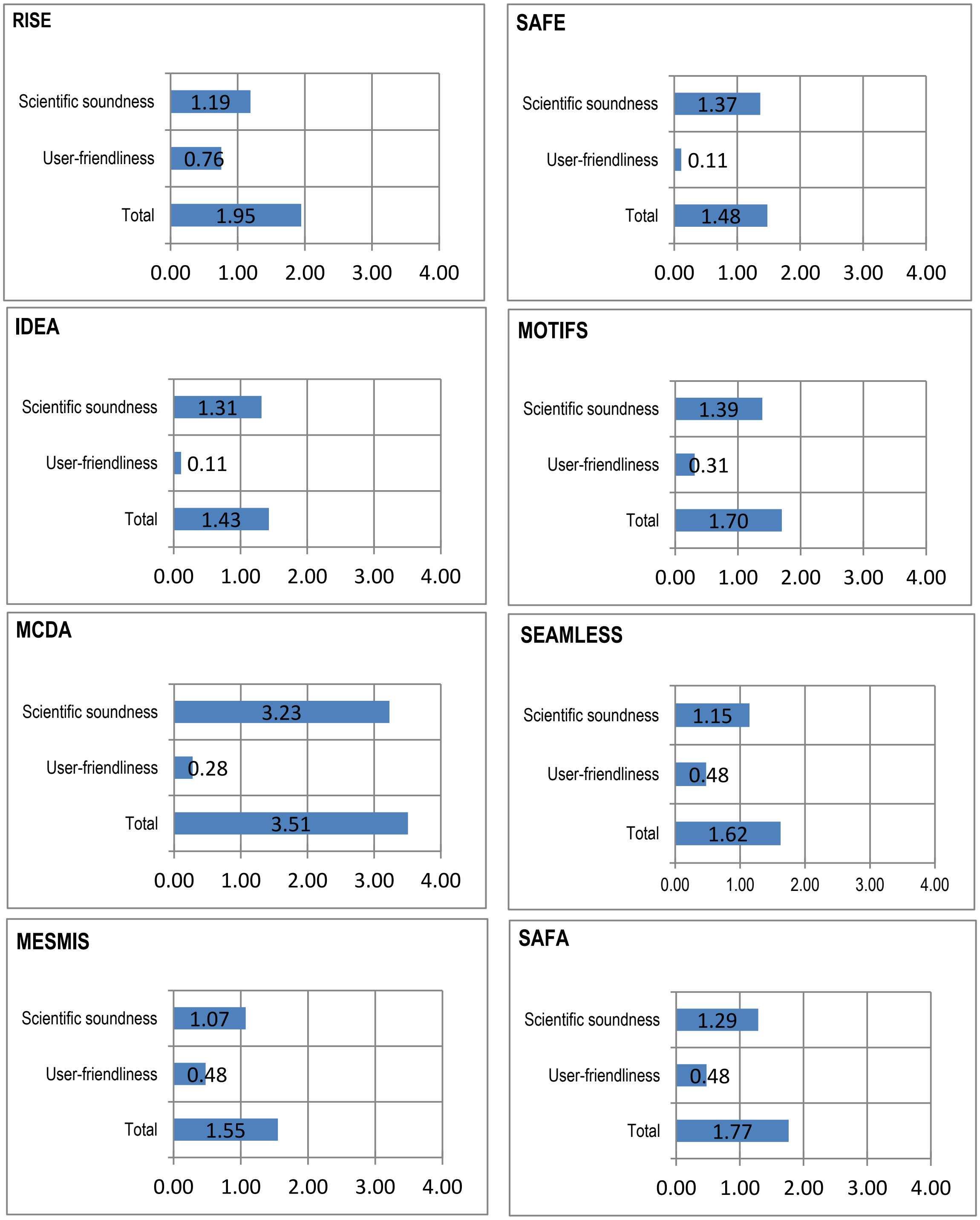

Figure 2.1: Effectiveness of the methods based on scoring systems of the criteria

Scientific soundness: All the methods have well-defined agricultural sustainability *concepts*, with RISE, IDEA and SAFA using principles-based approches (Studer et al., 2009). However, RISE and IDEA have a tendency to focus on the ecological dimension (Binder et al., 2010). The Triple Bottom Line approach is the basis of the SAFE, MOTIFS, MCDA, SEAMLESS and MESMIS methods.

MCDA, SEAMLESS and SAFA have strong *methodological paradigms* for developing indicators based on both top-down (experts) and bottom-up (stakeholders) aproaches. For example, in MCDA-based assessment the attributes and indicators are identified in a participative way, i.e., selected by experts and stakeholders (Van Calker et al., 2005), whereas other selected methods such as SAFE, IDEA and MOTIFS were developed using a top-down approach (Binder et al. 2010; Marchand et al., 2014; Roy & Chan 2012; Sauvenier et al., 2006; Zahm et al., 2008).

None of the methods offer *justifications* of the selecton of indicators except SAFE, MCDA and SAFA. Justification of the selection of indicators is important for understanding why the indicators are selected for the sustainability assessment and to explain the robustness of the indicators, as well as for replicability.

All the methods are capable of using both primary and secondary *data sources* with the exception of MESMIS, which uses only primary data. Except for RISE, all the methodologies have the capacity to use both *qualitative and quantitative* data. Data types in RISE include farm data, regional data and reference data (Grenz et al., 2011).

Only SAFE, IDEA and MESMIS use *indicator validation*. "An indicator will be validated if it is scientifically designed, if the information it supplies is relevant, if it is useful and used by the end users" (Bockstaller & Girardin, 2003:641). "Despite the great interest regarding indicator development, relatively little is written in terms of validation processes" (Rigby et al., 2001:472).

Reference values of indicators are only considered in SAFE, MCDA, MOTIFS, and MESMIS. Like validation, *threshold values* for indicators are used only in SAFA, IDEA and MESMIS.

A vital and multifaceted problem for determining the sustainability level of farming systems is the consideration of sustainability issues across scales in developing indicators of the different aspect measures (Hayati et al., 2010) into a sustainability function which measures overall sustainability. Only the SAFE, MCDA, SEAMLESS, and SAFA methods are able to integrate issues across scales.

Only MCDA techniques can actually handle *sensitivity analysis*. Sensitivity analysis is one of the main criteria for understanding the robustness of an indicator and the assessment method. It allows observation of the influence of indicators in sustainability assessment; it also allows the detection of resulting changes due to any change in the values of the indicators.

MCDA and MOTIFS are able to *normalize* the indicators. Normalization is built into the MCDA-based calculation, whereas "MOTIFS is a scoring method with indicators normalized on a scale between 0 and 100 with different benchmark methods" (Marchand et al., 2014:46). None of the methods can *aggregate* the indicator values with the exception of MCDA.

User-friendliness: All the methods provide a unique space for *learning* about agricultural sustainability and allow further study, training and thought. Like the learning dimension, all the methods are also capable of *presenting results* numerically as well as graphically except SAFE. For example, the results (scoring) presentation system of "MOTIFS allows for a comprehensive overview and comparison of the indicators under different sustainability themes" (Marchand et al., 2014:46). However, it has been noted that extra discussion in group meetings is needed for MOTIFS to help understand the results, and depending on the findings, end users are able to address (or not) the monitoring, modifying, communication, learning, and management functions

(Binder et al., 2010). The numerical results of RISE are visualized using radar charts and provide results that "can be relatively easily discussed with farmers and also allow for monitoring and benchmarking across regions" (Binder et al., 2010:78). The graphical and numerical results from IDEA can be discussed with farmers and also allow for "monitoring and benchmarking across regions" (Binder et al., 2010:78). In MCDA the numerical results can be presented graphically. Since MCDA aggregates social, economic and environmental data, it is possible to graphically present the contribution of different indicators to the total score in order to evaluate the effect of different trade-offs (Dantsis et al., 2010). In MESMIS, the results can be presented through an AMOEBA diagram that shows progress toward sustainability by means of trade-offs, or synergies, as well as trends of the indicators (Astier et al., 2012). In SAFA (FAO, 2012) the results are presented in the form of a polygon and can also be represented through "traffic light" rankings (red-unacceptable, orange-limited, yellow-moderate, light green-good and dark green-best).

In terms of supportive *software availability*, RISE and MESMIS have their own *software and demonstration videos*. The MCDA method is based on the platform of MUVT software and a demonstration video is also available. The results for MOTIFS are calculated using different Excel spreadsheets. The other methods do not have any specific software.

While RISE has its own *guideline*s, the other methodologies' guidelines are disorganized. RISE and SAFA are considered both *certification procedures and advisory tools*, whereas the other methods are only advisory tools for developing agricultural sustainability.

2.4 Discussion

On the basis of the selected criteria, the score for scientific soundness is highest (3.23) in MCDA-based ASA (Figure 2.1). MOTIFS scored second highest (1.39) and the third highest (1.37) score was calculated for SAFE. The lowest score (1.07) is obtained by MESMIS. IDEA, SAFA, RISE, and

SEAMLESS are scored 1.31, 1.29, 1.19 and 1.15 respectively. All the methods are based on some degree of scientific soundness and can handle a large amount of qualitative and quantitative data. Nevertheless, only the MCDA-based method allowed for mixing qualitative and quantitative data. There is an apparent advantage of the MCDA method over other methods since it can handle some of the scientific issues such as sensitivity analysis, incommensurability and aggregation of qualitative and quantitative data. RISE, IDEA, SAFE, MCDA and SAFA measure social, economic and environmental indicators separately rather than as aggregate indicators in a single index. When decision makers need a final result, RISE, SAFE and MCDA are good for consideration. Often decision makers do not have enough time to understand all the procedures of ASA, in which case viewing the final results is very important.

User-friendliness is a very important aspect of ASA, especially when the users are not experts in this field. With a 0.76 score, RISE is the most user-friendly method, followed by MESMIS, SEAMLESS and SAFA, each with a score of 0.48. The score for MCDA user-friendliness is lower (0.28) than for RISE because MCDA is still in the development stage and requires the user to be familiar with MCDA. MOTIFS scored 0.31. The lowest score (0.11) in User-friendliness was obtained by IDEA and SAFE.

MCDA scored highest (3.51) overall when the scores of scientific soundness and user friendliness are combined (Figure 2.1). RISE, SAFE, IDEA, MOTIFS, SEAMLESS, MESMIS, SAFA obtained total scores of 1.95, 1.48, 1.43, 1.70, 1.62, 1.55 and 1.77 respectively.

This type of comparative study helps to understand the various aspects and procedures that are used for the assessment of agricultural sustainability. It is also useful for the further development of ASA methods. With this overview of results in mind, we can now reflect on what this means for ASA.

2.5 Concluding remarks on comparison the selected methods

In general, most of the methods have a structure that is straightforward and easy to understand. However, in the case of SAFE, MCDA and SAFA, considerable time is required to understand and apply the methodological procedures for indicator development paradigms, indicators, reference values and final calculation. The assessment methods vary in how they address theoretical and practical issues of sustainability. In spite of these limitations, significant progress has been made in the development of ASA methods over the last decades. The assessment methods describe the status of the agricultural systems in terms of sustainability issues and can be used to support policy and programme formulation for agricultural system sustainability. As each assessment initiative was developed by individual scholars, groups or organizations, each method reflects local agricultural priorities and practices and has its own particular shortcomings. As a result, assessment methods vary in terms of their spatial, temporal and theoretical concerns.

From the analysis in this chapter, we can conclude that multi-criteria assessment methods provide the most effective assessment of agricultural sustainability, offering many benefits in terms of scientific soundness. They combine and aggregate sustainability indicators in order to quantify the objectives in a holistic manner. They are able to consider economic, environmental and social issues; evaluate the performance of agricultural systems based on selected criteria and prioritize the performance of the systems; incorporate the input of stakeholders; handle both qualitative and quantitative indicators; and calculate the degree of sustainability at the farm level (Dantsis et al., 2010). Considering the above analysis, an MCDA-based approach has the potential to be a good assessment tool, but the application of MCDA in sustainability assessment for agricultural systems is still new and requires further refinement. It is also less user-friendly than other methods.

Therefore, developing and applying variations of MCDA methods for ASA is the focus of the balance of this thesis.

Chapter Three: Methodology

3.0 Introduction

This chapter describes the research method used for this thesis. First, the conceptual framework that underpins the research method is described (Figure 3.1). This is followed by a brief overview of the research methodology stages. Next, a description of the dataset is provided. This includes a description of the methodological procedures used to develop the composite indicators, their results and a discussion about how the final set of composite indicators was developed for MAUT and PROMETHEE analysis.

The discussion describing the elaboration of the composite indicators is particularly important as this method is one of the key contributions of this thesis. Other contributions are the development and testing of three methodological approaches (i.e., MAUT, PROMETHEE and Elimination) for agricultural sustainability assessment using the same data. In Chapter Four, the results from the three methods are compared to find the preferred MCDA method for agricultural sustainability assessment using the data set described below.

3.1 Research methodology stages

Broadly, the methodological approach for this dissertation is divided into four stages (Figure 3.1). In the first stage, a conceptual overview of the agricultural sustainability literature was established. The literature survey was framed by the following definition of agricultural sustainability:

> Human activities to produce food and fiber in a manner that ensures the well-being of the present and future communities without diminishing the surrounding ecosystems' capacity and ensuring environmental integrity, social well-being, resilient local economies and effective governance (FAO, 2013; Jackson-Smith, 2010; vanLoon et al., 2005).

Building on this definition, the second stage identified the issues and concerns for agricultural sustainability. A detailed discussion of this is provided in Chapter One of this thesis. These issues and concerns facilitated the elaboration of a framework in Stage Three that considers both bottom-up and top-down approaches to the development of agricultural sustainability indicators. Many frameworks were reviewed from various sources including the FAO, HAFL[1], the EU, GIRA[2] and peer-reviewed papers in academic journals. As discussed in Chapters One and Two, the Productivity-Stability-Efficiency-Durability-Compatibility-Equity (PSEDCE) framework emerged as the best suited for this work as it has the capacity to cover the key issues and concerns related to agricultural capitals, vulnerability, resilience and scale issues. An illustration of agricultural sustainability with respect to the six PSEDCE categories is presented in Figure 3.2. The PSEDCE framework helps the researcher consider different sustainability indicators and identify an associated set of composite indicators to capture a complex picture of sustainability. The indicators that were developed using the PSEDCE framework by Talukder (2012) are the basis for a set of representative composite indicators. The process of indicator development and their relationships with various issues and concerns about sustainability are presented in section 3.3 of this chapter ('Description of the indicators'). In stage four, the MCDA methods are tested. A general methodological overview of MCDA as a research method was reviewed in Chapter One. The specific methodological procedures of MAUT, PROMETHEE, and Elimination for agricultural sustainability assessment and the results and discussion are covered in Chapter Four.

[1]The HAFL in Zollikofen, Switzerland is a center of excellence in the agricultural, forestry and food industries, Bern University of Applied Sciences (BFH-HAFL, 2016).

[2] The Interdisciplinary Group for Appropriate Rural Technology, a local NGO based in Western Mexico (GIRA, 2015).

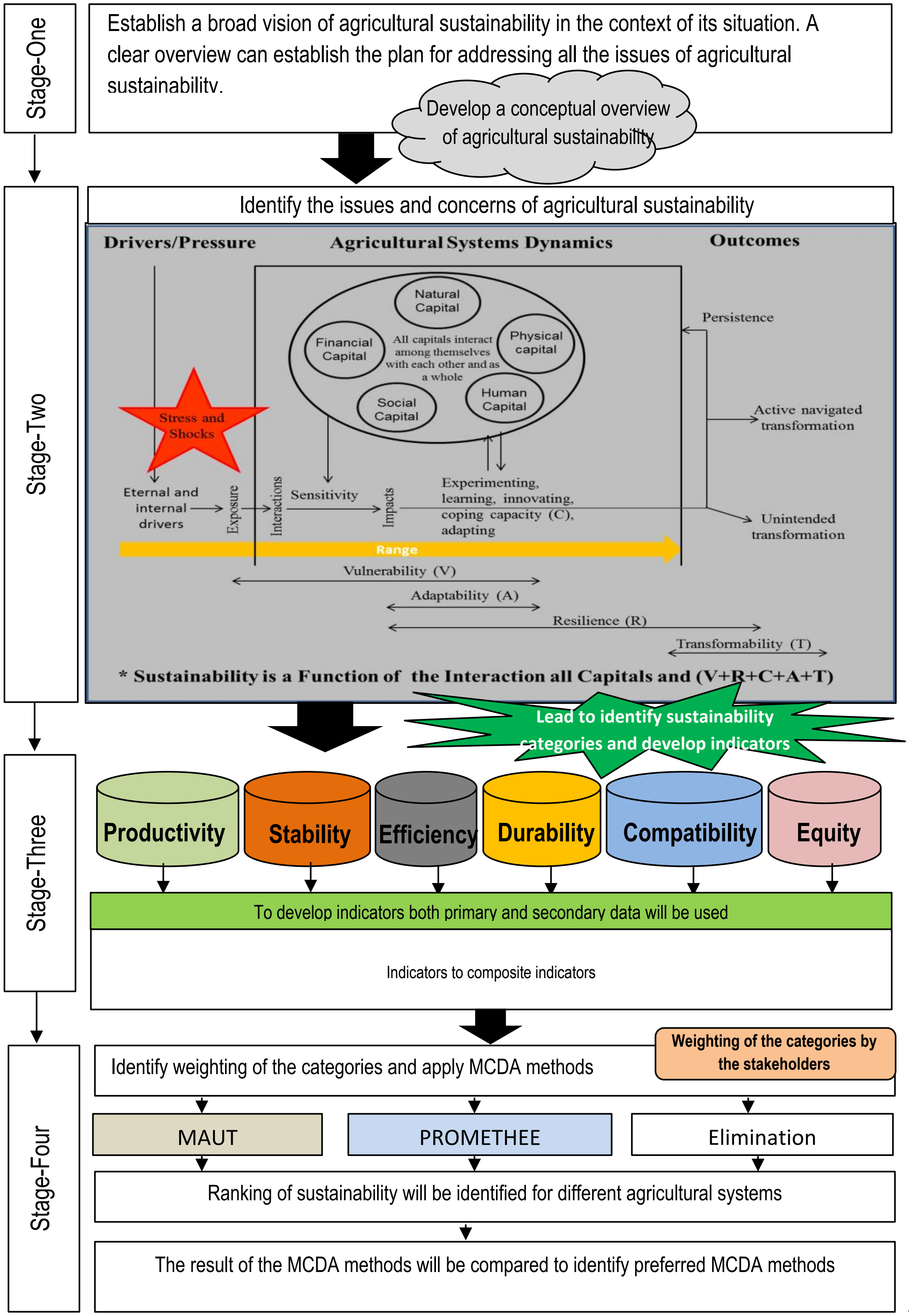

Figure 3.1: Methodological framework for the dissertation, Source: Scoones, 1998; Pretty, 1999:256 & 2008:452; Chapin et al., 2010; vanLoon et al., 2005, Hipel, 2013; OECD, 2008; PROMETHEE 1.4 Manual, 2013.

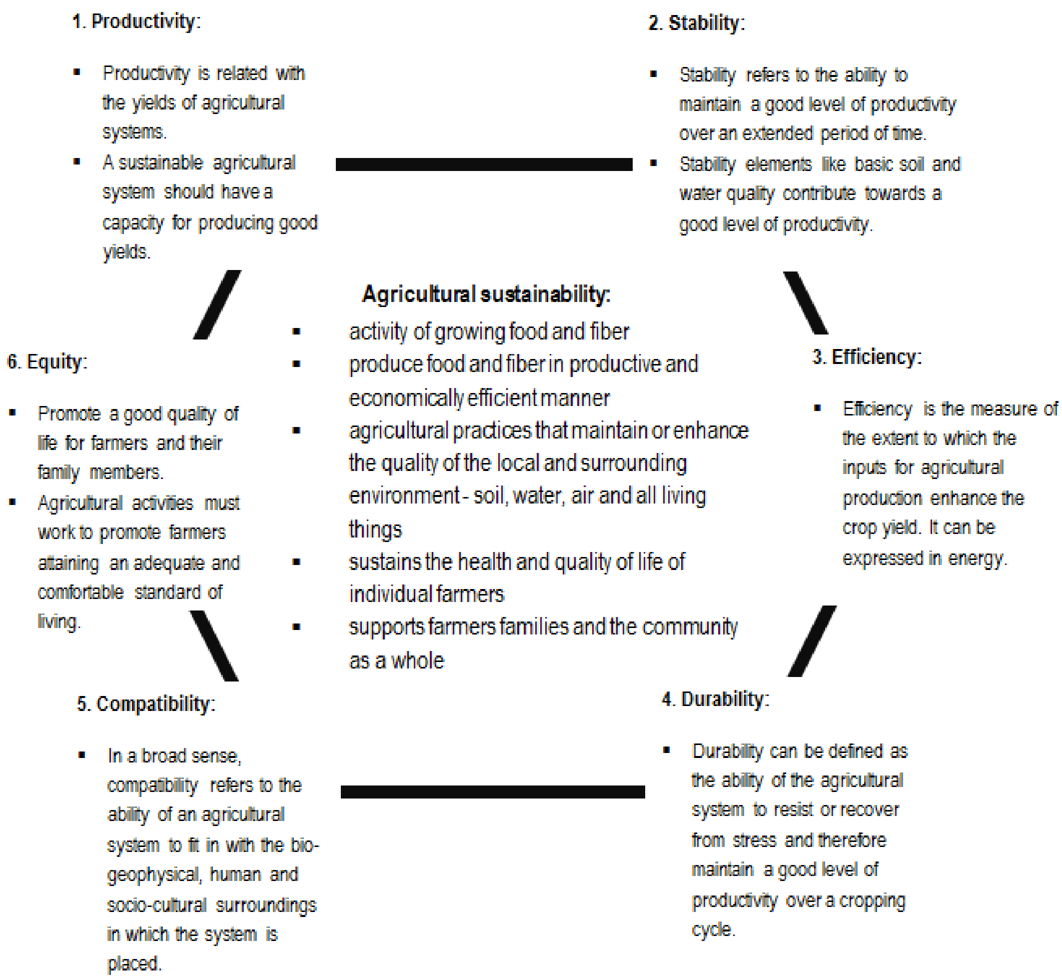

Figure 3.2: Illustration of agricultural sustainability with respect to six sustainability categories, Source: Adapted and modified from vanLoon et al., 2005.

3.2 Description of the dataset

The dataset for this study is based on Talukder (2012). In the first phase of data collection, the agricultural systems were identified based on matrices (Table 3.1) selected through a literature survey, brainstorming with people in the local communities and discussion with experts. On the basis of these matrices, five different agricultural systems were selected: shrimp-based agricultural systems (S), shrimp and rice-based agricultural systems (SR), improved methods-based rice systems (R), prawn, rice and vegetable-based integrated agriculture systems (I) and traditional methods-based agricultural systems (T).

Table 3.1: Matrices for selection of the agricultural systems

Sl.	Matrices	Selected agricultural systems				
		S	SR	R	I	T
1.	Location in Moribund Delta	✓	✓	✓	✓	
2.	Location in Active Delta					✓
3.	Exposed to sea	✓				✓
4.	Unexposed to sea		✓	✓	✓	
5.	Mostly intensive shrimp + other fish cultivation	✓				
6.	Mostly intensive shrimp+ other fish + rice cultivation		✓			
7.	Mostly semi traditional agriculture			✓		
8.	Mostly integrated agriculture (prawn+ rice+ vegetables)				✓	
9.	Mostly traditional agriculture					✓
10.	Livelihood dependency on local agriculture	✓	✓	✓	✓	✓
11.	Diversity of livelihood through agricultural activities	✓	✓	✓	✓	✓
12.	Time tested knowledgeable farmers	✓	✓	✓	✓	✓
13.	Community cohesiveness	✓	✓	✓	✓	✓
14.	Positive attitude of the community	✓	✓	✓	✓	✓
15.	Community eagerness to take part in questionnaire survey and Focus Group Discussion (FGD)	✓	✓	✓	✓	✓
16.	Support from local administration and non-governmental organizations (NGOs)	✓	✓	✓	✓	✓

Note: ✓ = fulfillment of the matrices. Source: Talukder, 2012:25

All the agricultural systems are located between 22.3500° N to 90.6525° E. 'T', 'S', 'SR', and 'I' are located in Shyamanagar *Upazila,* Kalijang *Upazila* and Dumuria *Upazila* respectively (Figure 3.3). Each of these *Upazilas* (local administrative units) is located in the Ganges tidal floodplain of the southwest coastal belt. 'R' is situated in Kalaroa *Upazila*, further north in the floodplain. 'T' is situated in Bhola sadar *Upazila* in the more recently formed Meghna estuarine floodplain east of the other sites (BARC, 1996; Rashid, 1991).

All the agricultural systems are in the range of a tropical monsoon climate Koppen A_m (Kottek et al., 2006). Rice, the staple food of the local people, is cultivated in each location. In addition, in 'S', 'SR' and 'I', one-third to half of the total agricultural land was involved in shrimp/prawn cultivation, whereas rice and other crops occupy the entire agricultural area in 'R' and 'T'. The main products of each agricultural system are briefly described in Table 3.2.

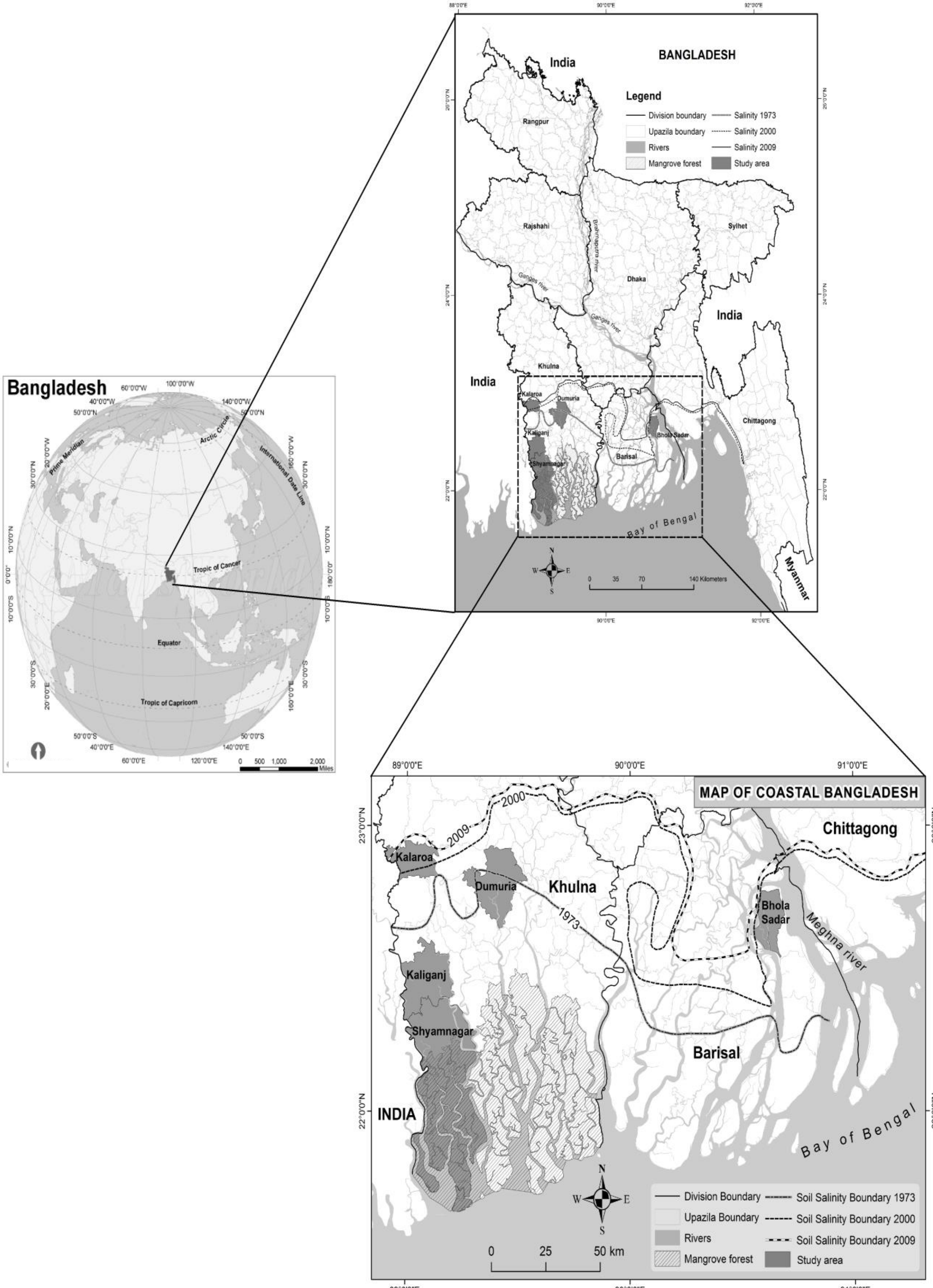

Figure 3.3: Location of the agricultural systems in Bangladesh and gradients of soil salinity (1973–2009) in the coastal zone of Bangladesh. The soil salinity contours represent the northern boundary of areas where soils may have salinity values of 2 dS m−1 or more. Source: SRDI, 2012, Reconstructed by using ArcGIS (ESRI, 2015).

Table 3.2: Description of the selected agricultural systems

S: Black Tiger shrimp (*Penaeus monodon*), which is locally called *Bagda Chingri*, is intensively cultivated in this system with some rice. The transplanted *Aman* rice is cultivated mainly in the *kharif-2* season (July to October). In some non-saline uplands Aus rice and *rabi* crops may grow in dry winter (October to March). This upland is typically 1 to 2 m above the shrimp-producing tidal flats. In the homestead areas betelnut, coconut and some vegetables can also be

SR: In this system from August to December when salinity is low *Aman* (salt-resistant) rice is cultivated in elevated parts with intensive *Bagda* in shrimp-producing tidal flats. In general the homestead areas of this system are characterised by the cultivation of rice and *rabi* crops and vegetables for personal consumption as well as for commercial purposes. Local fruits, betelnut and coconut can also be grown in the homesteads of this system.

R: In this system rice is cultivated in all seasons and in addition jute (Corchorus), sugarcane (Saccharum), and sesame (Sesamum indicum) are cultivated in the kharif season (April-September). However, in the monsoon season rain-based rice is cultivated widely. Boro rice is grown with irrigation in the winter. Local fruits and vegetables are found all year round in the homestead areas. Rice and other crops are grown mainly for commercial purposes and personal consumption.

I: In this system in the same gher1 rice, freshwater prawn (Macrobrachium rosenbergii, locally called Galda Chingri), a variety of fish and vegetables are cultivated throughout the year. Among fish, Tilapia and carp are prominent species. Water gourd, lady's finger, squash, bean, amaranth, and cucumber are common vegetables. Galda (along with fish in some cases) and rice are cultivated together in the same field during the winter season as well as on the dikes that surround ghers. Vegetables are grown throughout the year.

T: Throughout the year Aus, aman and boro rice are cultivated in sequence in this system. Among other crops pulses such as grass pea, beans, lentils, groundnuts, and mustard are also cultivated in this agricultural system. Recently boro rice, potato, and watermelon cultivation have increased. Some farmers are cultivating vegetables such as chili or okra plus sweet gourd or potato plus bitter gourd for commercial purposes.

Note: A = Shrimp-based agricultural systems (S), B = Shrimp and rice-based agricultural systems (SR), C = Improved methods-based rice systems (R), D = Prawn, rice and vegetable-based integrated agriculture systems (I), E = Traditional methods-based agricultural systems (T). Photos by Talukder, during field visit in 2011. Source: Talukder, 2012.

3.3 Data collection

In the second phase, the dataset was elaborated using both primary and secondary data sources. Primary data were collected from farmers. Five different categories of farmer were considered (Table 3.3) and in total 211 representative households were surveyed. All farmers in the study area were using very similar agricultural systems, so stratified purposeful sampling was deployed for the household questionnaire survey. At least 5 households each from Landless, Marginal, Small, Medium and Large farmers were selected. These 5 groups of farmers are categorized by land operational types: Landless: < 0.01 acres, Marginal: 0.01 - < 0.50 acres, Small: 0.50 - < 2.5 acres, Medium: 2.5 - < 5.0 acres, Large: > 5.0 acres (BBS, 2010). Small groups of farmers were surveyed using a 35-page questionnaire (Appendix – I) to collect detailed information about agricultural sustainability for each production system.

Table 3.3: Number of surveyed households

Categories of farmer	Agricultural systems					
	S	SR	R	I	T	Total farmers
Landless farmer	5	10	10	5	5	35
Marginal farmer	5	12	15	4	5	40
Small farmer	16	17	18	6	6	63
Medium farmer	12	9	11	4	5	41
Large farmer	7	12	5	3	5	32
Total farmers	45	60	59	22	26	211

Source: Talukder, 2012:28.

Large-scale questionnaire surveys are widely used for data collection in rural research in spite of their costs, errors and other defects (Gill, 1993). Focus group discussions (FGD[3]) were conducted to enable different categories of farmers, including disadvantaged farmers, to identify their priorities and interests with respect to agricultural sustainability. While the questionnaire was the basis of the

[3]"A focus group is a planned, facilitated discussion among a small group of stakeholders designed to obtain perceptions about a defined area of interest in a non-threatening environment (USAID, 2008:1).

checklist during the FGDs, different sustainability issues were also discussed. A total of 120 participants took part in the 1.5-2 hour FGDs that were conducted on farms, homesteads or in community settings. Twenty key informants were interviewed to verify the information from questionnaire surveys and FGDs. Key informants were selected for their significant knowledge regarding agricultural systems and sustainability from among agricultural extension officers, a fisheries office and a livestock office in each *Upazila*. Along with the primary data collection, reports from government agencies and NGOs, published papers and books were reviewed to collect secondary data.

From these data, 110 indicators were developed for the six categories of sustainability: productivity, stability, efficiency, durability, compatibility and equity (PSEDCE). These indicators aggregate information from across broader headings related to particular agricultural sustainability issues. Although it was difficult to include these issues in all cases, policy relevance, practicability, comprehensibility and measurability criteria were considered during indicator development. From the 110 indicators (Talukder, 2012), 50 were selected based on their connections to the three pillars of sustainability, agricultural capitals and also to the themes of vulnerability, adaptability and resilience. Different measurement methods were applied to develop these indicators. The selected indicators and related calculation methods are shown in Appendix II (Table A2-1).

The PSEDCE framework facilitates thinking about multidimensional sustainability indicators and serves as a link between indicators and sustainability issues (Sathaye et al., 2007). The PSEDCE framework can be categorized as a content-based framework (Van Cauwenbergh et al., 2007) since it can be applied to generate indicators for specific system issues and then to draw a holistic picture of system sustainability. PSEDCE helped Talukder (2012) develop indicators related to the spatial scale of the single farm and the agro-ecosystem as a whole. In the case of the Talukder

(2012) data set, the time-scale for the measurement of sustainability indicators was one year, as farmers in the coastal areas of Bangladesh repeat the same agricultural practices every year (have repeated essentially the same agricultural practices every year for more than 10-15 years). So it is assumed that a one-year measurement represents a broad picture of the sustainability of agricultural practices. Sustainability pillars can be assessed by objective or subjective approaches, and both were used to collect information and develop indicators. The objective approach is related to quantitative measurement of indicators, whereas the subjective approach is related to qualitative methods (Goldberger, 2011). The subjective approach allows the development of indicators based on farmers' perspectives about their agricultural systems (Shreck et al., 2006). Subjective information was later converted into quantitative forms.

In Talukder (2012), the sustainability categories and their respective indicators were weighted using subjective judgment methods (Cherchye et al., 2007) by involving experts, key informants and farmers. The experts, key informants and farmers were involved in weighting the categories and their indicators on a 1-100 scale. The opinions of these groups and individuals were taken into consideration to generate the relative importance of the categories and indicators and averaged to assign the weights for categories and indicators. For the purpose of this study, the weights of the indicators and categories were adjusted (Table 3.4).

Fifteen composite indicators were developed from the selected indicators (Table 3.4) from Talukder (2012). The indicators are grouped under six categories (Table 3.5). The detailed methodological procedure for developing the composite indicators is presented below.

Table 3.4: Selected indicators, justification of selection and their characteristics and values

SC	Indicators	Justification	Unit	Data type	DS	WOC	WOI	Agricultural systems					LM	PS
								S	SR	R	I	T		
Productivity	Weighted yield of rice[1] (main staple crop)	Rice is the most important agricultural product as both food and income.	t/ha	QNT	QS	20	0.40	2.26	4.41	5.23	6.51	2.86	RS	E
	Net income from the agro-ecosystem[1]	Income from the agro-ecosystem determines the economic conditions of a farmer.	$/ha	QNT	QS		0.40	311.15	1020.37	1585.81	1806.04	544.01	RS	E
	Protein yield from the agro-ecosystem[1]	Productivity of protein is important for the population dependent on the agro-ecosystem.	kg/ha	QNT	QS		0.20	68.42	147.23	552.00	373.01	318.87	RS	Eco
Stability	Land exposure to natural events: cyclone[2]	Lands that are exposed to cyclones are potentially unstable in terms of agricultural activities. Almost every year some parts of the coastal regions of Bangladesh are subject to damage from cyclones.	Binary yes/no	QUAL	SD	20	0.30	1.00	2.00	2.00	2.00	1.00	NS	Eco
	Land exposure to natural events: saline water[2]	Saline water causes an unfavorable environment that restricts normal crop production throughout the year.	Binary yes/no	QUAL	SD		0.30	1.00	1.00	3.00	2.00	3.00	NS	Eco
	Land exposure to natural events: drought in *kharif* to *rabi* season[3]	Periods of drought can have significant environmental, agricultural, health, economic and social consequences.	Binary yes/no	QUAL	SD		0.050	1.50	1.50	2.00	2.00	3.50	NS	Eco
	Land exposure to natural events: river bank erosion[4]	Riverbank erosion causes setbacks for village agriculture. Along with homestead settlements, it erodes farmland, infrastructure and communication systems.	Binary yes/no	QUAL	SD		0.050	2.00	2.00	2.00	2.00	1.00	NS	Eco

	Stability of embankment[5]	Coastal embankments provide safeguards against the intrusion of saline water and devastation associated with repeated attacks of tidal surges and cyclonic storms.	Binary yes/no	QUAL	FO		0.20	1.00	2.00	1.00	2.00	2.00	NS	Eco
	Withdrawal of upstream water[6]	Withdrawal of upstream water creates severe stress on soil moisture, soil salinity, and non-availability of fresh groundwater, thus affecting agricultural productivity in the long term.	Binary yes/no	QUAL	SD		0.10	1.00	1.00	1.00	1.00	2.00	NS	Eco
	Organic materials[7]	Soil organic matter affects the chemical and physical properties of the soil and its overall health.	%	QNT	SD		0.30	4.00	4.00	2.00	3.00	2.00	OS	Eco
	Salinity[7]	Soil salinity is a significant factor in reducing crop productivity.	dS/m	QNT	SD		0.35	1.00	5.00	6.00	3.00	6.00	OS	Eco
	Macronutrient: N[7]	Soil macronutrients, nitrogen (N), phosphorus (P), and potassium (K), are essential elements for crop growth.	meq/100gm	QNT	SD		0.10	2.00	2.00	2.00	1.00	2.00	OS	Eco
	Macronutrient: P[7]		meq/100gm	QNT	SD		0.10	3.00	2.00	3.00	3.00	3.00	OS	Eco
	Macronutrients: K[7]		meq/100gm	QNT	SD		0.10	6.00	4.00	3.00	2.00	4.00	OS	Eco
	Soil pH[7]	Soil pH plays an important role in controlling the availability of plant nutrients to crops.	Ratio (no unit)	QNT	SD		0.05	1.00	3.00	4.00	2.00	4.00	OS	Eco
	Water salinity in surface water (quality of surface water for irrigation) [7]	Too much salt in surface water can reduce or even prohibit crop production.	dS/m	QNT	SD		0.40	1.00	2.00	2.00	2.00	3.00	OS	Eco
	Water salinity in groundwater (quality of groundwater for irrigation) [7]	Too much salt in groundwater can reduce or even prohibit crop production.	dS/m	QNT	SD		0.40	1.00	2.00	2.00	4.00	3.00	OS	Eco

	Arsenic concentration (quality of groundwater for irrigation)[8]	Reduced agricultural productivity due to arsenic toxicity which is harmful to humans and possibly to animals when high-arsenic rice straw is used for feed.	ppm	QNT	SD		0.20	2.00	2.00	2.00	2.00	4.00	OS	Eco
Efficiency	Money input and output in the agro-ecosystem[1]	Total monetary efficiency is important from the farmers' economic point of view.	$ output/ $ input	QNT	QS	20	1.00	1.53	2.24	2.78	6.67	2.29	RS	E
	Overall energy efficiency[1]	Overall energy efficiency of an agro-ecosystem determines the efficiency of the agricultural practices. Overall energy efficiency includes renewable and non-renewable energy.	Ratio of energy output and input	QNT	QS		0.60	1.37	2.01	5.53	5.54	5.90	RS	Eco
	Non-renewable energy efficiency[1]	Efficiency in terms of non-renewable energy sources is especially important for the sustainability of an agro-ecosystem.	Ratio of energy output and input	QNT	QS		0.40	0.78	0.92	2.17	2.52	2.44	RS	Eco
Durability	Chemical response to pest stress[1]	Use of chemicals to respond to pest stress hampers agro-ecosystem and human health.	Binary yes/no response	QUAL	QS	10	0.25	1.78	4.17	4.24	5.45	6.54	NS	Eco
	Water availability at transplanting stage of rice[1]	Availability of water at the transplanting stage is important for crop growth.	Binary yes/no response	QUAL	QS		0.25	0.75	0.75	0.20	0.20	0.20	NS	Eco
	Water availability at flowering stage of rice[1]	Availability of water at the flowering stage is important for crop growth.	Binary yes/no response	QUAL	QS		0.25	0.75	0.75	0.20	0.20	0.20	NS	Eco
	Farm management (soil test, pest management, land management, soil fertility management)[1]	Improved farm management is necessary to enhance production of crops. Farms' productivity depends on the sustainable management of soils.	Binary yes/no response	QUAL	QS		0.25	0.67	0.83	1.69	1.36	0.00	NS	Eco

	Good product price[5]	Good price of agricultural products motivates farmers to employ good agricultural practices.	Binary yes/no response	QUAL	QS		0.35	8.44	5.00	4.58	4.55	3.80	NS	E
	Availability of seeds[5]	Availability of seeds ensures smooth agricultural activities.	Binary yes/no response	QUAL	QS		0.30	9.33	9.50	10.00	10.00	8.85	NS	Eco
	Availability of market (market diversification)[5]	Availability of multiple markets ensures the sale of the agricultural products.	Binary yes/no response	QUAL	QS		0.35	10.00	9.17	8.47	10.00	7.69	NS	S/E
	Agricultural training[5]	"Training provides efficient and effective needs-based extension services to all categories of farmers to enable them to optimize their use of resources and to promote sustainable agricultural and socioeconomic development" (DAE, 2016:1).	Binary yes/no response	QUAL	QS		0.40	1.33	1.83	0.33	2.27	1.15	NS	S/E
	Climate change awareness[1]	Climate change awareness training about agriculture helps farmers to employ agricultural practices that are better for climate adaptation.	Binary yes/no response	QUAL	QS		0.30	1.11	0.67	0.51	1.82	0.00	NS	S
	Advice from agricultural extension workers or NGO[5]	Awareness of climate change impacts on agriculture helps farmers to adapt their agricultural systems.	Binary yes/no response	QUAL	QS		0.30	0.66	1.17	0.51	0.45	0.38	NS	Eco
Compatibility	Drinking water quality (protected)[5]	Protected water supply ensures safe drinking water.	Binary yes/no response	QUAL	QS	15	0.50	0.00	8.00	9.00	10.00	9.00	NS	Eco
	Illness from drinking water[1]	Drinking -water related illness indicates the quality of drinking water in the agro-ecosystem.	Binary yes/no response	QUAL	QS		0.50	5.00	10.00	10.00	10.00	10.00	NS	Eco

	Overall biodiversity condition: percentage of non-crop area[1]	Non-crop area helps in sustainable pest control.	%	QNT	QS		0.25	7.54	6.48	23.01	15.73	18.68	OS	Eco
	Overall biodiversity condition: crop richness[1]	Overall biodiversity conditions leads to better agricultural practices and maintains ecosystem health.	Number of crops	QNT	QS		0.25	2.00	6.00	16.00	10.00	17.00	OS	Eco
	Overall biodiversity condition: crop rotation[1]	Crop rotation plays an important role in maintaining the health of crops.	Number	QNT	QS		0.25	2.00	3.00	5.00	4.00	4.00	OS	Eco
	Ecosystem connectivity[5]	Ecosystem connectivity in the agro-ecosystem helps to ensure sustainable agriculture.	Binary yes/no response	QUAL	FO		0.25	1.00	1.00	2.00	2.00	2.00	NS	Eco
Equity	Education of farmers[1]	Education of farmers is beneficial for promoting sustainable agriculture.	%	QNT	QS	15	0.25	8.56	9.25	4.75	10.00	5.00	OS	S
	Education status of farmers' male children[1]	Education of farmers' male children also helps the sustainable practice of agriculture.	%	QNT	QS		0.25	10.00	9.49	11.20	13.10	7.45	OS	S
	Education status of farmers' female children[1]	Female children's education indicates the openness of a community.	%	QNT	QS		0.25	9.07	10.54	11.17	12.50	6.36	OS	S
	Access to electronic media[5]	Access to electronic media indicates farmers' access to information in an agro-ecosystem.	%	QNT	QS		0.25	7.78	9.17	9.39	10.00	3.08	OS	S
	Farm profitability[1]	Average income of an agro-ecosystem provides information about economic status and wellbeing of the area.	$	QNT	QS		0.20	648.23	3340.55	1371.32	1992.39	1025.06	RS	E
	Average wage of farm labourer[1]	Average wage of farm labour indicates the economic status of the farm labourer.	$/person/day	QNT	QS		0.20	1.33	1.33	1.60	1.80	1.60	RS	E

	Livelihood diversity other than agriculture[1]	Diversity of livelihood ensures income from different sources which maintains stability of the economic status of the farmers.	Count, 0 to 5	QNT	QS		0.20	6.22	4.33	5.93	4.55	6.92	OS	E
	Years of economic hardship[1]	Economic hardship stops farmers from engaging in agricultural activities all year round.	Number of years	QNT	QS		0.20	0.73	0.73	0.91	0.82	0.64	OS	E
	Road network (establishing farm roads and access roads)[5]	Establishing farm roads and access roads are important for economic activities.	Access/no access	QNT	QS		0.20	2.00	3.00	3.00	3.00	1.00	NS	E/S
	Settings where treatment facilities is provided[5]	Available setting for treatment indicates heath care status in the agro-ecosystem community.	%	QNT	QS		0.50	3.51	4.76	4.07	8.14	4.29	OS	S
	Sanitation or public health[5]	Toilet facilities are a measure of a healthy environment for humans in the agro-ecosystem community.	%	QNT	QS		0.50	7.69	8.73	7.59	7.41	7.08	OS	S
	Women's involvement in decision making about agricultural activities[1]	Women's participation supports diversification and sustainable agriculture[9].	%	QNT	QS		0.50	3.00	4.00	5.00	6.50	2.50	OS	S
	Gender-based wage differentials[1]	Gender-based wage difference is an indication of the status of women in the farm labour market.	$/person/day	QNT	QS		0.50	0.33	0.33	0.50	0.59	0.00	RS	E

Note: All the justifications are driven by farmer's opinions supported by key informant interviews, expert opinions and personal experiences from the field. Legend: SC = Sustainability category, DS = Data source, DTQNT = Quantitative; QS = Questionnaire survey, FO = Field observation, WOC = Weighting of sustainability categories (adjusted from Talukder, 2012), WOI = Weighting of Indicators (adjusted from Talukder, 2012), LM= Level of measurement, RS = Ratio scale, NS = Nominal Scale, OS = Ordinal scale, PS = Pillars of sustainability; Eco = Ecological, E = Economic; S = Social. Source: Talukder, 2012:34-37; [1]vanLoon et al, 2005; [2]Uddin & Kaudstaa, 2003; [3]BARC, 2000; [4]WARPO, 2006; [5]Field observation by Talukder, 2011; [6]Mirza, 1997; [7](SRDIc, 1991; SRDId, 1993; SRDIb, 1997; SRDIa, 2001; SRDIe, 2008); [8]BGS & DPHE, 2001; [9]UNEP, 2004.

Table 3.5: Set of the indicators aggregated into composite indicators for each sustainability category

Sustainability category	Composite indicators	Indicators
Productivity	Productivity	Weighted yield of the main staple crop (rice) Net income from the agro-ecosystem Protein yield from the agro-ecosystem
Stability	Landscape stability	Land exposure to natural events: cyclone Land exposure to natural events: saline water Land exposure to natural events: drought in *kharif* to *rabi* season Land exposure to natural events: river bank erosion Stability of embankment Withdrawal of upstream water
	Soil health/ stability	Organic materials Salinity Macronutrient: N Macronutrient: P Macronutrient: K Soil pH
	Water quality	Water salinity in surface water (quality of surface water for irrigation) Water salinity in groundwater (quality of groundwater for irrigation) Arsenic concentration (quality of groundwater for irrigation)
Efficiency	Monetary efficiency	Money input and output in the agro-ecosystem
	Energy efficiency	Overall energy efficiency Non-renewable energy efficiency
Durability	Resistance to pest stress	Chemical response to pest stress Water availability at transplanting stage of rice Water availability at flowering stage of rice Farm management (soil test, pest management, land management, soil fertility management)
	Resistance to economic stress	Good product price Availability of seeds Availability of market (market diversification)
	Resistance to climate change	Agricultural training Climate change awareness Advice from agricultural extension workers or NGO
Compatibility	Human Compatibility	Drinking water quality (protected) Illness from drinking water
	Biophysical Compatibility	Overall biodiversity condition: percentage of non-crop area Overall biodiversity condition: crop richness Overall biodiversity condition: crop rotation Ecosystem connectivity
Equity	Education	Education of farmers Education status of farmers' male children Education status of farmers' female children Access to electronic media
	Economic	Farm profitability Average wage of farm laborer (US$) Livelihood diversity other than agriculture Years of economic hardship Road network (establishing farm roads and access roads)
	Health	Settings where treatment is provided Sanitation or public health
	Gender	Women's involvement in decision making about agricultural activities Gender-based wage differentials

Source: Talukder, 2012. Note: The indicators are related. For example, protein yield from the agro-ecosystem depends on weighted yield of the main staple crop (rice).

3.4 Developing composite indicators

The concept of composite indicators was introduced in the 1990s to capture the complexity and multidimensionality of a range of development issues (Sumner & Tezanos, 2014). Since then, international organizations like the United Nations, World Bank, and European Commission have developed composite indicators (Foa & Tanner, 2012) such as the Human Development Index (HDI), Environmental Performance Index (EPI), Gender Empowerment Measure (GEM) and Quality of Life Index. In the literature, the term "composite indicator" often refers to an index made up of aggregated data, ratings, league tables, and multidimensional measures (Benini, 2012; Nardo et al., 2005; Saisana & Saltelli, 2011). Bandura and Martin del Campo (as cited in Foa & Tanner, 2012) found 160 composite indicators used around the world.

Although composite indicators are being used extensively, there is a spirited debate over the conceptual and methodological parameters for this measurement technique (Cherchye et al., 2007). For example, Sharpe (2004) argued that producing a composite indicator/index is not a good idea because a single indicator is not appropriate to explain and compare any observed phenomenon and does not capture the relative importance of the components of the composite indicators (Nardo et al., 2005). In spite of this limitation, composite indicators are desirable among policy makers and stakeholders due to their capacity to summarize complex issues (Saisana et al., 2005), allow for cross comparisons, enable evaluation of results, set the bar for performance and indicate the steps of accomplishment of a project (Munda & Saisana, 2011). They are also useful for generating media interest about a phenomenon (Sharpe, 2004). Comprehensive discussions of the advantages and disadvantages of composite indicators are documented in Booysen (2002), Foa & Tanner (2012) and Nardo et al. (2005).

Conceptually, composite indicators are based on sub-indicators that may have no common meaningful unit of measurement (Nardo et al., 2005). Technically, composite indicators are mathematical combinations of a set of multidimensional indicators (Nardo et al., 2005; Saisana et al., 2005) and normal measures that combine the issues of a complex phenomenon (Booysen, 2002). Therefore, the construction of composite indicators requires transparency as to its process to facilitate replication and debate among stakeholders (Saisana et al., 2005). The construction of composite indicators requires more craftsmanship by the modeler than universally accepted scientific rules for encoding indicators (Nardo et al., 2005). Basically, a typical composite indicator "I" is built as follows (OECD, 2008):

$$I = \sum_{i=1}^{n} w_i \, x_i$$

Where

x_i = normalized variable

w_i = weight attached to x_i

$\sum_{i=1}^{n} w_i$ = 1 and $0 \leq w_i \leq 1, i = 1,2, \dots, n.$

From this formula, it is clear that a composite indicator requires a weighted linear aggregation rule that is applied to a set of variables. The formula indicates that normalization and weighted summation of the normalized variables are the two main steps for developing composite indicators.

Data can be aggregated without being scaled if all the variables are measured with the same unit (e.g., percent or ratios), but there are many situations when an attempt is made to aggregate variables that have different units and different measurement techniques (Salzman, 2003). Normalization simply means putting different variables on a common scale so that data can be compared to each other (Nardo et al., 2005). Indicators have different units, so they may be measured by various scales such as nominal, ordinal, interval and ratio. Normalization is the process by which the indicators in various scales and units are compared on a common basis, as depicted in Figure 3.4. It is, therefore, the process of reducing the measurements to a standard scale (Sajeva et al., 2005) which helps to avoid the dominance of extreme values in a data set and partially corrects data quality problems (Freudenberg, 2003). Normalization of indicators is required to make the indicators mathematically operational in aggregation (Gomez-Limon & Sanchez-Fernandez, 2010).

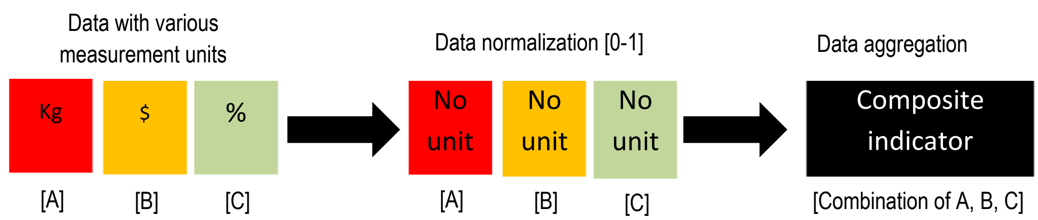

Figure 3.4: Generalized graphical representation of normalization for constructing a composite indicator

Every step of data transformation and/or normalization increases uncertainty and measurement error probability (Hudrlikova & Kramulova, 2013). Accordingly, the choice of the proper normalization technique is indisputably important. In developing composite indicators, the selection of a preferred normalization technique deserves special care, taking into account the objectives of the composite indicators as well as the data properties and the potential requirement of further analysis (Ebert & Welsch, 2004; Nardo et al., 2005). Different normalization techniques produce different results (OECD, 2008) and may have major effects on composite scores (Cherchye et al., 2007; Tate, 2012).

3.4.1 Methodology for developing composite indicators

Here, five normalization techniques are examined to investigate their effect and to identify the preferred technique for constructing composite indicators for coastal agricultural sustainability assessment in Bangladesh. Figure 3.5 shows the construction and evaluation process of the individual composite indicators. Sustainability was categorized in terms of productivity, stability, efficiency, durability, compatibility and equity. The indicators in Table 3.4 and groupings of the indicators fall under the broad heading of each sustainability category (Table 3.5) and are used to develop 15 composite indicators. Various normalizations, weightings and aggregation techniques were applied to reach the final set of composite indicators.

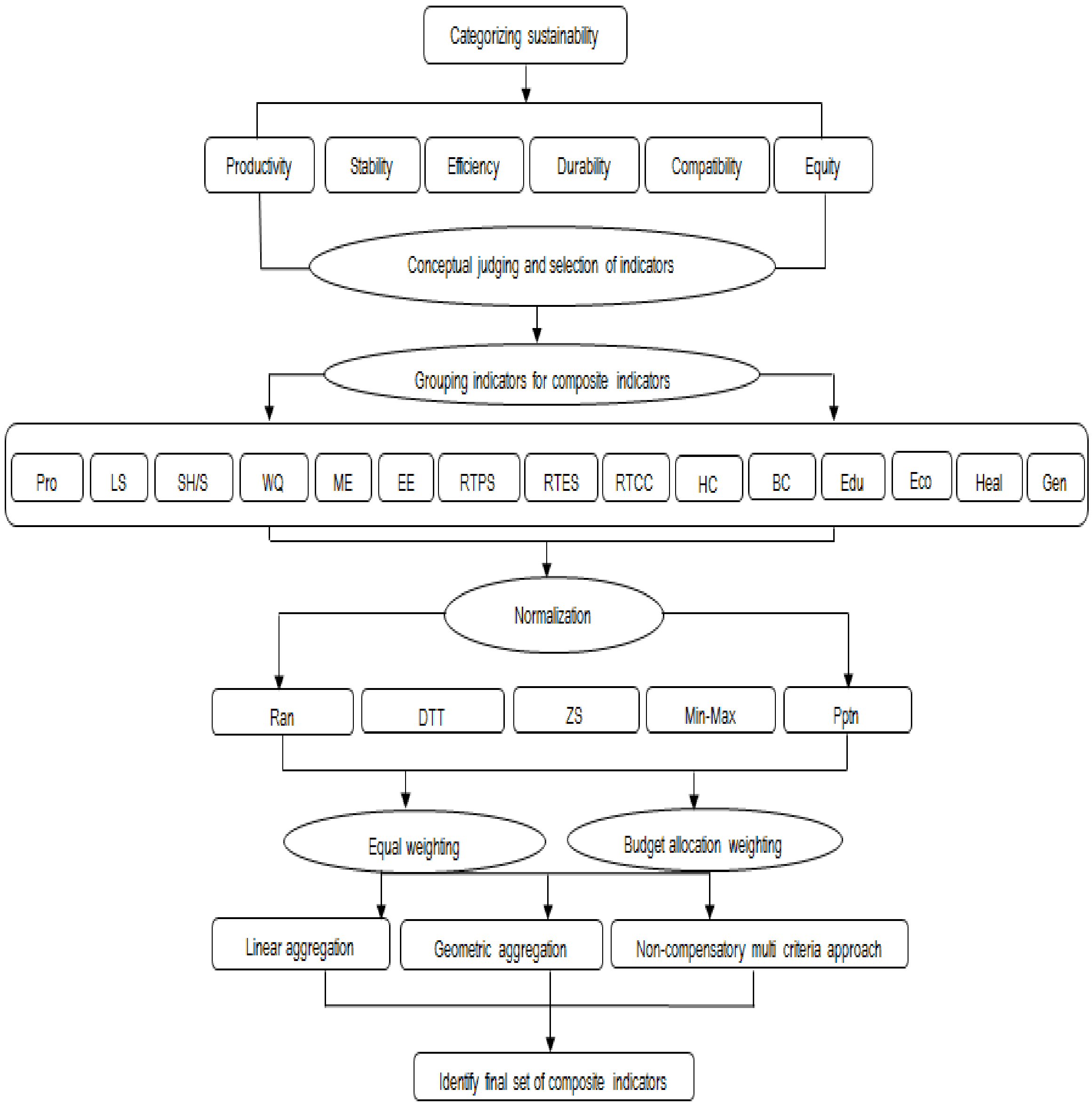

Figure 3.5: Scheme for the construction and evaluation process for single composite indicators. Legend: Pro = Productivity; LS = Landscape stability; SH/S = Soil health/ stability; WQ = Water quality; ME = Monetary efficiency; EE = Energy efficiency; RTPS =Resistance to pest stress; RTES = Resistance to economic stress; RTCC = Resistance to climate change; HC = Human compatibility; BC = Biophysical compatibility; Edu = Education; Eco = Economic; Heal = Health; Gen = Gender; Pptn = Proportionate; Ran = Ranking; DTT = Distance to target; CS = Categorical scale; Min-Max = Min-max technique; ZS = Z-score. Source: Compiled by the authors.

3.4.2 Normalization

A variety of transformation and/or normalization techniques are available (e.g., Blanc et al., 2008; Freudenberg, 2003; Nardo et al., 2009; Pomerol & Barba-Romero, 2012), but only the five most widely employed techniques (Nardo et al., 2009; Tofallis, 2014) are shown in Table 3.6. These five techniques are ranking, distance to target, z-score, min-max and proportionate normalization. The first four are the most commonly used normalization techniques (Saisana & Saltelli, 2011; OECD, 2008). For example, min-max is used in the Human Development Index. The proportionate normalization technique was considered because of its suitability for the development of composite indicators.

Table 3.6: Selected normalization techniques for this study

Name	Formula	Explanation
[1]Ranking	$N_{ias} = Rank(X_{ias})$	Where $\mathrm{N_{ias}}$ = Normalized value of indicator i for agricultural systems as, X_{ias} = Variable X for indicator i for agricultural systems as
[1]Distance to target	$N_{ias} = \frac{X_{ias}}{Target\ X_{ias}}$	Where N_{ias}= Normalized value of indicator i for agricultural systems as, X_{ias} = Variable X for indicator i for agricultural systems as
[1]Z-score (Standardization)	$N_{ias} = (X_{ias} - \mu)/\ \sigma$	Where N_{ias} = Normalized value of indicator i for agricultural systems as, X_{ias}= Variable X for indicator i for agricultural systems as, μ (Mu) = Mean of indicator values, σ (Sigma) = Standard deviation (square root of the variance) of indicators
[1]Min-max	$N_{ias} = \frac{X_{ias} - min_{as}(X_i)}{max_{as}(X_{ias}) - min_{as}(X_i)'}$	Where N_{ias} = Normalized value of indicator i for agricultural systems as, $\mathrm{X_i}$= Indicator, X_{ias}= Variable X for indicator i for agricultural systems as, max_{as} and min_{as} are the largest and smallest observed values
[2,3]Proportionate	$N_{ias} = \frac{I_i}{\sum_i I_i}$ $0 < N_{ias} < 1$	Where I_i = Indicator value, $\sum_i I_i$ = Sum of the indicators

Source: [1]Nardo et al. (2009); [2]Dailey (2000); [3]Pomerol & Barba-Romero (2012)

3.4.2.1 Ranking normalization

Ranking normalization replaces measurements with their rank. In the rank normalization process each data point is replaced by its rank, that is, by values ranging from 1 (lowest) to N (highest) (Mitchell, 2012). In this system, there is no score, only a rank; the absolute-level information is lost. This technique, while simple, cannot lead to any conclusion about the differences among performances of the indicator being assessed because there is no measure of the distance between values of the indicators (Jacob et al., 2004). Ranking normalization is employed in the "Information and Communications Technology Index" (Freudenberg, 2003) and "Medicare Study on Healthcare Performance across the United States" (Jencks et al., 2003).

3.4.2.2 Distance to target normalization

In the distance to target normalization technique, the indicator's value is divided by the target value to normalize the indicator (Saisana & Saltelli, 2011) so that the normalized values represent a fraction of the highest value. The highest value of the indicator set or any reference point can be the target value. The results of this technique are easy to handle and understand, but imbalance between scores and rankings remains, and the normalization results are more influenced by outliers than in other techniques. This method is useful for further analysis (e.g., geometric aggregation) since it does not generate any zero values. However, if outliers are chosen as target points, the result can be misleading. The distance to target normalization technique is used in "Eco-indicator 99" and the "Summary Innovation Index" (Saisana & Tarantola, 2002).

3.4.2.3 Z-score normalization

Z-score normalization is calculated by subtracting the mean from an indicator value and then dividing by its standard deviation. If the standard deviation is calculated for a set of variables with a mean of 0 and then all values are divided by the standard deviation, the resulting set of values will have a standard deviation of 1 (Salzman, 2003). After performing normalization, the data have a common scale with a 0 mean and standard deviation of 1. Since all Z-score distributions have the same mean and standard deviation, individual scores from different distributions can be directly compared. The advantage of this technique is that it provides no distortion from the mean, adjusting for different scales and variance. The output is dimensionless, and the relative differences are maintained due to the application of a linear transformation (Mei & Grummer-Strawn, 2007). Z-score is preferred when extreme values exist in the dataset (Nardo et al., 2005; Tate, 2012). Although the technique does not fully adjust for outliers, the minimum and maximum values are not as influential as in other techniques such as distance to target. As an extreme value for an indicator has a greater effect on a composite indicator, this technique is more representative of the original data. It is desirable that exceptional behaviour should be rewarded if excellent performance on a few indicators is considered to be better than other average performances (OECD, 2008; Salzman, 2003). The Z-scores technique is widely employed, such as in the knowledge-based economy index (WB, 2009). The World Health Organization also used it for its child growth standards index (de Onis, 2006).

3.4.2.4 Min-max normalization

The Min-max technique rescales data into different intervals based on minimum and maximum values. The advantage of this method is that boundaries can be set and all indicators have an identical range (0, 1). However, the normalized values do not maintain proportionality, and normalized values reflect the percentage of the range of $max_{as}(X_{ias}) - min_{as}(X_{ias})$. This technique is based on extreme values (minimum and maximum), but because these two values can be outliers, the range of max and min strongly influences the final output. Another disadvantage is that the difference in variance is not fully eliminated (OECD, 2008). Nevertheless, this technique is very popular and has been applied in the construction of many composite indicators, the best-known of which is the Human Development Index (HDI, UNDP, 2014).

3.4.2.5 Proportionate normalization

In proportionate normalization, the single attribute value is divided by the sum total of the values of attributes (Dailey, 2000; Tofallis, 2014). The normalized values maintain proportionality such that the normalized value reflects the percentage of the sum of the total value of the indicators. Here, values of the indicator are relatively normalized. Normalizing the indicators by dividing them by their sums has a number of attractive properties, including that the normalized values are identical to the original except for a scaling factor and the process is easily understandable. The value differences among indicators become narrow. Dividing by the sum ensures that even the smallest value greater than zero comes out with a positive normalized value (Benini, 2012; Tofallis, 2014). The proportionate normalization technique is frequently used in normalizing census data in ArcView GIS (Geographical Information System, Dailey, 2000). Benini (2012) also suggested using this technique for developing composite measures for disaster impact assessment.

3.4.3 Weighting

The final score and ranking of the composite indicators depend on the weighting of the normalized values of the indicators. Weighting reflects the importance of each indicator relative to the overall composite indicators (Saisana & Saltelli, 2011). Weights should ideally be selected according to an underlying and agreed-upon or at least clearly stated theoretical framework so that the process is transparent (Decancq & Lugo, 2008; Sen & Foster, 1997). Weighting can be a very important step in creating composite indicators before aggregation can take place because it modifies the sub-indicator values. However, Sajeva et al. (2005) showed that the use of different weighting schemes has no real effect on the ranking of the composite indicators. For example, Dantsis et al. (2010) showed that weighting does not affect the ranking of the composite indicators. This observation is also confirmed in the later part of the thesis. No agreed-upon methodology exists to weight individual indicators. Different types of weighting techniques and their explanations are provided by Nardo et al. (2005).

In this thesis, equal weighting is used for all rank, distance to target, z-score, max-min and proportionate normalization and arithmetic mean and geometric mean aggregation. In equal weighting, all sub-indicators are given the same weight. Simplicity is the main advantage of equal weighting, but the composite indicator that is developed by the combination of more indicators will have a stronger influence on the list of composite indicators. Using this weighting system may be justified when no other available means of weighting are known (Hudrlikova & Kramulova, 2013). Equal weighting is used in the HDI (UNDP, 2011). Budget allocation techniques for weighting are used for MCA aggregation (as shown in Table 3.4). A budget allocation technique for weighting is chosen because the sustainability of agriculture is very contextual, so stakeholders' opinions are very important for weighting of the indicators. Geometric and multi-criteria as well as linear aggregation can be employed with these weightings (OECD, 2008). The OECD's Handbook on Constructing Composite Indices (2008) describes expert weighting as a budget allocation technique. In expert weighting, an expert allocates 100 points among indicators according to their importance (Saisana & Saltelli, 2011). Selection of the appropriate expert and number of experts is the biggest problem for this system because point allocation may be influenced by the expert's experience (Hudrlikova & Kramulova, 2013). This subjective judgment of the weights of sub-indicators is used to allocate relative worth for each sub-indicator (Cherchye et al., 2007). Subjective weighting is often affected by strong inter-individual disagreement (Freudenberg, 2003) and is particularly sensitive in the case of complex, interrelated and multidimensional phenomena (Nardo et al., 2005). Nevertheless, Sen and Foster (1997:206) pointed out that "while the possibility of arriving at a unique set of weights is rather unlikely, that uniqueness is not really necessary to make acceptable judgments in many situations, and may indeed not even be required for a complete ordering."

3.4.4 Aggregation

The rules for aggregation are well documented in the Handbook on Constructing Composite Indices (OECD, 2008), but steps are still debated in the development of composite indicators (Saltelli, 2007). The fundamental issue in aggregation is compensability of indicators, which is defined as compensating for any indicator's dimension with a suitable surplus in another indicator's dimension. The rules for aggregating composite indicators can be compensatory or non-compensatory (Tarabusi & Guarini, 2013). A compensatory technique deals with the unbalances in the indicators and uses linear functions, whereas non-compensatory techniques use unbalance-adjusted functions (Mazziotta & Pareto, 2015). Different aggregation rules are possible to develop composite indicators. Commonly applied aggregation options include additive aggregation (arithmetic mean), geometric aggregation (multiplication) and multi-criteria analysis (OECD, 2008).

The arithmetic mean is a linear function (Munda & Nardo, 2005). The normalized and weighted or unweighted indicators are summed to compute the arithmetic mean[4] (Booysen, 2002; Tate, 2012). In this method, compensability can be a disadvantage if a low value in one indicator or dimension masks a high value in another, that is, a deficit in one indicator or dimension can be compensated for by a surplus in another (Tate, 2012, Hudrlikova & Kramulova, 2013).

Geometric aggregation, which is the product of normalized weighted indicators, is used to avoid concerns related to interaction and compensability (Tate, 2012). Non-comparable data measured in a ratio scale can only be meaningfully aggregated by using geometric functions, provided that indicators are strictly positive (Nardo et al., 2005; Hudrlikova & Kramulova, 2013). A geometric mean[5] takes into consideration differences in achievement across dimensions (Nardo et al., 2005). Poor performance in any dimension or indicator is directly reflected in the composite indicator's value. According to Hudrlikova and Kramulova (2013), this technique is partly compensable since it rewards composite indicators with higher indicator scores.

"When different goals are equally legitimate and important, and in addition trade-offs exist between the dimensions of a composite indicator (namely negative correlations between dimensions) then a non-compensatory logic may be necessary" (Saisana & Saltelli, 2011:256). Multi-Criteria Analysis (MCA) is used for aggregating non-compensatory data (Mazziotta & Pareto, 2015). In general, MCA provides an overall ranking based on the weight and values of given indicators. One of the shortcomings of MCA is that when the number of indicators to develop composite indicators is high, it is difficult to compute MCA (Hudrlikova & Kramulova, 2013). MCA is based on an outranking matrix. The standard procedure for performing an MCA consists of three steps:

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[4] The formula for evaluating arithmetic mean is $\bar{x} = \frac{\sum_{i=1}^{n} \bar{x}}{N}$

[5] The formula for evaluating geometric mean is $(\prod_{i=1}^{n} x_1)^{\frac{1}{n}}$

identifying the weighting of the criteria, preparing an “outranking matrix” by pairwise comparison of the weighted performance of each criterion[6] (EC, 2015), and calculating the composite indicator score of the criteria by adding the values of the row of the outranking matrix (Brand et al., 2007).

3.4.5 Robustness

The outcome of the composite indicators depends on the selection of variables, normalization, weighting (if it is used) and aggregation techniques (Nardo et al., 2005), so it is necessary to examine the robustness of the developed composite indicators. Various statistical tests can help ensure that the composite is reliable. Freudenberg (2003) and Hudrlikova and Kramulova (2013) mentioned correlation as a technique to assess the impacts of different normalization techniques on composite indicators. The correlation coefficient can show whether the results of the composite indicator are heavily influenced by the choice of normalization rules (Hudrlikova & Kramulova, 2013) and aggregation methods. In this thesis, correlation is used to assess the robustness of composite indicators.

3.4.6 Results and discussion for developing composite indicators

The results for the composite indicators using various normalization techniques, weighting and different aggregation techniques are presented in Tables 3.7-3.12. The results of the robustness tests of the composite indicators are presented in Tables 3.14-3.27.

[6] For n options, there are n (n-1)/2 comparisons.

Table 3.7: Results of composite indicators after applying rank normalization and aggregation techniques

Results of rank normalization and geometric mean						
Category	Composite indicators	S	SR	R	I	T
Productivity	Productivity	1.00	2.62	4.31	4.64	2.29
Stability	Landscape stability	1.12	1.41	1.70	1.78	1.82
	Soil health/ stability	1.91	2.33	2.24	1.59	2.40
	Water quality	1.00	1.59	1.59	2.00	2.62
Efficiency	Monetary efficiency*	0.10	0.14	0.18	0.43	0.15
	Energy efficiency	1.00	2.00	3.00	4.47	4.47
Durability	Resistance to pest stress	1.68	2.21	1.97	2.00	1.71
	Resistance to economic stress	3.42	3.30	2.88	3.17	1.00
	Resistance to climate change	3.17	3.91	1.82	3.68	0.14
Compatibility	Human compatibility	1.00	2.00	2.45	2.83	2.45
	Biophysical compatibility	1.19	1.41	3.56	2.71	3.31
Equity	Education	2.45	2.91	3.36	5.00	1.19
	Economic	1.74	2.27	2.93	2.93	1.82
	Health	2.00	4.47	2.45	3.16	1.73
	Gender	1.41	2.45	3.46	4.47	1.00
Results of rank normalization and arithmetic mean						
Category	Composite indicators	S	SR	R	I	T
Productivity	Productivity	1.00	2.67	4.33	4.67	2.33
Stability	Landscape stability	1.17	1.50	1.83	1.83	2.00
	Soil health/stability	2.17	2.50	2.50	1.67	2.67
	Water quality	1.00	1.67	1.67	2.33	2.67
Efficiency	Monetary efficiency*	0.10	0.14	0.18	0.43	0.15
	Energy efficiency	1.00	2.00	3.00	4.50	4.50
Durability	Resistance to pest stress	1.75	2.25	2.50	2.50	2.00
	Resistance to economic stress	3.67	3.33	3.00	3.33	1.00
	Resistance to climate change	3.33	4.00	2.00	4.00	1.67
Compatibility	Human compatibility	1.00	2.00	2.50	3.00	2.50
	Biophysical compatibility	1.25	1.50	3.75	2.75	3.50
Equity	Education	2.50	3.00	3.50	5.00	1.25
	Economic	2.00	2.60	3.00	3.00	2.20
	Health	2.50	4.50	2.50	3.50	2.00
	Gender	1.50	2.50	3.50	4.50	1.00

Legend: S = Bagda (shrimp)-based agricultural systems (S) from Shyamnagar, SR = Bagda-rice-based agricultural systems (SR) from Kalijang, R = Rice-based agricultural systems (R) from Kalaroa, I = Galda-rice-vegetable-based integrated agricultural systems (I) from Dumuria and T = traditional practices-based agricultural systems (T) from Bhola Sadar. *Only proportionate normalization, no aggregation.

Table 3.8: Results of composite indicators after applying distance to target normalization and aggregation techniques

Category	Composite indicators	S	SR	R	I	T
Results of distance to target normalization and geometric mean						
Category	Composite indicators	S	SR	R	I	T
Productivity	Productivity	0.19	0.47	0.89	0.88	0.42
Stability	Landscape stability	0.51	0.64	0.72	0.76	0.79
	Soil health/stability	0.59	0.81	0.79	0.56	0.83
	Water quality	0.35	0.55	0.55	0.69	0.91
Efficiency	Monetary efficiency*	0.10	0.14	0.18	0.43	0.15
	Energy efficiency	0.27	0.35	0.90	0.97	0.98
Durability	Resistance to pest stress	0.57	0.75	0.46	0.47	0.41
	Resistance to economic stress	0.98	0.80	0.77	0.81	0.67
	Resistance to climate change	0.59	0.67	0.26	0.73	0.14
Compatibility	Human compatibility	◘	0.89	0.95	1.00	0.95
	Biophysical compatibility	0.30	0.42	0.98	0.75	0.90
Equity	Education	0.78	0.85	0.76	1.00	0.46
	Economic	0.59	0.82	0.79	0.81	0.58
	Health	0.62	0.76	0.66	0.92	0.65
	Gender	0.24	0.27	0.38	0.47	◘
Results of distance to target normalization and arithmetic mean						
Category	Composite indicators	S	SR	R	I	T
Productivity	Productivity	0.21	0.50	0.89	0.89	0.44
Stability	Landscape stability	0.54	0.71	0.76	0.79	0.83
	Soil health/stability	0.74	0.82	0.83	0.60	0.86
	Water quality	0.36	0.56	0.56	0.72	0.92
Efficiency	Monetary efficiency*	0.10	0.14	0.18	0.43	0.15
	Energy efficiency	0.27	0.35	0.90	0.97	0.98
Durability	Resistance to pest stress	0.67	0.78	0.55	0.54	0.38
	Resistance to economic stress	0.98	0.82	0.80	0.85	0.70
	Resistance to climate change	0.59	0.72	0.29	0.79	0.28
Compatibility	Human compatibility	0.25	0.90	0.95	1.00	0.95
	Biophysical compatibility	0.34	0.43	0.99	0.77	0.90
Equity	Education	0.78	0.85	0.79	1.00	0.47
	Economic	0.66	0.83	0.83	0.83	0.65
	Health	0.66	0.79	0.68	0.92	0.67
	Gender	0.33	0.35	0.51	0.61	0.04

Legend: S = Bagda (shrimp)-based agricultural systems (S) from Shyamnagar, SR = Bagda-rice-based agricultural systems (SR) from Kalijang, R = Rice-based agricultural systems (R) from Kalaroa, I = Galda-rice-vegetable-based integrated agricultural systems (I) from Dumuria and T = traditional practices-based agricultural systems (T) from Bhola Sadar. *Only proportionate normalization, no aggregation. ◘ means calculation is not possible due to a zero value of one of the indicators. The reasons for the zero values are explained later in this section in page 84-87.

Table 3.9: Results of composite indicators after applying z-score normalization and aggregation techniques

Results of Z-score normalization and geometric mean						
Category	Composite indicators	S	SR	R	I	T
Productivity	Productivity	◘	◘	0.96	0.97	◘
Stability	Landscape stability	◘	◘	◘	◘	◘
	Soil health/stability	◘	◘	◘	◘	◘
	Water quality	◘	◘	◘	◘	1.23
Efficiency	Monetary efficiency*	0.10	0.14	0.18	0.43	0.15
	Energy efficiency	◘	◘	0.63	0.86	0.91
Durability	Resistance to pest stress	◘	◘	◘	◘	◘
	Resistance to economic stress	◘	◘	◘	◘	◘
	Resistance to climate change	◘	◘	◘	◘	0.14
Compatibility	Human compatibility	◘	0.33	0.50	0.62	0.50
	Biophysical compatibility	◘	◘	1.12	◘	0.71
Equity	Education	◘	◘	◘	1.16	◘
	Economic	◘	◘	◘	◘	◘
	Health	◘	◘	◘	◘	◘
	Gender	◘	◘	0.64	1.38	◘
Results of z-score normalization and arithmetic mean						
Category	Composite indicators	S	SR	R	I	T
Productivity	Productivity	-1.29	-0.27	1.03	1.08	-0.54
Stability	Landscape stability	0.09	0.54	-0.10	-0.06	-0.47
	Soil health/stability	0.84	-0.04	-0.01	0.56	-1.34
	Water quality	0.16	0.78	-0.85	0.78	-0.86
Efficiency	Monetary efficiency*	0.10	0.14	0.18	0.43	0.15
	Energy efficiency	-1.34	-1.08	0.64	0.87	0.91
Durability	Resistance to pest stress	0.09	0.54	-0.10	-0.06	-0.47
	Resistance to economic stress	0.84	-0.04	-0.01	0.56	-1.34
	Resistance to climate change	0.16	0.78	-0.85	0.78	-0.86
Compatibility	Human compatibility	-1.98	0.36	0.50	0.63	0.50
	Biophysical compatibility	-1.32	-0.94	1.14	0.35	0.77
Equity	Education	-0.03	0.30	0.11	1.18	-1.56
	Economic	-0.50	-0.05	0.54	0.42	-0.42
	Health	-0.45	0.87	-0.37	0.71	-0.76
	Gender	-0.47	-0.12	0.65	1.40	-1.46

Legend: S = Bagda (shrimp)-based agricultural systems (S) from Shyamnagar, SR = Bagda-rice-based agricultural systems (SR) from Kalijang, R = Rice-based agricultural systems (R) from Kalaroa, I = Galda-rice-vegetable-based integrated agricultural systems (I) from Dumuria and T = traditional practices-based agricultural systems (T) from Bhola Sadar. *Only proportionate normalization, no aggregation. ◘ means calculation is not possible due to a zero value of one of the indicators. The reasons for the zero values are explained later in this section in page 84-87.

Table 3.10: Results of composite indicators after applying max-min normalization and aggregation techniques

Results of max-min normalization and geometric mean						
Category	Composite indicators	S	SR	R	I	T
Productivity	Productivity	¤	0.34	0.84	0.86	0.22
Stability	Landscape stability	¤	¤	¤	¤	¤
	Soil health/stability	¤	¤	¤	¤	¤
	Water quality	¤	¤	¤	¤	0.87
Efficiency	Monetary efficiency*	0.10	0.14	0.18	0.43	0.15
	Energy efficiency	¤	0.11	0.86	0.96	0.98
Durability	Resistance to pest stress	¤	0.70	¤	¤	¤
	Resistance to economic stress	0.75	0.45	0.38	0.54	¤
	Resistance to climate change	0.48	0.66	¤	0.45	0.14
Compatibility	Human compatibility	¤	0.89	0.95	1.00	0.95
	Biophysical compatibility	¤	¤	0.98	0.67	0.84
Equity	Education	0.56	0.65	¤	1.00	¤
	Economic	¤	¤	0.68	0.53	¤
	Health	¤	0.52	0.19	0.45	¤
	Gender	0.26	0.46	0.73	1.00	¤
Results of max-min normalization and arithmetic mean						
Category	Composite indicators	S	SR	R	I	T
Productivity	Productivity	0.00	0.38	0.85	0.88	0.27
Stability	Landscape stability	0.17	0.50	0.54	0.63	0.67
	Soil health/stability	0.67	0.66	0.71	0.37	0.75
	Water quality	0.00	0.28	0.28	0.50	0.89
Efficiency	Monetary efficiency*	0.10	0.14	0.18	0.43	0.15
	Energy efficiency	0.00	0.11	0.86	0.96	0.98
Durability	Resistance to pest stress	0.60	0.75	0.38	0.39	0.25
	Resistance to economic stress	0.81	0.49	0.50	0.72	0.00
	Resistance to climate change	0.49	0.71	0.15	0.70	0.14
Compatibility	Human compatibility	0.00	0.90	0.95	1.00	0.95
	Biophysical compatibility	0.02	0.15	0.98	0.69	0.85
Equity	Education	0.57	0.69	0.58	1.00	0.00
	Economic	0.35	0.50	0.79	0.72	0.34
	Health	0.19	0.64	0.22	0.60	0.08
	Gender	0.34	0.47	0.74	1.00	0.00

Legend: S = Bagda (shrimp)-based agricultural systems (S) from Shyamnagar, SR = Bagda-rice-based agricultural systems (SR) from Kalijang, R = Rice-based agricultural systems (R) from Kalaroa, I = Galda-rice-vegetable-based integrated agricultural systems (I) from Dumuria and T = traditional practices-based agricultural systems (T) from Bhola Sadar. *Only proportionate normalization, no aggregation. ¤ means calculation is not possible due to a zero value of one of the indicators. The reasons for the zero values are explained later in this section in page 84-87.

Table 3.11: Results of composite indicators after applying proportionate normalization and aggregation techniques

Category	Composite indicators	S	SR	R	I	T
Results of proportionate normalization and geometric mean						
Productivity	Productivity	0.07	0.16	0.30	0.30	0.14
Stability	Landscape stability	0.14	0.18	0.20	0.21	0.22
	Soil health/stability	0.15	0.21	0.21	0.15	0.22
	Water quality	0.11	0.18	0.18	0.22	0.29
Efficiency	Monetary efficiency*	0.10	0.14	0.18	0.43	0.15
	Energy efficiency	0.07	0.16	0.30	0.30	0.14
Durability	Resistance to pest stress	0.20	0.26	0.16	0.16	◘
	Resistance to economic stress	0.24	0.20	0.19	0.20	0.17
	Resistance to climate change	0.22	0.25	0.10	0.27	◘
Compatibility	Human compatibility	◘	0.22	0.24	0.25	0.24
	Biophysical compatibility	0.09	0.12	0.29	0.22	0.26
Equity	Education	0.20	0.22	0.20	0.26	0.12
	Economic	0.16	0.22	0.21	0.22	0.15
	Health	0.17	0.21	0.18	0.25	0.18
	Gender	0.16	0.19	0.26	0.32	◘
Results of proportionate normalization and arithmetic mean (additive aggregation)						
Category	**Composite indicators**	**S**	**SR**	**R**	**I**	**T**
Productivity	Productivity	0.07	0.16	0.30	0.30	0.14
Stability	Landscape stability	0.14	0.18	0.20	0.21	0.22
	Soil health/stability	0.15	0.21	0.21	0.15	0.22
	Water quality	0.11	0.18	0.18	0.22	0.29
Efficiency	Monetary efficiency*	0.10	0.14	0.18	0.43	0.15
	Energy efficiency	0.07	0.16	0.30	0.30	0.14
Durability	Resistance to pest stress	0.20	0.26	0.16	0.16	0.14
	Resistance to economic stress	0.24	0.20	0.19	0.20	0.17
	Resistance to climate change	0.22	0.25	0.10	0.27	0.14
Compatibility	Human compatibility	0.11	0.22	0.24	0.25	0.24
	Biophysical compatibility	0.08	0.12	0.30	0.21	0.27
Equity	Education	0.20	0.22	0.20	0.26	0.12
	Economic	0.16	0.22	0.21	0.22	0.15
	Health	0.17	0.21	0.18	0.25	0.18
	Gender	0.16	0.19	0.26	0.32	0.12

Legend: S = Bagda (shrimp)-based agricultural systems (S) from Shyamnagar, SR = Bagda-rice-based agricultural systems (SR) from Kalijang, R = Rice-based agricultural systems (R) from Kalaroa, I = Galda-rice-vegetable-based integrated agricultural systems (I) from Dumuria and T = traditional practices-based agricultural systems (T) from Bhola Sadar. *Only proportionate normalization, no aggregation. ◘ means calculation is not possible due to a zero value of one of the indicators. The reasons for the zero values are explained later in this section in page 84-87.

Table 3.12: Results of composite indicators after applying weight and multi-criteria aggregation

Results of multi-criteria analysis (MCA) aggregation						
Category	Composite indicators	S	SR	R	I	T
Productivity	Productivity	0.00	1.40	3.20	4.00	1.20
Stability	Landscape stability	1.30	2.85	3.25	3.25	2.90
	Soil health/stability	2.40	2.70	2.80	1.40	3.00
	Water quality	3.20	2.60	2.60	3.40	3.60
Efficiency	Monetary efficiency*	0.10	0.14	0.18	0.43	0.15
	Energy efficiency	0.00	2.00	5.00	7.40	6.40
Durability	Resistance to pest stress	2.25	2.75	2.50	2.50	2.00
	Resistance to economic stress	3.10	2.35	2.25	2.95	0.00
	Resistance to climate change	2.60	3.00	1.30	3.10	0.00
Compatibility	Human compatibility	0.00	2.50	3.50	4.00	3.50
	Biophysical compatibility	0.75	0.75	3.75	2.75	3.50
Equity	Education	1.50	2.00	2.25	4.00	0.25
	Economic	1.20	2.60	3.00	3.00	1.60
	Health	2.50	3.50	1.50	2.50	1.00
	Gender	1.50	2.00	3.00	4.00	0.00

Legend: S = Bagda (shrimp)-based agricultural systems (S) from Shyamnagar, SR = Bagda-rice-based agricultural systems (SR) from Kalijang, R = Rice-based agricultural systems (R) from Kalaroa, I = Galda-rice-vegetable-based integrated agricultural systems (I) from Dumuria and T = traditional practices-based agricultural systems (T) from Bhola Sadar. *Only proportionate normalization, no aggregation.

The values of data and different normalization techniques and arithmetic aggregation imply different assumptions and have specific consequences that produce different results for the composite indicators (Tables 3.7-3.12). In this regard, Nardo et al. (2005) mentioned that the ranking of composite indicators is heavily influenced by the nature of the data. Saisana and Saltelli (2011) also pointed out that it is beyond doubt that composite indicators are a value-laden construct. In arithmetic aggregation it is also observed that poor performance in some indicators is covered by sufficiently high values of other indicators in composite indicators.

In the dataset, the score for some of the indicators is “0”. For example, as shown in Table 3.4, in the compatibility category ‘S’ scored “0” in drinking water quality. Indicators which have “0” scores have the normalization result “0” in proportionate, distance and z-score normalization, but not a “0” ranking normalization since the score “0” is ranked as the lowest number. The max-min normalization also generates “0” scores as normalized values. Whenever the normalization score is “0” or negative, those indicators are not suitable for geometric mean aggregation because geometric aggregation requires all positive numbers. Geometric aggregation is appropriate when indicator values are always positive (Nardo et al, 2005).

When aggregation was carried out considering indicators’ values and budget allocation weight and MCA techniques, the results also generated different values for some of the composite indicators (Table 3.12) compared to other types of aggregation. Due to the nature of the data, MCA also generates “0” values for productivity, energy efficiency and human compatibility composite indicators of ‘S’ as well as “0” values for resistance to economic stress, resistance to climate change and gender composite indicators of ‘T’ (Table 3.12). Therefore, budget allocation weighting and MCA combinations cannot be recommended for composite indicators.

These different values of the composite indicators by applying different combination of normalization techniques, weighting and aggregation reflect that the properties of the indicators are very crucial for the final output values of the composite indicators. This study shows that the normalization technique and arithmetic mean and geometric mean should take into account the data properties, as well as the objectives of the composite indicator. From the results it appears that not all normalization techniques are suitable for the dataset, and not all normalization techniques support arithmetic mean and geometric mean. Even when MCA techniques are applied, some “0” values are generated for the composite indicators.

Nardo et al. (2005) suggested that in the case of non-compensatory composite indicators, MCA is the best way to develop indicator values. However, due to the nature of the present dataset, MCA is not suitable for this experiment because the “0” scores of some of the indicators do not reflect the weight of the indicator, so the results may be difficult to interpret and compare. In MCA, composite indicators are based on weight, so the magnitudes of values of the different indicators are disregarded in the composite. “This means any issue that does marginally better on many indicators score highest than the issue that does a lot better on a few indicators because outstanding performances of the indicators cannot compensate for the deficiencies in some indicators” (Saltelli et al., 2005:364).

In this study it is observed that proportionate normalization produced values that conserve the proportionality of the indicator values (Table 3.11), whereas other normalization techniques show different outcomes. For example, the normalization results of rank, distance to target, z-score, max-min and proportionate normalization for weighted yield of rice indicators of ‘S’ in Table 3.4 are 1, 0.35, -1, 0 and 0.11 respectively. Here only the 0.11 that is generated using proportionate normalization represents the proportionate value of the original score 2.26 of weighted yield of rice indicator of ‘S’ in Table 3.4. Therefore, proportionate normalization is selected to develop composite indicators in this study because the original values of the data do not change through this process. If the values of the data change due to the transformation technique/normalization, they are mathematically not meaningful. Therefore, it is always preferable to follow a technique by which original data are transformed in such a way that their informational content is not fundamentally altered (Cherchye et al., 2007). In proportionate normalization, the rank of the composite indicator depends on actual values since proportionate normalization does not alter the actual importance of the values of the indicators. This is the strength of this technique (Cherchye et al., 2007). Furthermore, proportionate normalization seems preferable in this experiment to the most popular min-max normalization because there are no goalpost values for any of the 50 indicators.

There is clearly no universal best aggregation method because aggregation depends on the requirement of the developer of the composite indicators. In the data there are some “0” values.

Therefore, for aggregation of the indicators, a hybrid aggregation is suggested: indicator values with the “0” normalization result will be aggregated by arithmetic mean and the rest will be aggregated by geometric mean. Hybrid aggregation techniques use more than one aggregation function at different levels (Stano, 2014). For example, the “Multidimensional Poverty Assessment Tool (UNIFAD, 2010 as cited in Stano, 2014) used arithmetic averages within a subcomponent and geometric average within a component, while the Food and Nutrition Security Index (FAO, 2014 as cited in Stano, 2014) used arithmetic averages within dimensions and geometric average across dimensions” (Stano, 2014:16). When comparing all applied normalization and aggregation techniques, it appeared that, for the present research, the proportionate normalization and hybrid aggregation techniques (geometric mean and arithmetic mean) produced the most preferred results. Therefore, 15 single composite indicators are developed from the 50 indicators in Talukder et al. (2012) using proportionate normalization and hybrid aggregation. These 15 single composite indicators (Table 3.13) are proposed to create a set of the most representative variables of agricultural sustainability in the study areas. Among these 15 composite indicators, “Monetary efficiency” carries the proportionate normalization values of the original values without any aggregation but is normalized by proportionate normalization.

It is the responsibility of the designer of the composite indicator to choose the most appropriate normalization and aggregation techniques. These techniques will have to have a sound and transparent methodological framework. Nardo et al. (2005) also stated that the selection of the normalization process deserves special care.

Table 3.13: Composite indicators developed using proportionate normalization and hybrid aggregation techniques

Sustainability categories	Indicators	Agricultural systems					Aggregation technique/ comments
		S	SR	R	I	T	
Productivity	Productivity	0.07	0.16	0.30	0.30	0.14	GM
Stability	Landscape stability	0.14	0.18	0.20	0.21	0.22	GM
	Soil health/stability	0.15	0.21	0.21	0.15	0.22	GM
	Water quality	0.11	0.18	0.18	0.22	0.29	GM
Efficiency	Monetary efficiency	0.10	0.14	0.18	0.43	0.15	Only normalized
	Energy efficiency	0.07	0.16	0.30	0.30	0.14	GM
Durability	Resistance to pest stress	0.24	0.27	0.19	0.18	0.12	AM
	Resistance to economic stress	0.25	0.20	0.19	0.20	0.17	AM
	Resistance to climate change	0.22	0.27	0.11	0.30	0.10	AM
Compatibility	Human compatibility	0.06	0.22	0.24	0.25	0.24	AM
	Biophysical compatibility	0.10	0.13	0.29	0.22	0.27	AM
Equity	Education	0.20	0.22	0.20	0.26	0.12	AM
	Economic	0.17	0.23	0.21	0.22	0.17	AM
	Health	0.17	0.21	0.18	0.26	0.18	AM
	Gender	0.17	0.19	0.26	0.32	0.06	AM

Legend: GM = Geometric Mean, AM = Arithmetic Mean. Note: Monetary efficiency was not normalized or aggregated as original data are used for composite indicator values. S = Bagda (shrimp)-based agricultural systems (S) from Shyamnagar, SR = Bagda-rice-based agricultural systems (SR) from Kalijang, R = Rice-based agricultural systems (R) from Kalaroa, I = Galda-rice-vegetable-based integrated agricultural systems (I) from T = Dumuria and traditional practices-based agricultural systems (T) from Bhola Sadar.

Table 3.14: Productivity: Spearman correlation (in %)

Productivity	RNAM	DFTNAM	ZSNAM	M-MNAM	PNAM	MCA
RNAM	100	10	50	15	45	15
DFTNAM	10	100	30	95	85	95
ZSNAM	50	30	100	85	80	100
M-MNAM	15	95	85	100	80	100
PNAM	45	85	80	80	100	80
MCA	15	95	100	100	80	100

Legend: RNAM = Rank normalization and arithmetic mean; DFTNAM = Distance to target normalization and arithmetic mean; ZSNAM = Z-score normalization and arithmetic mean; M-MNAM = Max-Min normalization and arithmetic mean; PNAM = Proportionate normalization and arithmetic mean; MCA = Multi-criteria analysis.

Table 3.15: Landscape stability: Spearman correlation (in %)

Landscape stability	RNAM	DFTNAM	ZSNAM	M-MNAM	PNAM	MCA
RNAM	100	85	-45	85	85	85
DFTNAM	85	100	-80	100	100	60
ZSNAM	-45	-80	100	-80	-80	-50
M-MNAM	85	100	100	100	100	60
PNAM	85	100	-80	100	100	60
MCA	85	60	-50	60	600	100

Legend: RNAM = Rank normalization and arithmetic mean; DFTNAM = Distance to target normalization and arithmetic mean; ZSNAM = Z-score normalization and arithmetic mean; M-MNAM = Max-Min normalization and arithmetic mean; PNAM = Proportionate normalization and arithmetic mean; MCA = Multi-criteria analysis.

Table 3.16: Soil health/stability: Spearman correlation (in %)

Soil health/stability	RNAM	DFTNAM	ZSNAM	M-MNAM	PNAM	MCA
RNAM	100	85	-25	75	95	85
DFTNAM	85	100	-80	90	70	100
ZSNAM	-25	-80	100	-80	90	70
M-MNAM	75	90	-80	100	60	90
PNAM	95	70	90	60	100	70
MCA	85	70	90	90	70	100

Legend: RNAM = Rank normalization and arithmetic mean; DFTNAM = Distance to target normalization and arithmetic mean; ZSNAM = Z-score normalization and arithmetic mean; M-MNAM = Max-Min normalization and arithmetic mean; PNAM = Proportionate normalization and arithmetic mean; MCA = Multi-criteria analysis.

Table 3.17: Water quality: Spearman correlation (in %)

Water quality	RNAM	DFTNAM	ZSNAM	M-MNAM	PNAM	MCA
RNAM	100	100	10	55	85	10
DFTNAM	100	100	10	100	55	85
ZSNAM	10	10	100	10	25	55
M-MNAM	55	100	10	100	55	85
PNAM	85	55	25	55	100	70
MCA	10	85	55	85	70	100

Legend: RNAM = Rank normalization and arithmetic mean; DFTNAM = Distance to target normalization and arithmetic mean; ZSNAM = Z-score normalization and arithmetic mean; M-MNAM = Max-Min normalization and arithmetic mean; PNAM = Proportionate normalization and arithmetic mean; MCA = Multi-criteria analysis.

Table 3.18: Energy efficiency: Spearman correlation (in %)

Energy efficiency	RNAM	DFTNAM	ZSNAM	M-MNAM	PNAM	MCA
RNAM	100	80	80	80	70	85
DFTNAM.	80	100	100	100	30	85
ZSNAM	80	100	100	100	30	85
M-MNAM	80	100	100	100	30	85
PNAM	70	30	30	30	100	65
MCA	85	85	85	85	85	100

Legend: RNAM = Rank normalization and arithmetic mean; DFTNAM = Distance to target normalization and arithmetic mean; ZSNAM = Z-score normalization and arithmetic mean; M-MNAM = Max-Min normalization and arithmetic mean; PNAM = Proportionate normalization and arithmetic mean; MCA = Multi-criteria analysis.

Table 3.19: Resistance to pest stress: Spearman correlation (in %)

Resistance to pest stress	RNAM	DFTNAM	ZSNAM	M-MNAM	PNAM	MCA
RNAM	100	-10	-10	-10	30	75
DFTNAM	-10	100	90	90	90	65
ZSNAM	-10	90	100	100	90	65
M-MNAM	-10	90	100	100	90	65
PNAM	30	90	90	90	100	85
MCA	75	65	65	65	85	100

Legend: RNAM = Rank normalization and arithmetic mean; DFTNAM = Distance to target normalization and arithmetic mean; ZSNAM = Z-score normalization and arithmetic mean; M-MNAM = Max-Min normalization and arithmetic mean; PNAM = Proportionate normalization and arithmetic mean; MCA = Multi-criteria analysis.

Table 3.20: Resistance to economic stress: Spearman correlation (in %)

Resistance to economic stress	RNAM	DFTNAM	ZSNAM	M-MNAM	PNAM	MCA
RNAM	100	85	75	75	100	85
DFTNAM	85	100	90	90	85	100
ZSNAM	75	90	100	100	75	90
M-MNAM	75	90	100	100	75	90
PNAM	100	85	75	75	100	85
MCA	85	100	90	90	85	100

Legend: RNAM = Rank normalization and arithmetic mean; DFTNAM = Distance to target normalization and arithmetic mean; ZSNAM = Z-score normalization and arithmetic mean; M-MNAM = Max-Min normalization and arithmetic mean; PNAM = Proportionate normalization and arithmetic mean; MCA = Multi-criteria analysis.

Table 3.21: Resistance to climate change: Spearman correlation (in %)

Resistance to climate change	RNAM	DFTNAM	ZSNAM	M-MNAM	PNAM	MCA
R.N.A.M	100	80	100	80	70	80
D.F.T.N.A.M	80	100	80	90	90	100
Z.S.N.A.M	100	80	100	80	70	80
M.-M.N.A.M	80	90	80	100	80	90
P.N.A.M	70	90	70	80	100	90
MCA	80	100	80	90	90	100

Legend: RNAM = Rank normalization and arithmetic mean; DFTNAM = Distance to target normalization and arithmetic mean; ZSNAM = Z-score normalization and arithmetic mean; M-MNAM = Max-Min normalization and arithmetic mean; PNAM = Proportionate normalization and arithmetic mean; MCA = Multi-criteria analysis.

Table 3.22: Human compatibility: Spearman correlation (in %)

Human compatibility	RNAM	DFTNAM	ZSNAM	M-MNAM	PNAM	MCA
RNAM	100	100	100	95	55	100
DFTNAM	100	100	100	95	55	100
ZSNAM	100	100	100	95	55	100
M-MNAM	95	95	95	100	50	95
PNAM	55	55	55	50	100	95
MCA	100	100	100	95	95	100

Legend: RNAM = Rank normalization and arithmetic mean; DFTNAM = Distance to target normalization and arithmetic mean; ZSNAM = Z-score normalization and arithmetic mean; M-MNAM = Max-Min normalization and arithmetic mean; PNAM = Proportionate normalization and arithmetic mean; MCA = Multi-criteria analysis.

Table 3.23: Biophysical compatibility: Spearman correlation (in %)

Biophysical compatibility	RNAM	DFTNAM	ZSNAM	M-MNAM	PNAM	MCA
RNAM	100	95	100	100	100	95
DFTNAM	95	100	95	95	95	90
ZSNAM	100	95	100	100	100	95
M-MNAM	100	95	100	100	100	95
PNAM	100	95	100	100	100	95
MCA	95	90	95	95	95	100

Legend: RNAM = Rank normalization and arithmetic mean; DFTNAM = Distance to target normalization and arithmetic mean; ZSNAM = Z-score normalization and arithmetic mean; M-MNAM = Max-Min normalization and arithmetic mean; PNAM = Proportionate normalization and arithmetic mean; MCA = Multi-criteria analysis.

Table 3.24: Education: Spearman correlation (in %)

Education	RNAM	DFTNAM	ZSNAM	M-MNAM	PNAM	MCA
RNAM	100	85	90	90	80	55
DFTNAM	85	100	95	95	75	40
ZSNAM	90	95	100	100	90	45
M-MNAM	90	95	100	100	90	45
PNAM	80	75	90	90	100	45
MCA	55	40	45	45	45	100

Legend: RNAM = Rank normalization and arithmetic mean; DFTNAM = Distance to target normalization and arithmetic mean; ZSNAM = Z-score normalization and arithmetic mean; M-MNAM = Max-Min normalization and arithmetic mean; PNAM = Proportionate normalization and arithmetic mean; MCA = Multi-criteria analysis.

Table 3.25: Economic: Spearman correlation (in %)

Economics	RNAM	DFTNAM	ZSNAM	M-MNAM	PNAM	MCA
RNAM	100	75	80	70	80	100
DFTNAM	75	100	25	35	85	75
ZSNAM	80	25	100	90	50	80
M-MNAM	70	35	90	100	60	70
PNAM	80	85	50	60	100	80
MCA	100	75	80	70	80	100

Legend: RNAM = Rank normalization and arithmetic mean; DFTNAM = Distance to target normalization and arithmetic mean; ZSNAM = Z-score normalization and arithmetic mean; M-MNAM = Max-Min normalization and arithmetic mean; PNAM = Proportionate normalization and arithmetic mean; MCA = Multi-criteria analysis.

Table 3.26: Health: Spearman correlation (in %)

Health	RNAM	DFTNAM	ZSNAM	M-MNAM	PNAM	MCA
RNAM	100	70	90	90	65	95
DFTNAM	70	100	80	80	15	45
ZSNAM	90	80	100	100	25	75
M-MNAM	90	80	100	100	25	75
PNAM	65	15	25	25	100	75
MCA	95	45	75	75	75	100

Legend: RNAM = Rank normalization and arithmetic mean; DFTNAM = Distance to target normalization and arithmetic mean; ZSNAM = Z-score normalization and arithmetic mean; M-MNAM = Max-Min normalization and arithmetic mean; PNAM = Proportionate normalization and arithmetic mean; MCA = Multi-criteria analysis.

Table 3.27: Gender: Spearman correlation (in %)

Gender	RNAM	DFTNAM	ZSNAM	M-MNAM	PNAM	MCA
RNAM	100	95	100	100	100	100
DFTNAM	95	100	95	95	95	95
ZSNAM	100	95	100	100	100	100
M-MNAM	100	95	100	100	100	100
PNAM	100	95	100	100	100	100
MCA	100	95	100	100	100	100

Legend: RNAM = Rank normalization and arithmetic mean; DFTNAM = Distance to target normalization and arithmetic mean; ZSNAM = Z-score normalization and arithmetic mean; M-MNAM = Max-Min normalization and arithmetic mean; PNAM = Proportionate normalization and arithmetic mean; MCA = Multi-criteria analysis.

Spearman correlation coefficients were computed to assess the robustness of the relation between normalization and arithmetic and MCA aggregation techniques (Table 3.15-3.27). Geometric aggregation techniques are not considered as they could not generate values (e.g., 0) for many composite indicators. A correlation coefficient close to 100 implies that the rankings of the majority of the composite indicators remain unchanged when different techniques are applied (Freudenberg, 2003; Hudrlikova, 2013). In this experiment, however, the correlation coefficient results of ranking, distance to target, z-score and max-min normalization and arithmetic mean varied a lot (Table 3.14-3.27), implying that the normalization techniques led to different rankings for the composite indicators but in the case of proportionate normalization and arithmetic mean the result of correlation and coefficient of all composite indicators are 100 in all cases. This means that when proportionate normalization and arithmetic mean are used for developing composite indicators, the positions of the composite indicators of the five different agricultural systems remain the same. A lot of data are presented in Tables 3.14 to 3.27, but it is very important to put this analyzed data here in order to understand the effect of different normalizations and aggregation techniques on the position of composite indicators.

3.4.7 Conclusions from developing the composite indicators

This study tested various normalization and aggregation techniques for developing composite indicators, providing a comparison among different combinations to find out the best normalization and aggregation combination. Normalization techniques, weighting and aggregation all influence the final outcomes of composite indicators, so it is important to compare different combinations of normalization, weighting and aggregation techniques. Rank, distance to target, Z-score, max-min and proportionate methods were used for normalization, while equal weight and budget allocation for weighting and arithmetic mean, geometric mean and multi-criteria analysis were used for aggregation. The results show that the normalization and characteristics of data have a huge influence on composite indicators. For example, the human compatibility composite indicator in the compatibility category has a score of 0 using rank normalization and geometric aggregation, distance to target normalization and geometric mean, z-score normalization and geometric mean, z-score normalization and geometric mean, max-min normalization and arithmetic mean, proportionate normalization and geometric mean, proportionate normalization and arithmetic mean, or MCA. A score of 1 results from using rank normalization and arithmetic mean, a score of 0.25 from using distance to target normalization and arithmetic mean and a score of -1.98 using z-score normalization and arithmetic mean.

Both methodological and empirical conclusions can be drawn from this study. From a methodological point of view, it can be said that proportionate normalization and the hybrid aggregation technique are suitable for developing composite indicators from this empirical data, which are developed through a questionnaire and secondary data and have a score of “0” for several indicators. These techniques allow the aggregation of a multidimensional set of indicators into a unique composite indicator that can facilitate the understanding of a complex concept such as agricultural sustainability. In the case of proportionate normalization, weighting the indicators has no effect. However, these techniques depend on the properties of the indicators, and some subjectivity is associated with the selection of normalization and aggregation rules. Depending on the methodology selected for constructing indicators, the results of the composite indicators can vary and sometimes be misleading. Based on the properties of the dataset, it appears that proportionate normalization is appropriate, and a hybrid of aggregation rules are suitable for developing composite indicators.

Chapter Four: Application of MAUT, PROMETHEE and Elimination methods to Agricultural Sustainability Assessment

4.0 Introduction

This chapter brings together the findings as analyzed using MAUT, PROMETHEE and Elimination, application of MAUT, PROMETHEE and Elimination methods for agricultural sustainability assessment. Once the results are reported for each analytical approach, they are compared in order to determine the relative capacities for sustainability assessment. This comparison points to various strengths and weaknesses for each method in terms of data analysis capabilities and relevance for various end-users and audiences.

4.1 Application of Multi-Attribute Utility Theory of Multi-Criteria Decision Analysis

Multi-Attribute Utility Theory (MAUT) (Munda, 2008) is an important subfield of MCDA which is also referred to as Multi-Attribute Value Theory, the attribute values are known with "certainty in a deterministic approach" (Sadok et al, 2009:165). MAUT constitutes a simple way to understand MCDA and is widely used in multi-criteria evaluation (Antunes et al., 2012). "The term utility is preferred to indicate that the preferences of stakeholders against risk are formally included in the analytical procedure" (Sadok et al., 2009:165). Decision makers can use MAUT to evaluate alternatives in a reliable manner through assigning appropriate weights for criteria. The weights are considered in terms of trade-offs across criteria. In MAUT a normalization process for different dimensions provides a common framework to compare alternatives (Antunes et al., 2012). This technique is also popular in participatory settings (Renn, 2003). "MAUT resolves multiple preferences and value scores into an overall utility value for each metric alternative, enabling comparison" (Convertino et al., 2013:81). In MAUT, uncertainty is related to the utility of the criterion, but it is not considered with the preferences (weights) of the stakeholder (Belton & Stewart, 2002). “The alternatives are evaluated with respect to each attribute and the attributes are weighted according to their relative importance” (Mustajoki et al., 2004:539). Typically in MAUT a hierarchy of criteria or a “Value Tree” is identified and the criteria are evaluated quantitatively using numerical values (Keeney & Raiffa, 1993). MAUT usually follows a three-step process: (A) structure the problem (value tree, criteria, alternatives); (B) create the preference model (making value functions and giving weights for the criteria); and (C) analyze the results (reliability and sensitivity analyses) (Marttunen & Hämäläinen, 2008). Detailed important procedural steps of MAUT can be found in Keeney and Raiffa (1993) and De Montis et al. (2004).

In this study, the Web-HIPRE (Hierarchical Preferences) MAUT (MCDA) technique, an Internet-based free software program (http://hipre.aalto.fi/), was used to aggregate the values, weight indicators and to generate a sustainability score for agricultural systems. “Web-HIPRE is a web-version of the HIPRE 3+ software for decision analytic problem structuring, multi-criteria evaluation and prioritization” (Mustajoki & Hämäläinen, 2000:1). The MCDA technique in Web-HIPRE allows the evaluation of sustainability alternatives in a reliable manner (Mustajoki & Hämäläinen, 2000). Before generating an aggregated score of sustainability, a hierarchical structure (value tree) of the criteria of productivity, stability, efficiency, durability, compatibility and equity was developed to assist in the organisation of criteria and to ensure that all criteria are present (Figure 4.1).

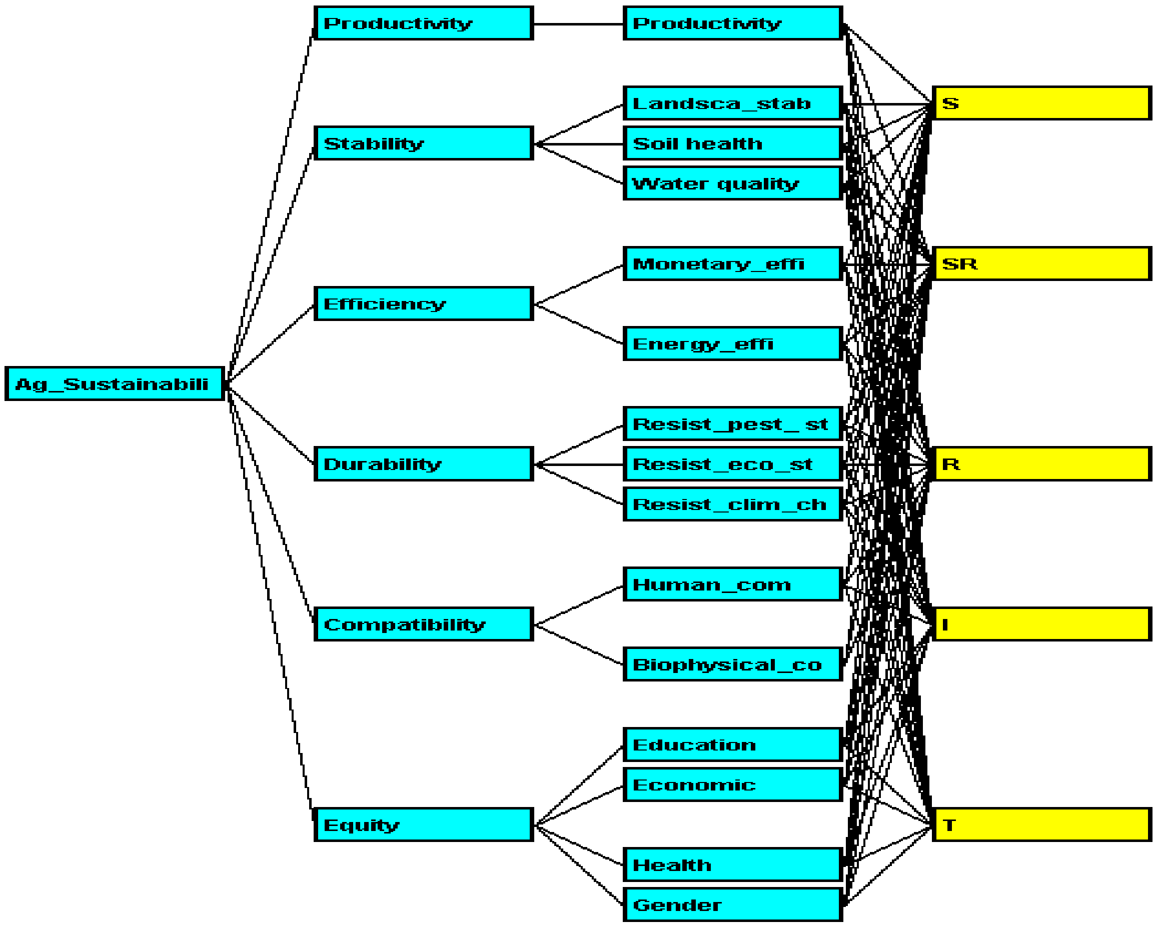
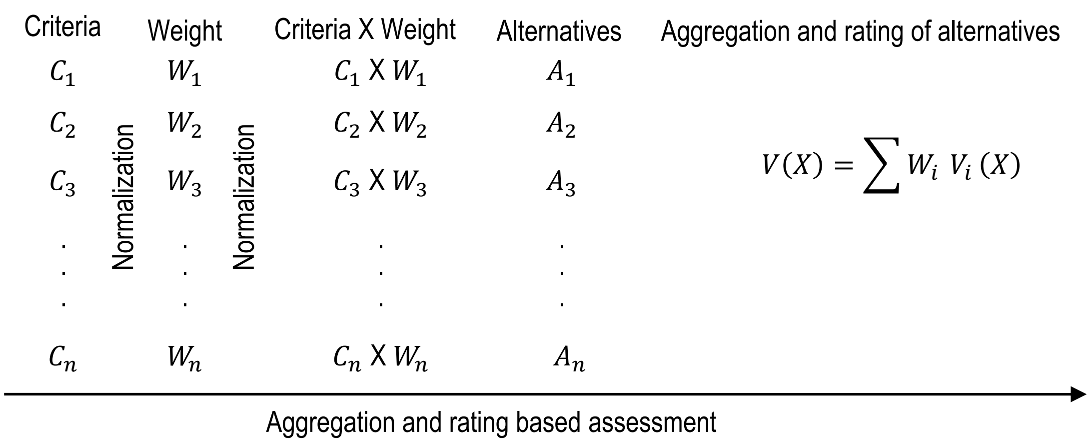


Figure 4.1: Hierarchical structure or value tree and sustainability level generated through Web-HIPRE software. This figure shows that an MAUT analysis considers 16 composite indicators from six categories of sustainability for selected agricultural systems

For this study, weighting the composite indicators (Table 3.5, Chapter Three: Methodology) that estimate the relative importance of the different attributes of sustainability of agriculture was carried out by subjective judgment methods involving stakeholders (farmers, key informants and local experts). It might be argued that non-expert stakeholders cannot be expected to give a valid relative importance (weight) of the criteria (Steele et al., 2009). Therefore, explaining the weighting system to stakeholders is very important so that they understand the reasons for giving relative weighting to each criterion. Stakeholders were asked to rate the indicators on a scale of 1 to 100, and the average scale was taken as the weight of each indicator. The weights of the indicators were also carefully reviewed before finalizing them. These weightings were assigned for each category of sustainability as well as each indicator of the categories by the “DIRECT” weighting method of Web-HIPRE to indicate the relative importance of each indicator value. “DIRECT” weighting was selected because this method is frequently applied to evaluate environmental problems due to its simplicity and user-friendliness (Yoe, 2002).

After assigning weights for each composite indicator, the normalization process was carried out for each category and then an additive process was used to find the final composite score of sustainability for each agricultural system. Normalization was carried out to bring the dimensions of the indicators into a common framework (Antunes et al., 2012). The whole process of calculation of the final score using Web-HIPRE (Mustajoki & Hämäläinen, 2000) is presented below:



Here, $V(X)$ = overall value of an alternative,

n = number of criteria,

W_i = weight of criteria $_i$, and

$V_i(X)$ = rating of an alternative x with respect to a criteria $_i$.

$V_i(X)$ is normalized to the 0-1 range and Wi is the importance weight assigned to criterion i. Through Wi the decision maker considers the range of values from the worst to the best possible level of the criteria compared to the corresponding ranges in the other criteria (Huang et al., 2011).

4.1.1 Application of MAUT: A test case

The application of MAUT is tested by using the composite indicators that were developed in Chapter Three. Combining the overall scores of all categories and their respective weightings (as shown in Table 3.7), MAUT (MCDA) analysis shows that the sustainability score is highest in ‘I’ (Figure 4.2 and Table 4.1). A higher score should be interpreted as a better overall result, meaning that the agricultural practice in ‘I’ is most sustainable compared with that in the other agricultural systems. Among the six categories, the scores of productivity (0.025), efficiency (0.150) and equity (0.148) are highest at that site, and the scores of the other three categories are also good. ‘R’ had the second highest overall score after ‘I’. The productivity score (0.025) of ‘R’ is the same as ‘I’. ‘R’ also has the highest compatibility score (0.147). ‘I’ and ‘R’ are both rich in agro-biodiversity and mostly follow traditional farming practices, but in terms of performance of sustainability, ‘I’ is better than ‘R’. The farmers of ‘R’ are practicing mostly traditional agriculture with some improved methods.

The sustainability score of ‘SR’ is much better than that of ‘S’. ‘SR’ has the highest durability score (0.090) and the third highest sustainability score. The sustainability score of ‘T’ is fourth highest. The stability score (0.200) is highest in ‘T’. The lowest score of agricultural sustainability is observed in ‘S’, with particularly low scores in the productivity (0.058), stability (0.115), efficiency (0.035) and compatibility (0.044) categories (Table 4.1). This is consistent with findings from site visits when the farmers in ‘S’ and ‘SR’ expressed concern about the low sustainability of shrimp cultivation; during the field visit, some farmers stated that they were considering adjusting their agriculture practices to be more like those of ‘I’.

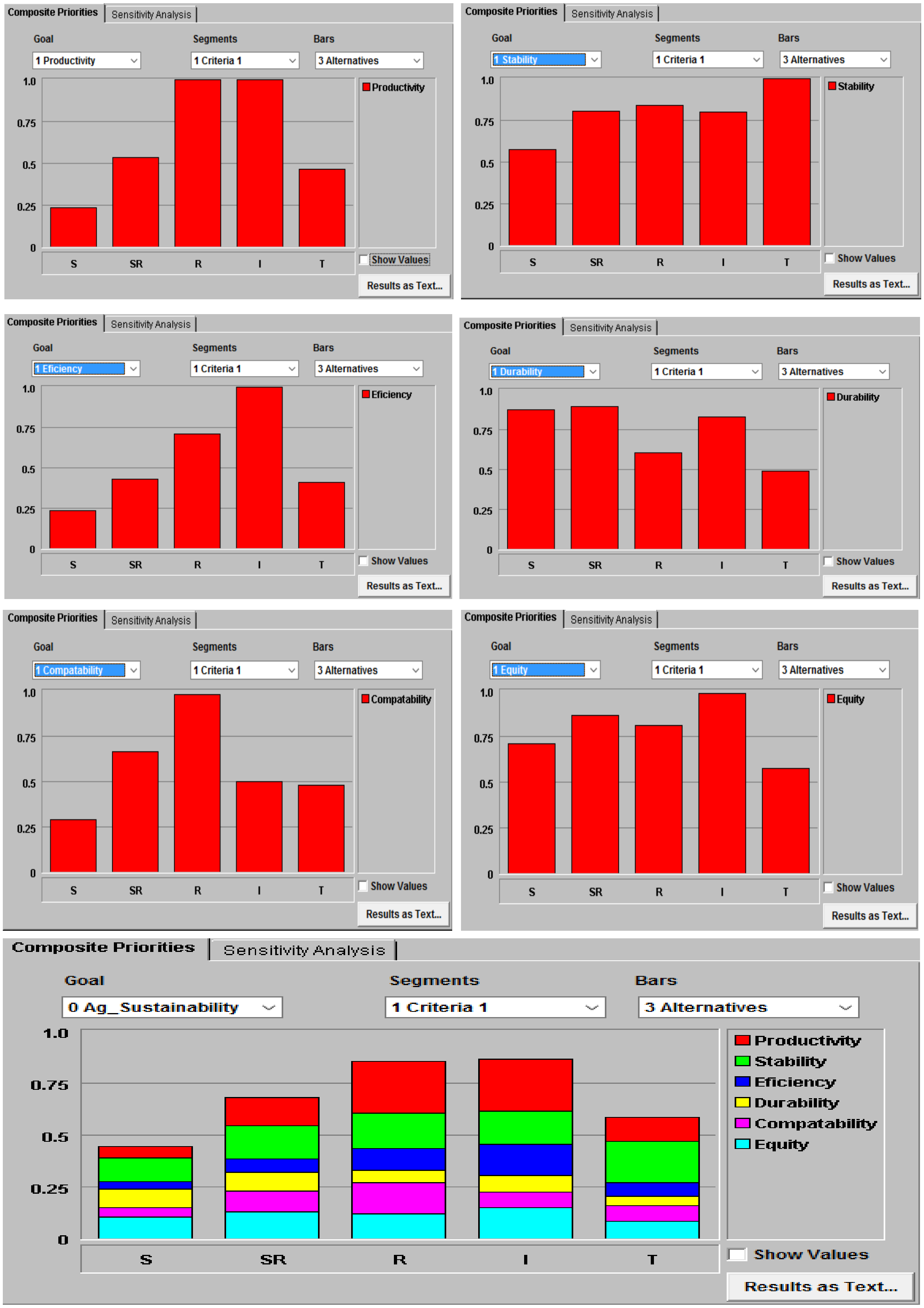


Figure 4.2: Levels of six categories of sustainability and overall sustainability levels. Results generated by using Web-HIPRE software.

Table 4.1: Overall score of the sustainability of the agricultural systems

Categories	Agricultural systems				
	S	SR	R	I	T
Productivity	0.058	0.133	0.250	0.250	0.117
Stability	0.115	0.161	0.168	0.160	0.200
Efficiency	0.035	0.064	0.106	0.150	0.061
Durability	0.087	0.090	0.061	0.083	0.049
Compatibility	0.044	0.100	0.147	0.075	0.072
Equity	0.107	0.130	0.121	0.148	0.087
Overall	**0.446**	**0.678**	**0.853**	**0.866**	**0.585**

One-way sensitivity analysis was done to validate the effect of the weights on sustainability. Figure 4.3 shows the sensitivity analysis window generated by the Web-HIPRE software for the indicator of landscape stability in the "stability" category, where the overall values of the five agricultural systems are shown as a function of the weight. As seen in Figure 4.3, changes in weights from 0.20 to 0.50 do not have any effect on the agricultural systems' rankings. Even with the change in weight in both cases, "I" ranked first. Likewise, when one-way sensitivity analysis was applied to all the individual indicators of the sustainability categories it illustrates that there was no consequence on final ranking. This finding is consistent with others (e.g. Dantsis et al., 2010 and Sajeva et al., 2005). Sensitivity analysis allows the identification of critical inputs/judgments and the identification of any close competitors to the preferred alternative. In this case, it shows that no matter what the weighting is, 'I' is the most sustainable agricultural system. Likewise, testing one-way sensitivity analysis for the 15 composite indicators demonstrates that there was no effect on final ranking. This favours the applicability of the suggested weighting concept and indicates that if the categories of sustainability are evenly weighted, then this will also produce the same sustainability assessment result.

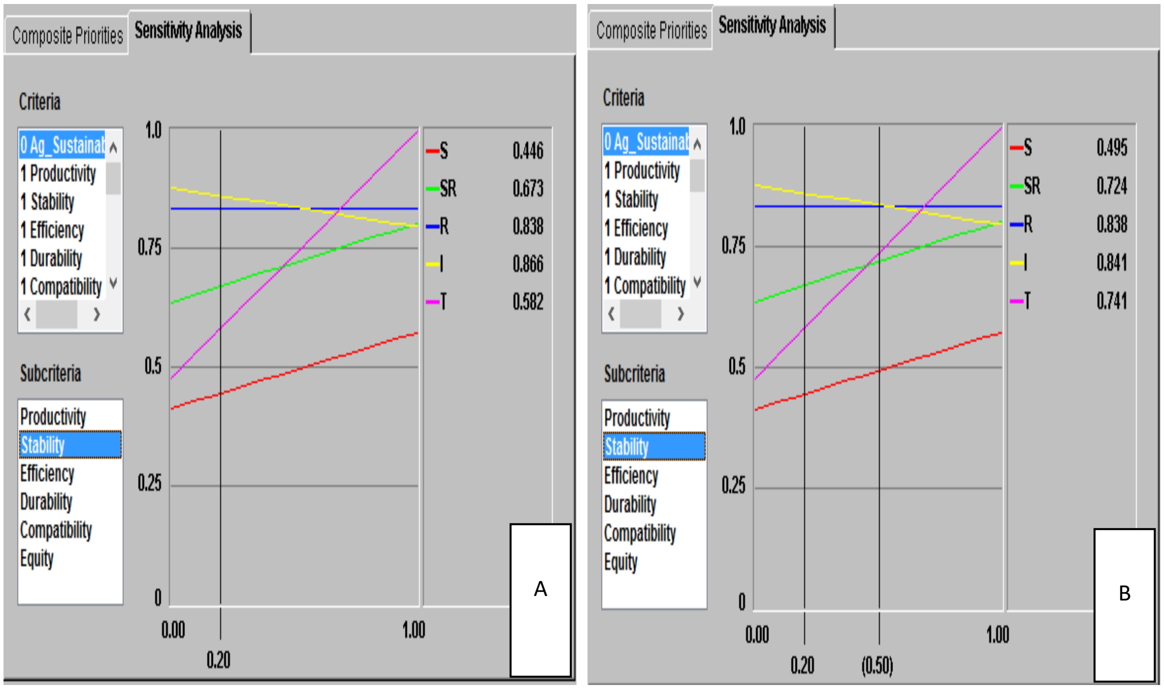


Figure 4.3: No change in ranking of landscape stability with respect to change of weighting 0.20(A) to 0.50(B). Note: There is no scale in the software. All scores are between 0 and 1.

4.1.2 Discussion of the results of MAUT application

The proposed framework models how agricultural systems are assessed and ranked based on multiple criteria of six categories of sustainability. Aggregated scores are used to rank five different farming systems. Ranking was done by an additive utility function that calculates the sum of the multiples of the weight of the criteria and normalized criteria values (Prato & Herath, 2007). Along with showing aggregate scores, the MCDA results also show the contribution of each sustainability category to the overall performance through the bar colours, which provide an effective way to visualize the results. In the Web-HIPRE software, the overall values of the alternatives can be presented by bar graphs. Figure 4.2, which was generated by Web-HIPRE, shows that the overall score bar can be further broken down in different ways, for example, by dividing them into segments according to the contribution of the different attributes (Mustajoki et al., 2004).

Agricultural sustainability assessment using this framework is one way to initiate discussion of a very complex issue like sustainability. In many ways, the building of the hierarchical structures (value trees) of the six categories (Figure 4.1) and overall sustainability, the ranking (Table 4.1) of sustainability categories in the five agricultural systems and the overall ranking of sustainability and weight judgment of the categories and associated indicators are just as important as the final results. The results show that the MCDA approach facilitates the quantitative and qualitative assessment of agricultural sustainability because it allows the comparison of information obtained by indicators as a whole as well as on an individual level.

Agricultural sustainability assessment using sustainability categories and MCDA techniques requires multiple indicators for a holistic assessment, but the choice of indicators can be very challenging. Most of the currently used frameworks only cover some sustainability issues, but indicators selected through a sustainability categories framework capture more of the agricultural systems. The proposed categories-based framework allows system-wide thinking and a systems-of-systems approach (Hipel et al., 2010) in selecting indicators in a structured way. However, identifying indicators through this framework requires the assessor and stakeholders to have substantial knowledge and to be transparent in explaining their choices. All the key sustainability issues fall in the range of the categories-based framework, and indicators selected through this framework are representative and comprehensive. The categories-based framework allows data to be collected from all levels of agro-ecosystems from individual farms to regional or national agriculture, whereas most agro-ecosystem sustainability assessment studies are conducted at a national or international level with only a few at the field or farm level (Van Cauwenbergh et al., 2007). The categories-based framework can be adjusted to and applied in different agro-ecosystem contexts because it is easy to understand and flexible for developing holistic indicators.

It also has the capacity to generate site-specific indicators; therefore, it has a universal appeal. The categories of this framework are theoretically sound and clearly related to the issues of agricultural sustainability

Nevertheless, “a large number of indicators often give a mixed message about the degree of sustainability” (vanLoon et al., 2005:96). Further, the quantification of agricultural sustainability using a large set of indicators can be difficult to interpret. As a result, “it is sometimes useful to combine or aggregate the various indicator values into a single index or a very small number of integrative indices” (vanLoon et al., 2005:96). Integrative indicators have some benefits in that they cover a range of multidimensional aggregated subject matter and are simpler, easy to interpret, and more attention-grabbing for policymakers and the general public alike (OECD, 2008). For example, in Chapter 3, productivity indicators include detailed information about yield (t/ha), energy (kcal/ha), protein (kg/ha) and income ($/ha) (Table 3.5). An integrative productivity value could be useful for tracking general trends in productivity during a given year and over a series of years. It could also be used to forecast productivity or call for action to improve productivity. “Integrative indices essentially report a single piece of information, but that information takes on a particular value because of its relation to all the factors from which it has been derived” (vanLoon et al., 2005:76). However, there is some debate as to the usefulness of composite indicators because they may lack accuracy unless they are well-constructed. In addition, the argument could be made that if an appropriate set of indicators is developed then there is no need for the further step of aggregating indicators because the weighting process in the aggregating method is arbitrary (Sharpe, 2004).

There are different ways of developing an aggregated score. The OECD (2008) has described the methodology of developing aggregate indexes and other ways of applying MCDA techniques that have the capacity to aggregate various indicators and consider weighting of the indicators to generate a composite score or index on a 0 to 1 scale. In MCDA analysis, there is general agreement to express the outcome scores on a 0 to 1 scale, for which 0 is the worst-case outcome and 1 is the best-case outcome (Steele et al., 2009). This indicates that a score close to one represents a system that is more sustainable than a score close to zero. In spite of its simplicity, this method requires substantial technical expertise, local knowledge and an understanding of sustainability principles.

In this study, during aggregate score calculation, the utility functions were considered as being additive and linear. "Applying a linear utility function implies that the results do not represent absolute ratings of sustainability of agricultural systems but a relative ranking order" (Dantsis et al., 2010:262). The weights used in this study possess a degree of subjectivity of different perspectives and stakeholders, but they can still be a good way to assess sustainability. In reality, sustainability itself is relative. There is no universal sustainability level since it varies from place to place and time to time, and goals are set according to the priorities of the society. It is important to note that weights must be used as importance coefficients and not as trade-offs. One of the strengths of the methodology is that it incorporates experts' and stakeholders' judgment in the selection of the weighting of the indicator and sustainability categories.

The proposed framework can handle heterogeneous measurement levels of criteria information (i.e., quantitative vs. qualitative) and their uncertainty (Antunes et al., 2012). It deals with "criteria incommensurability, data uncertainty and preference imprecision" (El-Zein & Tonmoy, 2015:51). To avoid the issue of incommensurability, indicator values and weighting were normalized to bring the data into the same scale. This methodology allows a "transparent, replicable, sound and quantitative evaluation of sustainability of agricultural systems" (Castoldi & Bechini, 2010: 59). This methodological framework has the flexibility to be adapted for a variety of purposes at different scales of agricultural systems by adding other indicators. In addition, sensitivity analysis supports the applicability of the proposed weighting concept. “One of the advantages of sensitivity analysis is that the modelling procedure is based on a notion of a ‘pseudo-criterion,’ which may result in a lack of stability and undesirable discontinuities, and sensitivity analysis can be used to balance this” (Dantsis et al., 2010:263).

The framework presented in this thesis offers a multidimensional and multilevel methodology to assess agricultural sustainability like SAFE (Van Cauwenbergh et al., 2007) and SAFA (FAO, 2012b) and also captures the multifunctional aspects of agriculture. This framework has the ability to perform holistic sustainability assessment and is suitable for use in comparing different agro-ecosystems. Furthermore, the model in this test case produces very steady rankings that “are relatively insensitive to changes in attribute and aspect of weights” (Van Calker et al., 2005) (see Figure 4.3). “Based on these results, it is concluded that the method based on stakeholder and expert perceptions can be used with reasonable confidence to determine the sustainability of different farming systems” (Van Calker et al., 2005). However, it is essential to remember that the weighting of the criteria and indicator scores will have to be made clear and be properly considered; otherwise, the final result of the assessment will reflect the stakeholders’ views (Steele et al., 2009). Although the developed overall sustainability function is applied to coastal farming in Bangladesh, there is the potential for it to be tested in other contexts and used for other agricultural sectors and other countries as well.

4.2 Application of PROMETHEE for agricultural sustainability assessment

PROMETHEE was developed by Brans in 1982 (Behzadian et al., 2010). It is a pair-wise comparison-based outranking methodology to evaluate and compare a finite set of alternatives in terms of multiple criteria (Antunes et al., 2012). The PROMETHEE method is clustered as PROMETHEE I for partial ranking and PROMETHEE II for complete ranking of a fixed set of possible alternatives from the best to the worst and GAIA plane is for visualisation (Cavallaro, 2013). PROMETHEE II with GAIA (Geometrical Analysis for Interactive Assistance) tool, also known as PROMETHEE-GAIA methodology (Cavallaro, 2013), is used in this thesis. The PROMETHEE II-GAIA methodology is better for the purposes of this thesis than other methods as it provides a complete ranking of alternatives. In GAIA a clear graphical representation of alternatives and their values can be seen. GAIA is able to show the best alternative as well as represent the criteria that make the alternatives best and provide graphical presentation of the sensitivity analysis (PROMETHEE 1.4 Manual, 2013). For more details about the PROMETHEE-GAIA methodology, Brans and Mareschal (2005) and the PROMETHEE 1.4 Manual (2013) can be consulted.

The alternatives in PROMETHEE II are evaluated according to the maximum or minimum values of the criteria. The weighting of the criteria and the preference function of the criteria are two important elements of PROMETHEE II (Behzadian et al., 2010). PROMETHEE does not offer particular guidelines for determining weights for criteria, but it is assumed that the decision-maker is able to weight the criteria appropriately. Weighting is thus influenced by the skills of the decision-maker (Nasiri et al., 2012), at least when the number of criteria is not too large (Macharis et al., 2004). Each weighting remains subjective and is restricted only to the evaluated alternatives. Therefore, sensitivity analyses, which clarify how far the chosen weights influence the output, become important (Geldermann & Rentz, 2001). It is also important to be transparent and clear so the results can be fully understood and replicated as needed. The sum of the weighting is 1. The preference functions of PROMETHEE for each criterion reflect the intensity of preference of an alternative over another alternative. Values of the preference function are between 0 and 1 (Brinkhoff, 2011). For pairwise comparisons, six specific types of generalized preference functions are suggested (Lerche et al., 2014): (a) True/Usual criterion, (b) Threshold criterion, (c) Linear with threshold criterion, (d) Linear over range criterion, (e) Stair step/Level criterion and (f) Gaussian criterion. These six types are illustrated in Appendix II (Table A2-2).

Figure 4.4 presents the steps for the PROMETHEE procedure. The procedure usually begins by identifying the alternatives (a, b) and associated criteria $\left(f_j\right)$. The deviations of the criteria $\left(f_j\right)$ of alternatives (a, b) are determined based on pair-wise comparisons in step two. Next, a relevant preference function for each criterion is determined. The fourth step is to calculate the global preference index. Fifth, the positive and negative outranking flows are calculated for each alternative. Net outranking flow for each alternative and complete ranking takes place in step six. The final step is a sensitivity analysis of the weighting and the calculation of the complete final ranking.

Steps	Description	Mathematical interpretation	Symbols denote
1	Problem formulation: Identify alternatives and criteria of the alternatives	$(a, b), f_j$	(a, b) denotes alternatives, f_j denotes criterion
2	Determination of deviations based on pair-wise comparison	$d_j(a, b) = f_j(a) - f_j(b)$	$d_j(a, b)$ denotes the difference between the evaluations of alternatives a and b on criterion f_j
3	Application of the preference function	$P_j(a, b) = f_j[d_j(a, b)], j = 1, \ldots, k$	$P_j(a, b)$ denotes the preference of alternative a with regard alternative b on each criterion as a function of $d_j(a, b)$
4	Calculation of an overall or global performance index	$\forall a, b \in A$ $\pi(a, b) = \sum_j^k P_j(a, b) w_j$	$\pi(a, b)$ of a over b (from 0 to 1) is defined as the weighted sum $P_j(a, b)$ for each criterion, and w_j is the weight associated with jth criteria
5	Calculation of positive and negative outranking flow	$\emptyset^+(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a, x)$ $\emptyset^-(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a, x)$	$\emptyset^+$ (a) denotes the positive outranking flow for each alternative, whereas $\emptyset^-$ (a) denotes the negative outranking flow for each alternative
6	Calculation of net outranking flow [Complete ranking]	$\emptyset(a) = \emptyset^+(a) - \emptyset^-(a)$	$\emptyset$(a) denotes the net outranking flow for each alternative
7	Sensitivity analysis of the weighting of the criteria	*Using GAIA* platform	Final ranking and conclusion

Figure 4.4: General steps of the procedure of PROMETHEE. Source: Based on Behzadian et al. (2010) and PROMETHEE 1.4 Manual (2013).

4.2.1 Agricultural sustainability assessment methodology based on PROMETHEE

Agricultural sustainability assessment methodology based on PROMETHEE is illustrated in Figure 4.5. To perform the analysis, Visual PROMETHEE 1.4 Academic Edition software was selected as it is free for students and has a wider application in natural resources applications.

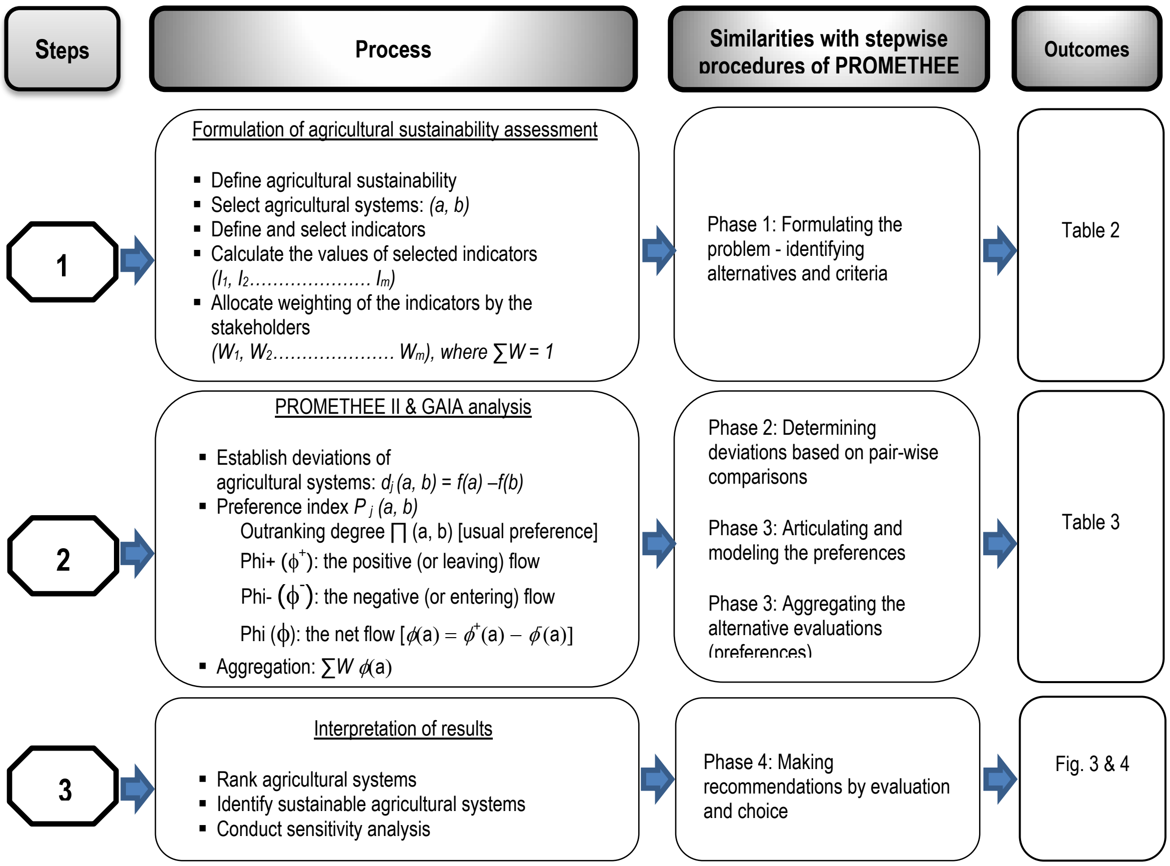


Figure 4.5: Steps of PROMETHEE for agricultural sustainability assessment, developed from the ideas of the general steps (Figure 4.4) of the procedure of PROMETHEE and MCDA. Source: Based on PROMETHEE 1.4 Manual (2013).

First, the agricultural systems to be assessed were identified. Following the first step of MCDA and PROMETHEE (Problem formulation), agricultural sustainability was defined as mentioned in Chapter One and Three (i.e., human activities to produce food and fiber in a manner that ensures the well-being of the present and future communities without diminishing the surrounding ecosystems' capacity and ensuring environmental integrity, social well-being, resilient local economies and effective governance) (FAO, 2013; Jackson-Smith, 2010; vanLoon et al., 2005).

This definition helps to identify the indicators and the indicator values of agricultural systems. Positive values of the criteria indicate better sustainability, which means the higher the value of the criteria, the more sustainability is achieved; therefore, all the criteria are set as a maximized preference function. Due to the qualitative character of the criteria, the usual criterion function was used because it has no threshold. Here, the stakeholders' weighting (Table 3.5 in Chapter Three: Methodology) for the indicator was used as criteria weighting.

In the second step, the deviations of the indicators of the agricultural systems are determined by pairwise comparisons. From these deviations, the preference indexes are calculated and then the net flow of the preferences is calculated based on the positive (or leaving) flow and negative (or entering) flow. Subsequently, the aggregate rankings are calculated by using weighting and the net flow of the preferences (see step 2 of Figure 4.5). In the third step, the most sustainable alternatives (i.e., sustainable agriculture systems) are identified from the aggregate rankings. To investigate the impacts of weighting, a sensitivity analysis is carried out and from these results the most sustainable agriculture system in terms of the selected criteria can be recommended.

4.2.2 Results of application of PROMETHEE for agricultural sustainability assessment

The action profiles deployed in Figure 4.6 show the disaggregated view of the strengths and weaknesses of the alternatives based on the inserted values of the criteria. The action profiles are a graphical representation of the net flow scores for the criteria (composite indicators) listed in the categories of the five agricultural systems in Table 3.8 in Chapter 3: Methodology. For each alternative, upward bars (positive scores) correspond to preferred features, while downward bars (negative scores) link to negative ones. For example, in 'I', only the SH/S (Soil health/stability) and RTPS (Resistance to pest stress) criteria have negative scores; all other criteria have positive scores.

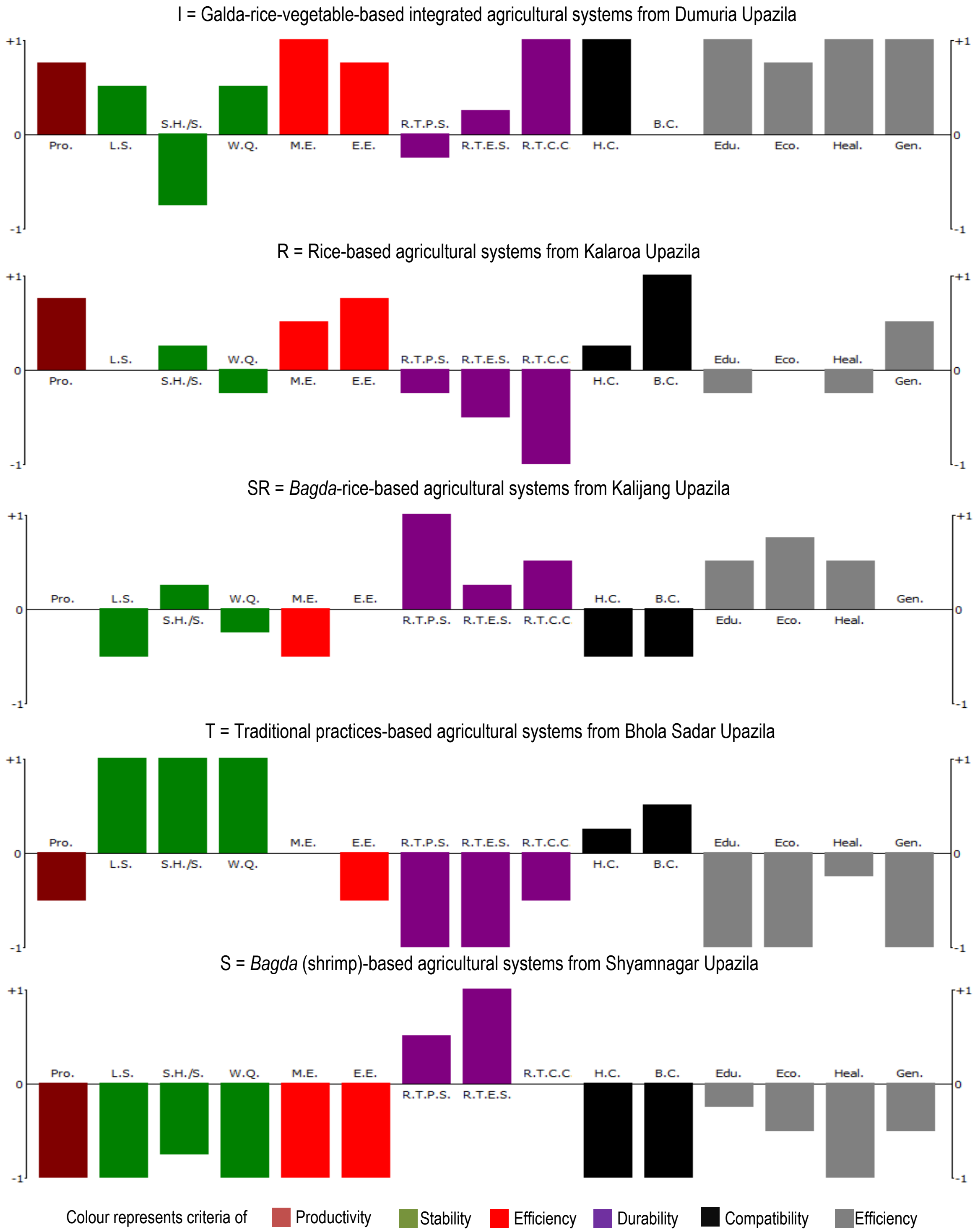


Figure 4.6: Comparison of unicriteria net flow scores of criteria of the agricultural systems. Result generated by PROMETHEE-GAIA software. Note: Pro. = Productivity, LS = Landscape stability, SH/S = Soil health/stability, WQ = Water quality, ME = Monitory efficiency, EE = Economic efficiency, RTPS = Resistance to pest stress. RTES = Resistance to economic stress; RTCC= Resistance to climate change; HC = Human compatibility, BC = Biophysical compatibility, Edu = Education, Eco = Economic, Heal = Health, Gen =Gender. Source: Result generated by PROMETHEE-GAIA software.

In ‘R’, WQ (Water quality), RTPS, RTES (Resistance to economic stress) and RTCC (Resistance to climate change) criteria have negative scores. This action profile demonstrates that ‘I’ is doing well, followed by ‘R’, ‘SR’, ‘T’ and ‘S’ with respect to the decision criteria. ‘S’ is only doing well in terms of RTPS and RTCC. An interesting observation that can be made from Figure 4.6 is that ‘SR’ and ‘S’ have a good durability score, which is supported by the existence of certain features related to durability like improved availability of seed due to government support, less use of pesticide due to shrimp cultivation and better climate awareness after the cyclone Aila event in 2009 (Talukder, 2012).

The results of the final ranking are obtained, and their values are illustrated in Figure 4.7, which represents the final rank of alternatives based on net flow of the alternatives. This ranking gives an overview of all alternatives, including their preference scores. The ranking score is the final score of the net preference flow of the PROMETHEE analysis combining weights, preference functions and values for the criteria per alternative. Among alternatives, ‘I’ (0.54) is first in terms of sustainability on the rank list, while ‘S’ and ‘T’ were the lowest ranked (-0.66). The higher weight on productivity criteria increased the ranking score of ‘I’ and ‘R’ since they have a good productivity score.

The results of this case study indicate that ‘I’ has a higher level of agricultural sustainability compared to ‘R’, ‘SR’, ‘T’ and ‘S’. ‘I’ is characterized by positive scores for all categories of sustainability. For example, productivity is high in ‘I’. This is consistent with the findings of Rahman and Barmon (2012), who also found that productivity was good in integrated agricultural systems and positive for overall agricultural sustainability. Similar results were determined in a previous analysis of these Bangladeshi agricultural systems that made use of an energy analysis to evaluate environmental sustainability (Talukder et al., 2015). In the action profile, energy use efficiency in ‘I’ and 'R' is better than in 'SR', 'T' and 'S', indicating better environmental performance in integrated and rice-based agricultural systems because energy efficiency is one of the measures of environmental sustainability. One of the reasons for the increased energy efficiency may be that integrated and rice-based agricultural systems are supported by diverse crops.

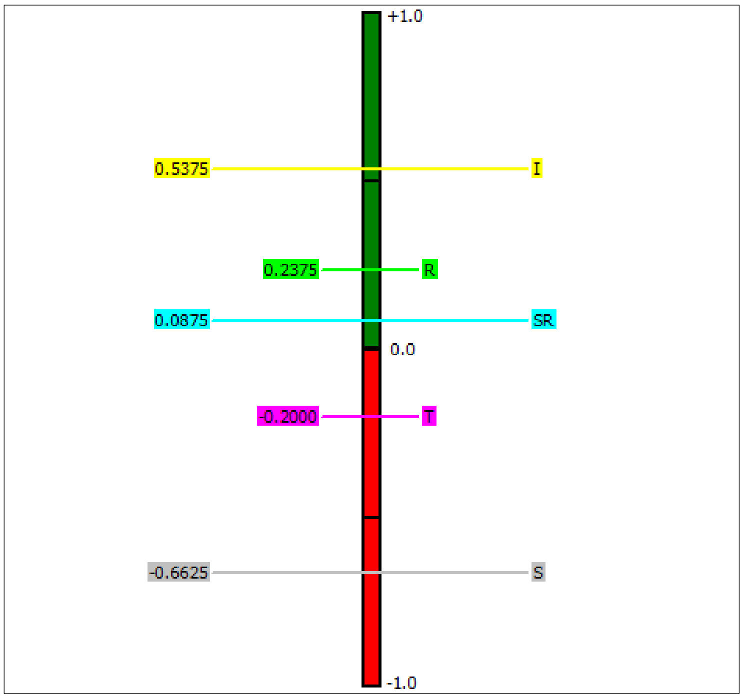


Figure 4.7: Overall ranking by considering criteria values and weighting. Result generated by PROMETHEE-GAIA software.

4.2.3 Sensitivity analysis in PROMETHEE to assess agricultural sustainability

It is clear that the outranking results are influenced by the weights allocated to the criteria, so it is important to know how the ranking changes when the weights change. Therefore, using a special feature of the software called "walking weights," a sensitivity analysis was carried out to verify how sensitive the results are when weights change (Figure 4. 8). The walking weights feature of the Visual PROMETHEE 1.4 Academic Edition software allows weights of a particular criterion to be increased while proportionately decreasing the weights of the other criteria. When the criteria were given equal weight, sensitivity analysis showed that the ranking of the five alternatives is rather stable as displayed in Figure 4.8. The weight of productivity was increased by 50% and no change was found in the rankings. However, the rankings of the agricultural systems varied when the weights of other criteria were changed by different percentages, but the position of 'I' remained the same in each case. From this analysis, it became clear that most of the criteria (and their weights) do not influence the final ranking.

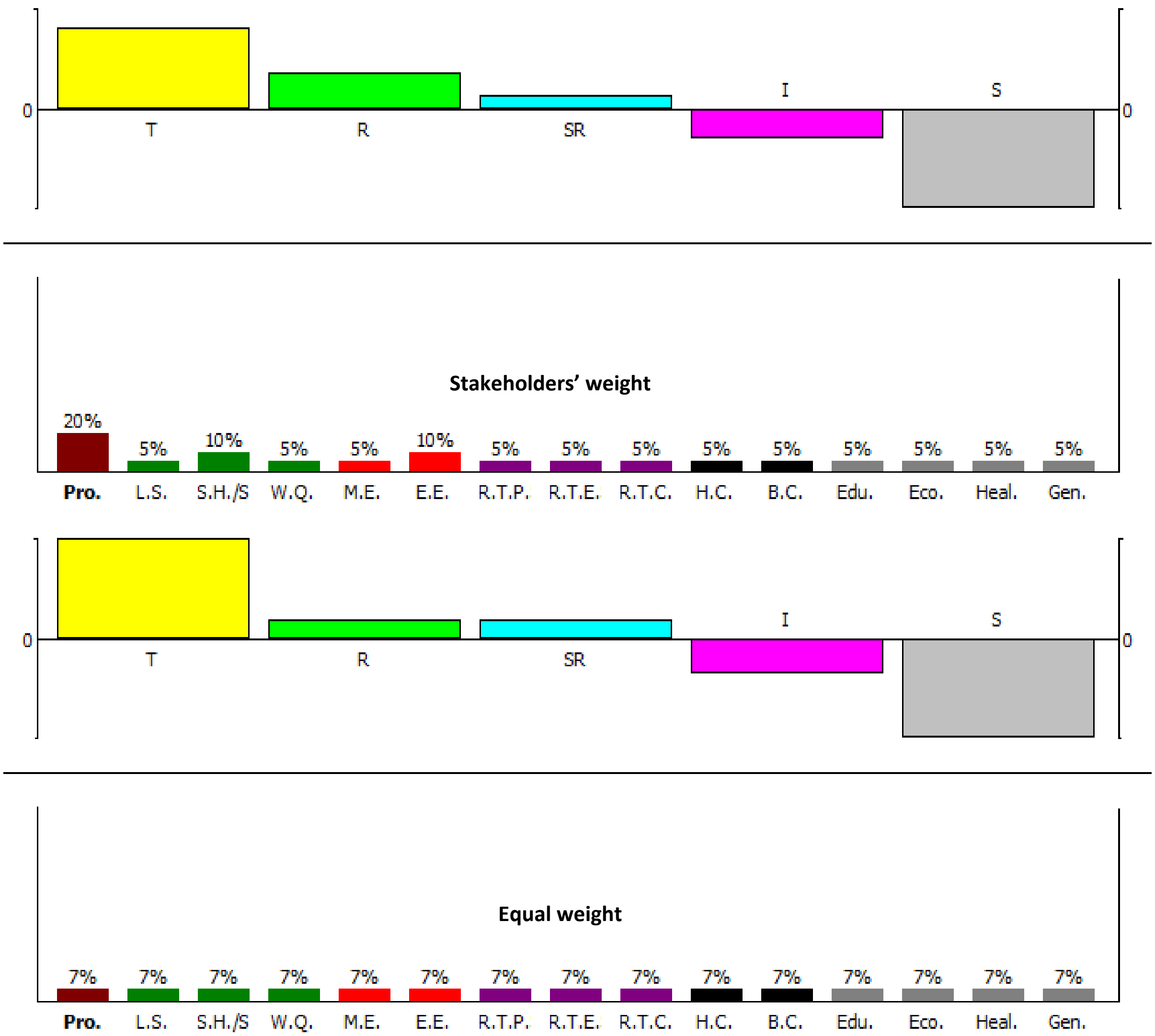


Figure 4.8: Walking Weight (sensible score analysis) used for sensitivity analysis. Result generated by PROMETHEE-GAIA software. Top and bottom analyses show the ranking of the agricultural systems after considering stakeholders' weight and equal weight. Note: Scale is the same for all panels.

4.2.4 Discussion of the result of the PROMETHEE application

This methodology calculates relative rankings and levels of sustainability by comparing different agricultural systems and can also indicate the weak and strong sustainability criteria of the different agricultural systems within the total. As agricultural sustainability depends on complex considerations, assessment needs to consider multiple criteria. The PROMETHEE system is very robust as it has the capability to consider multiple criteria in assessing the final sustainability ranking as well as comparing the criteria. It also facilitates an understanding of the positive and negative roles of different criteria for final additive ranking. The net flow graph (Figure 4.7) helps to visualize the strengths and weaknesses of the criteria (Schmidtmann et al., 2014). As the final sustainability ranking of the alternatives critically depends on the criteria values and weighting (assumptions), the criteria information should be as precise and appropriate as possible (Hyde et al., 2003). While the selection of essential criteria for agricultural sustainability is challenging (Bossel, 2003), this study shows that, by using a set of multiple criteria, PROMETHEE makes it possible to rank the sustainability of different agricultural systems as well as analyze and compare significant information.

A further advantage is that the PROMETHEE-based methodological approach takes into consideration all the multiple criteria holistically through pairwise comparison, which most of the existing frameworks for agricultural sustainability assessment have failed to do (Van Cauwenbergh et al., 2007). It also aggregates the preference values into an individual additive score. The proposed framework evaluation shows that PROMETHEE is capable of handling a holistic set of indicators and ranking the level of sustainability of agricultural systems, making it suitable for agricultural system sustainability assessment. Criteria with different scales can be handled by this method, and it can generate a complete ranking of the sustainability of agricultural systems from best to worst (Antunes et al., 2012). This method is also capable of using the weighting generated by participatory processes (Tsoutsos et al., 2009). It allows for a graphic representation of the criteria using GAIA, which provides a better understanding of the inter-dimensional interactions and conflicts of the criteria of agricultural sustainability, thereby facilitating learning, debate and consensus building among the stakeholders, and as demonstrated in Figure 4.7 it also offers a fairly robust sensitivity analysis tool.

The application of this methodology requires the simplification of some functions of PROMETHEE. For example, setting preferences for the agricultural sustainability criteria is difficult since all criteria are important. Given this challenge, the values of the criteria were developed to show that the higher values of criteria are the "best" in terms of sustainability. Therefore, in the preference function, the usual preference function of the criteria was considered rather than applying the threshold values preference function. This is one of the limitations of this approach. However, determining thresholds of different criteria of agricultural sustainability is difficult since agricultural sustainability is relative and influenced by social, economic and environmental factors (Dantsis et al., 2010). That said, this adaptation of the PROMETHEE assessment tool is a positive step in understanding and comparing multiple dimensions of sustainability.

Another drawback is that the calculation of preference information in PROMETHEE is a complicated process and may be hard for a non-expert or practitioner to apply or understand at a glance. The rather complex calculation process of the final ranking and the difficult interpretation of the ranking and other results may be a limitation of PROMETHEE from a practical application point of view (PROMETHEE 1.4 Manual, 2013). Moreover, like MAUT-based MCDA, PROMETHEE does not provide the possibility to really structure a sustainability problem (Gavade 2014). This limitation prevents users from understanding issues and concerns related to sustainability problems. This could be a goal for PROMETHEE developers to make their program more widely relevant. Another limitation is that PROMETHEE does not provide any formal guidelines for the weighting of the criteria. Rather, it depends on the capabilities of the decision-maker and assumes the decision-makers are able to weigh the criteria appropriately. To understand various weighting methods for the criteria, OCED (2008) documents can be consulted. When there are many criteria, weighting becomes even more challenging. Many criteria may make it difficult to create a clear view of the alternatives and evaluate the results. Nevertheless, in general, the transparency of PROMETHEE is relatively high. This method also has a non-compensatory rationality and the meaning of criteria weights is related to the degree of their relative importance (Morais et al., 2015).

4.3 Applying the Elimination method to agricultural sustainability assessment

Scoring of the criteria and allocating weights to each criterion are the most challenging aspects of applying different MCDA techniques. In some decision-making problems, it is difficult to quantify the criteria quantitatively and to identify the weights of the criteria. In these situations, the Elimination method is recommended for MCDA analysis because it has the advantage of ranking the alternatives' quantitative weights and it handles both qualitative and quantitative criteria scores (Kassab, 2006, Ma et al., 2008).

4.3.1 Elimination method of MCDA

The Elimination method was proposed by MacCrimmon (1973) and Radford (1989). It is based on linguistic rules-based models, which "focus on expressions of preferences on criteria via some linguistic rules, mostly expressed as 'If ..., then ...'. The advantage of this kind of preference data is that people make decisions by searching for rules that provide good justification of their choices"

(Chen, 2006:19). This method allows the user to remove unfeasible alternatives, rank feasible alternatives and consider numeric and non-numeric criteria (Ma et al., 2008).

Reference values[1] (thresholds) are an important consideration for elimination methods. Reference values can be determined using normative and relative considerations. "Normative reference values are defined based on science or policy[2], whereas relative reference values are based on indicator values for similar systems or a reference/ideal system. Normative reference values allow comparison of a system with previously defined reference values" (Acosta-Alba & Van der Werf, 2011:433). To make sustainability assessment robust, comparable and transparent among stakeholders, it is important to clarify what type of reference point is being used in sustainability assessment as well as how the reference points were determined and why (Acosta-Alba & Van der Werf, 2011).

The first step of the Elimination method is to identify a meaningful set of criteria for ranking the alternatives. In the second step, the indicators are arranged in decreasing order with the most important indicator at the top. Then each indicator is compared with the other indicators based on a threshold performance. The rankings of the alternatives are obtained from an examination of each one against the criteria and the priorities of all criteria. A detailed explanation of the procedure of Elimination can be found in Ma et al. (2008). For this study, Elimination is carried out in an alternative way: the most and least important criteria are not established since every criterion is important for assessing agricultural sustainability. Here, the highest indicator values of the agricultural systems are considered as reference (threshold) values to which the other values of the indicators of the agricultural systems are compared. The reference value represents the

[1] Reference value is also referred to as "threshold," "fair earthshare," "critical flow" and "sustainability standard" (Acosta-Alba & Van der Werf, 2011:433).
[2] Experts and stakeholders may be involved.

highest achievable value in this data set. The scores of the criteria are developed in such a way that the highest value of the criteria represents a higher level of sustainability. Therefore, all the highest scores of the criteria of different agricultural systems are considered as reference values for the respective criteria. If the indicator value is equal to the reference value, the agricultural system fulfills the criteria. In a sense, this statement describes new decision elimination rules, altering the conventional rules of the Elimination method. These new rules can be considered as an addition and innovation in the Elimination framework that make it easier to use in sustainability assessment. The total number of criteria fulfilled for each sustainability category determines the rank for each agricultural system. The steps of this Elimination method are shown in Figure 4.9.

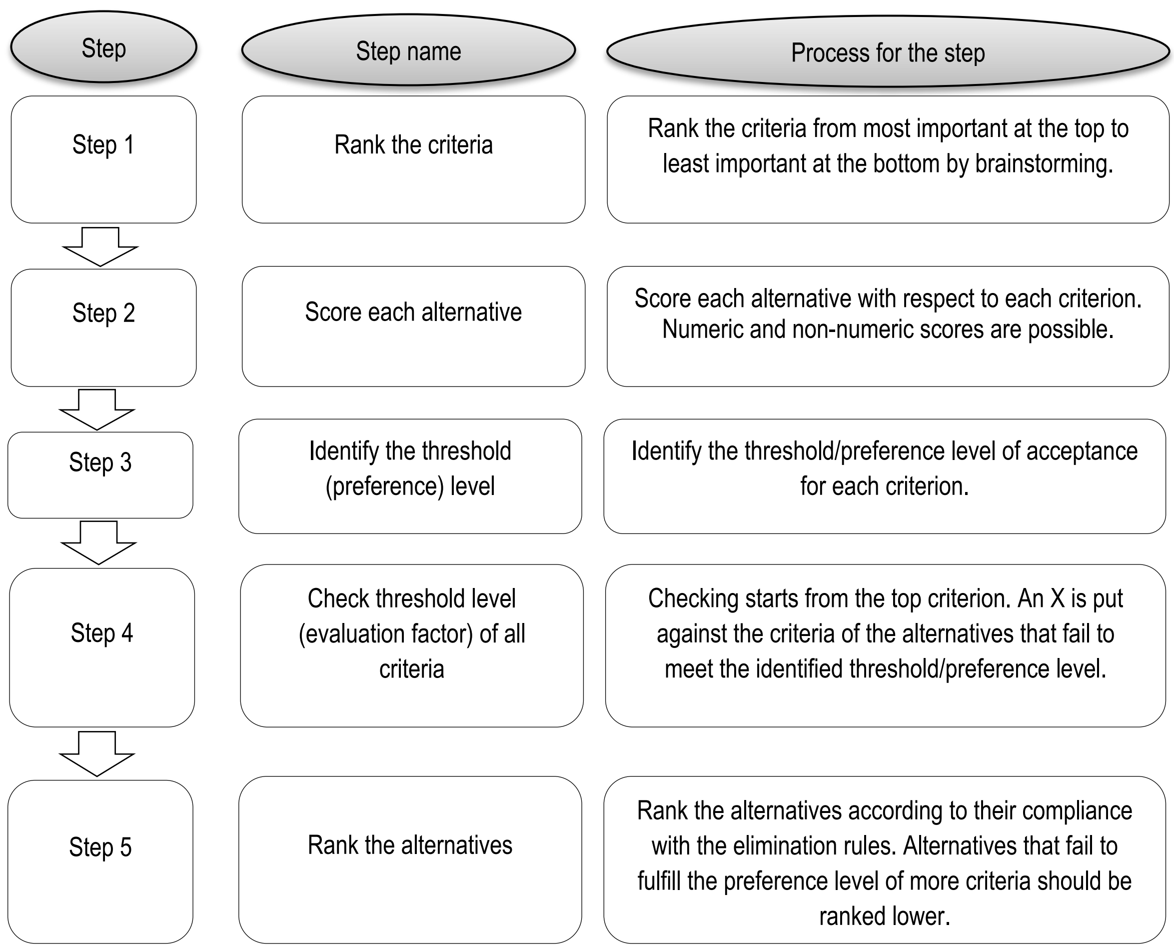


Figure 4.9: Steps in Elimination method. Source: Based on Ma et al., 2008 and Hipel, 2013

4.3.2 Mathematical algorithm of the rules of the Elimination method

The modified Elimination method used in this study can be illustrated mathematically (based on Kassab, 2006, Ma et al., 2008, and Hipel, 2013) as follows:

Let a represent a set of alternatives and c represent the set of the criteria of alternatives of set a:

Where $a = [a_{1,} a_2, a_3 \dots \dots a_n]$, n is always ≥ 2, and

$c = [c_{1,} c_2, c_3 \dots \dots c_q]$, q is always ≥ 2

Based on the reference value, the c of a will be evaluated on the basis of the following preference functions:

$$If\ c_1 of\ a_1 \geq\ reference\ value\ of\ c_1\ then\ a_1\ will\ not\ get\ \text{X}\ (cross)\ for\ c_1, but$$

$$If\ c_1 of\ a_1 <\ reference\ value\ of\ c_1\ then\ a_1\ will\ get\ \text{X}\ (cross)\ \ for\ c_1$$

The rank of the alternatives is based on the total number of X (see Table 4.2- 4.3 and Figure 4.10).

4.3.3 Results of Elimination method

Ranking the sustainability of agricultural systems depends on all the scores of the criteria of all categories. Scores of the indicators vary across the agricultural systems. For example, in the productivity category, 'I' (Integrated agriculture system) has the highest yield and net income (Table 3.8 in Chapter Three: Methodology). A comparison of results and an in-depth knowledge of on the ground production and community considerations are instructive and help to interpret results. For example, the overall productivity is higher in 'I' due to the year-round production of many crops including three rice harvests a year, as well as simultaneously produced crops such as jute, oilseed, and vegetables. Among environmental indicators, the energy output and input ratio, crop richness, and biodiversity condition are very good in 'I' compared to other systems. Due to fewer crops, the energy output to input ratio and crop richness are smaller in 'SR' and 'S'. The condition of biodiversity is poor in ‘S’ because shrimp farming causes biodiversity degradation (Hossain et al., 2013). Since it is near the tidal zone, the study area ‘S’ is more exposed to salt water. However, according to the local people, the soil salinity is low in ‘R’ and close to zero in ‘T’ due to the significant input of rainwater and especially freshwater from the upstream rivers. Among responding farmers, those in ‘I’ have a higher level of education than their counterparts in ‘S’, ‘SR’, ‘R’ and ‘T’.

Table 4.2 shows the reference values and scores of the criteria of the agricultural systems. Here, all the criteria are considered important for agricultural sustainability. The results of the case study are presented in Table 4.2 and Figure 4.10 and are self-explanatory. Here every aspect of sustainability is considered important for sustainability assessment, so no relative factor or group is considered important.

The relative reference values are considered here since it is very difficult to identify the normative reference values in the context of the coastal agriculture of Bangladesh because there are not enough secondary data related to sustainability of the agricultural systems. This is appropriate as the determination of normative reference values is time-consuming and sometimes pointless since agricultural sustainability is a very relative concept that varies over time and space (Dantsis et al., 2010). Table 4.3 presents the evaluation results after applying the rules of the Elimination method as described in the methodology section.

Table 4.2: Scoring of criteria and rules of reference values

Category	Sl. No.	Criteria	Reference values	Agricultural systems				
				S	SR	R	I	T
Productivity	1	Weighted yield of the main staple crop	≥ 6.51	2.26	4.41	5.23	6.51	2.86
	2	Net income from the agro-ecosystem	≥ 1806.04	311.15	1020.37	1585.81	1806.04	544.01
	3	Protein yield from the agro-ecosystem	≥ 552.00	68.42	147.23	552.00	373.01	318.87
Stability	4	Land exposure to natural events: cyclone	≥ 2.00	1.00	2.00	2.00	2.00	1.00
	5	Land exposure to natural events: saline water	≥ 3.00	1.00	1.00	3.00	2.00	3.00
	6	Land exposure to natural events: drought in *kharif* to *rabi* season	≥ 3.50	1.50	1.50	2.00	2.00	3.50
	7	Land exposure to natural events: river bank erosion	≥ 2.00	2.00	2.00	2.00	2.00	1.00
	8	Stability of embankment	≥ 2.00	1.00	2.00	1.00	2.00	2.00
	9	Withdrawal of upstream water	≥ 2.00	1.00	1.00	1.00	1.00	2.00
	10	Organic materials	≥ 4.00	4.00	4.00	2.00	3.00	2.00
	11	Salinity	≥ 6.00	1.00	5.00	6.00	3.00	6.00
	12	Macronutrient: N	≥ 2.00	2.00	2.00	2.00	1.00	2.00
	13	Macronutrient: P	≥ 3.00	3.00	2.00	3.00	3.00	3.00
	14	Macronutrient: K	≥ 6.00	6.00	4.00	3.00	2.00	4.00
	15	Soil pH	≥ 4.00	1.00	3.00	4.00	2.00	4.00
	16	Water salinity in surface water (quality of surface water for irrigation)	≥ 3.00	1.00	2.00	2.00	2.00	3.00
	17	Water salinity in ground water (quality of ground water for irrigation)	≥ 4.00	1.00	2.00	2.00	4.00	3.00
	18	Arsenic concentration (quality of ground water for irrigation)	≥ 4.00	2.00	2.00	2.00	2.00	4.00
Efficiency	19	Money input and output in the agro-ecosystem	≥ 6.67	1.53	2.24	2.78	6.67	2.29
	20	Overall energy efficiency	≥ 5.90	1.37	2.01	5.53	5.54	5.90
	21	Non-renewable energy efficiency	≥ 2.52	0.78	0.92	2.17	2.52	2.44
Durability	22	Chemical response to pest stress	≥ 6.54	1.78	4.17	4.24	5.45	6.54
	23	Water availability at transplanting stage of rice	≥ 0.75	0.75	0.75	0.20	0.20	0.20
	24	Water availability at flowering stage of rice	≥ 0.75	0.75	0.75	0.20	0.20	0.20
	25	Farm management (soil test, pest management, land management, soil fertility management)	≥ 1.69	0.67	0.83	1.69	1.36	0.00
	26	Good product price	≥ 8.44	8.44	5.00	4.58	4.55	3.80
	27	Availability of seeds	≥ 10.00	9.33	9.50	10.00	10.00	8.85
	28	Availability of market (market diversification)	≥ 10.00	10.00	9.17	8.47	10.00	7.69
	29	Agricultural training	≥ 2.27	1.33	1.83	0.33	2.27	1.15
	30	Climate change awareness	≥ 1.82	1.11	0.67	0.51	1.82	0.00
	31	Advice from agricultural extension workers or NGO	≥ 1.17	0.66	1.17	0.51	0.45	0.38
Compatibility	32	Drinking water quality (protected)	≥ 10.00	0.00	8.00	9.00	10.00	9.0
	33	Illness from drinking water	≥ 10.00	5.00	10.00	10.00	10.00	10.0
	34	Overall biodiversity condition: percentage of non-crop area	≥ 23.01	7.54	6.48	23.01	15.73	18.68
	35	Overall biodiversity condition: crop richness	≥ 17.00	2.00	6.00	16.00	10.00	17.00
	36	Overall biodiversity condition: crop rotation	≥ 5.00	2.00	3.00	5.00	4.00	4.00
	37	Ecosystem connectivity	≥ 2.00	1.00	1.00	2.00	2.00	2.00
Equity	38	Education of farmers	≥ 10.00	8.56	9.25	4.75	10.00	5.00
	39	Education status of farmers' male children	≥ 13.10	10.00	9.49	11.2	13.10	7.45
	40	Education status of farmers' female children	≥ 12.50	9.07	10.54	11.17	12.50	6.36
	41	Access to electronic media	≥ 10.00	7.78	9.17	9.39	10.00	3.08
	42	Farm profitability	≥ 3340.55	648.23	3340.55	1371.32	1992.39	1025.06
	43	Average wage of farm labourer ($)	≥ 1.80	1.33	1.33	1.60	1.80	1.60
	44	Livelihood diversity other than agriculture	≥ 6.92	6.22	4.33	5.93	4.55	6.92
	45	Years of economic hardship	≥ 0.91	0.73	0.73	0.91	0.82	0.64
	46	Road network [establishing farm roads and access roads]	≥ 3.00	2.00	3.00	3.00	3.00	1.00
	47	Availability of medical treatment or public health	≥ 8.14	3.51	4.76	4.07	8.14	4.29
	48	Sanitation or public health	≥ 8.73	7.69	8.73	7.59	7.41	7.08
	49	Women's involvement in decision making about agricultural activities	≥ 6.50	3.00	4.00	5.00	6.50	2.50
	50	Gender-based wage differentials	≥ 0.59	0.33	0.33	0.50	0.59	0.00

Table 4.3: Evaluation results after applying rules of Elimination method

Category	Sl. No.	Criteria	Reference values	Agricultural systems				
				S	SR	R	I	T
Productivity	1	Weighted yield of the main staple crop	≥ 6.51	X	X	X		X
	2	Net income from the agro-ecosystem	≥ 1806.04	X	X	X		X
	3	Protein yield from the agro-ecosystem	≥ 552.00	X	X		X	X
Stability	4	Land exposure to natural events: cyclone	≥ 2.00	X				X
	5	Land exposure to natural events: saline water	≥ 3.00	X	X		X	
	6	Land exposure to natural events: drought in *kharif* to *rabi* season	≥ 3.50	X	X	X	X	
	7	Land exposure to natural events: river bank erosion	≥ 2.00					X
	8	Stability of embankment	≥ 2.00	X		X		
	9	Withdrawal of upstream water	≥ 2.00	X	X	X	X	
	10	Organic materials	≥ 4.00			X	X	X
	11	Salinity	≥ 6.00	X	X		X	
	12	Macronutrient: N	≥ 2.00				X	
	13	Macronutrient: P	≥ 3.00		X			
	14	Macronutrient: K	≥ 6.00		X	X	X	X
	15	Soil pH	≥ 4.00	X	X		X	
	16	Water salinity in surface water (quality of surface water for irrigation)	≥ 3.00	X	X	X	X	
	17	Water salinity in ground water (quality of ground water for irrigation)	≥ 4.00	X	X	X		X
	18	Arsenic concentration (quality of ground water for irrigation)	≥ 4.00	X	X	X	X	
Efficiency	19	Money input and output in the agro-ecosystem	≥ 6.67	X	X	X		X
	20	Overall energy efficiency	≥ 5.90	X	X	X	X	
	21	Non-renewable energy efficiency	≥ 2.52	X	X	X		X
Durability	22	Chemical response to pest stress	≥ 6.54	X	X	X	X	
	23	Water availability at transplanting stage of rice	≥ 0.75			X	X	X
	24	Water availability at flowering stage of rice	≥ 0.75			X	X	X
	25	Farm management (soil test, pest management, land management, soil fertility management)	≥ 1.69	X	X		X	X
	26	Good product price	≥ 8.44		X	X	X	X
	27	Availability of seeds	≥ 10.00	X	X			X
	28	Availability of market (market diversification)	≥ 10.00		X	X		X
	29	Agricultural training	≥ 2.27	X	X	X		X
	30	Climate change awareness	≥ 1.82	X	X	X		X
	31	Advice from agricultural extension workers or NGO	≥ 1.17	X		X	X	X
Compatibility	32	Drinking water quality (protected)	≥ 10.00	X	X	X		X
	33	Illness from drinking water	≥ 10.00	X				
	34	Overall biodiversity condition: percentage of non-crop area	≥ 23.01	X	X		X	x
	35	Overall biodiversity condition: crop richness	≥ 17.00	X	X	X	X	
	36	Overall biodiversity condition: crop rotation	≥ 5.00	X	X		X	X
	37	Ecosystem connectivity	≥ 2.00	X	X			
Equity	38	Education of farmers	≥ 10.00	X	X	X		X
	39	Education status of farmers' male children	≥ 13.10	X	X	X		X
	40	Education status of farmers' female children	≥ 12.50	X	X	X		X
	41	Access to electronic media	≥ 10.00	X	X	X		X
	42	Farm profitability	≥ 3340.55	X		X	X	X
	43	Average wage of farm labourer ($)	≥ 1.80	X	X	X		X
	44	Livelihood diversity other than agriculture	≥ 6.92	X	X	X	X	
	45	Years of economic hardship	≥ 0.91	X	X		X	X
	46	Road network (establishing farm roads and access roads)	≥ 3.00	X				X
	47	Availability of medical treatment or public health	≥ 8.14	X	X	X		X
	48	Sanitation or public health	≥ 8.73	X		X	X	X
	49	Women's involvement in decision making about agricultural activities	≥ 6.50	X	X	X		X
	50	Gender-based wage differentials	≥ 0.59	X	X	X		X

Note: Yellow, gray, blue, green and red colours represent degree of fulfilment of the reference values by the indicators in each category of 'S', 'SR', 'R', 'I' and 'T' respectively, X = non-fulfilment of the reference values.

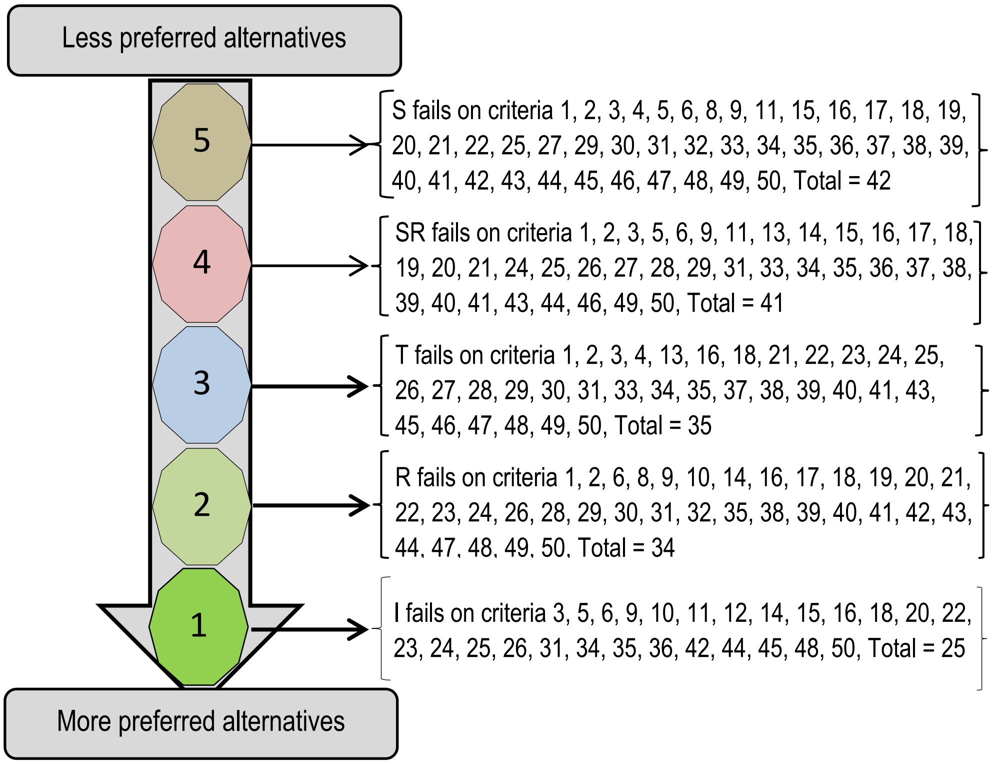


Figure 4.10: Ranking of the agricultural systems. Note: Ranking 2 and 3 could switch since there is a narrow difference. Note that the result of elimination depends on the total number of failed criteria.

Figure 4.10 displays the final results, that is, the ranking of the sustainability of agricultural systems. According to the ranking of the sustainability of agricultural systems, ‘I’ is the most preferred sustainable system in comparison to the other four systems. ‘I’ fails on 25 of the 50 criteria, meaning that for ‘I’, the remaining 25 criteria are equivalent to the reference values. The farmers of ‘I’ also expressed their satisfaction with most of the sustainability issues like productivity, biodiversity, social health, and economics. This finding also echoes the finding of Rahman and Barmon (2012) that ‘I’-type agricultural systems are more sustainable compared to others. Among agricultural systems, ‘S’ failed in most of the reference criteria and ranked as the least preferred system. Hossain et al. (2013) also expressed that shrimp-based agricultural systems are less sustainable due to the socio-ecological effects of shrimp cultivation.

While this type of assessment is based on very simple conditional statements and is easy to calculate, it depends entirely on the calculation of the indicators' values. Therefore, the selection of indicators and calculation of indicator values requires a high degree of transparency for this type of calculation to be clear and as robust as possible. While agricultural sustainability in this assessment is divided into six categories, it does not reflect the actual performance of the individual categories in the overall ranking. It is important to note that the overall rank is heavily influenced by the number of indicators in each category as the indicators are added up and thus have a significant impact on the final outcome. For example, 'S' as a whole ranked lowest, but if we examine the performance of each category, durability is tied between 'S' and 'I' (Table 4.4). If we explain this result by category, we see that "I" is highlighted as the "most sustainable" agricultural system for each category: 'I' for productivity, efficiency, durability (tied with 'S'), and equity; 'T' for stability, and 'R' for compatibility. Therefore, while final rankings based on all the indicators are important for this study, it is also useful to check the performance of each category individually. This will allow a more refined consideration of the performance of different categories and also help to suggest ways to improve the categories of agricultural systems for agricultural sustainability.

Table 4.4: Category-wise performance (number of indicators that fulfill the reference values) of the agricultural systems

Category	Agricultural systems				
	S	SR	R	I	T
Productivity	0	0	1	2	0
Stability	4	3	7	5	10
Efficiency	0	0	0	2	1
Durability	4	2	2	4	1
Compatibility	0	1	4	3	3
Equity	0	6	2	8	0
Totals	8	12	16	25	15

Note: Top values for each category are highlighted in yellow.

4.3.4 Discussion

There are several considerations in applying an MCDA Elimination method as an agricultural sustainability assessment tool. First, MCDA is appropriate in general because it can consider many criteria and thus allow for the complexity needed for sustainability analysis. However, when using the MCDA framework, assigning the weighting of the criteria is very subjective. To avoid this subjectivity, using reference values based on the Elimination method is a useful approach for sustainability assessment. By using criteria scores and relative reference values, the Elimination method offers the ability to rank the sustainability of agricultural systems (Ma et al., 2008). The advantage of this method is that using the highest score in each category readily allows for the identification of the criteria that fulfill the reference values. This makes it a flexible, transparent, time-saving and holistic process that can handle the imprecision and subjectivity of the information associated with sustainability criteria. If the sustainability criteria fall in a regular pattern, such as higher positive values of the criteria indicating higher sustainability, it can handle large data with ease. However, having to eliminate many criteria and not consider all the indicators' values will lessen the actual effect of the total indicators in the overall ranking (Munda, 2008).

The results of Elimination analysis reveal that shrimp-based agricultural systems perform poorly in comparison with integrated and rice-based agricultural systems. There is significant difference in how these systems fulfill the criteria of sustainability. It should be noted that farmers consider shrimp-based agricultural systems to be profitable, but there are adverse ecological consequences and the production of shrimp has dropped over successive years. Rice yields are very low in S and SR, which is jeopardizing the food supply. Biodiversity is also low in these systems, which suggests a trend of agricultural unsustainability. Therefore, some of the farmers interviewed by Talukder (2012) reported that they are considering changing to integrated agricultural systems.

This suggested modified Elimination method allows the user to set a threshold value in a category as a bar below which all data are eliminated. This leaves the top value for that category. Once all top values for each category have been determined, these category values can be summed and the results can be ranked. This case study demonstrates that Elimination is able to determine sustainability rankings for the different systems. This finding may motivate other researchers to collect more reliable indicators with which to apply the Elimination method to sustainability assessment. The ranking of agricultural sustainability raises various questions about the sustainability performance of the agricultural systems. The Elimination method can be an option to assess agriculture holistically (Marta-Costa & Silva, 2012) as it can consider indicators from all three pillars of sustainability.

4.4 Comparing the results of MAUT, PROMETHEE and Elimination

MAUT, PROMETHEE and Elimination methods are each applied to calculate the overall rankings of the sustainability for the case study agricultural systems in coastal Bangladesh using indicators from selected categories. Figure 4.11 compares the respective rankings of these agricultural systems. In every case, the sustainability of ‘I’ and ‘R’ ranked first and second, respectively, and ‘S’ ranked fifth. MAUT and PROMETHEE resulted in identical rankings for all five agricultural systems. This is because under certain conditions an identical ranking can be obtained by MAUT and PROMETHEE given the additive nature of the criteria scores in generating final rankings (Lerche et al., 2012). ‘SR’ and ‘T’ are ranked third and fourth, respectively, in the MAUT and PROMETHEE analyses, but ‘SR’ is fourth and ‘T’ is third in Elimination. The positions of ‘SR’ and ‘T’ changed in the Elimination analysis because of the non-aggregation and non-pairwise comparison effects that are part of the Elimination method.

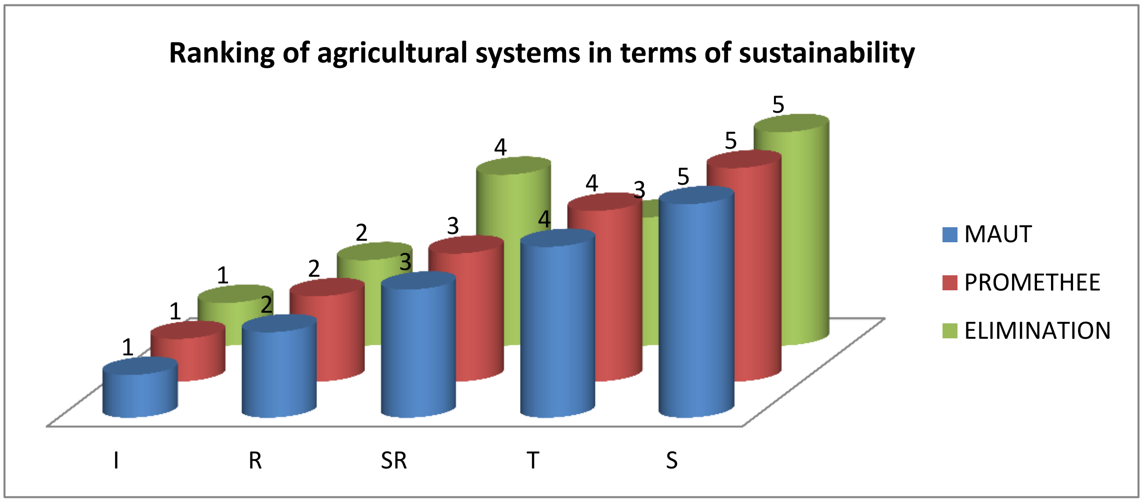


Figure 4.11: Comparative ranking of agricultural systems' sustainability using MAUT, PROMETHEE and Elimination

While MAUT, PROMETHEE and Elimination are capable of ranking the sustainability of agricultural systems, their methodological procedures are different. MAUT ranks the sustainability of agriculture depending on the aggregate scores of the indicators' values and weighting, whereas PROMETHEE obtains ranks through pairwise comparison of the criteria and rankings in Elimination are carried out with reference values-based conditional statements. All the techniques are able to handle nominal, ordinal, interval and ratio data. While the data in this study were entirely quantitative, these three methods can all handle both qualitative and quantitative data (Cinelli et al., 2014; De Montis et al., 2004; Ma et al., 2008).

4.4.1 Assessing MAUT

MAUT provides a good framework for evaluating the sustainability of agricultural systems as it provides a more complete analysis of the data in five different ways. First, MAUT allows the comparison of sustainability categories as a whole as well as on an individual level. This is important when making comparisons as it is difficult to assess agricultural sustainability given the many factors in play at once. A second advantage of MAUT is that it provides the summary information necessary to sort out the best agricultural systems, which leads to logical consistency in comparing one production system to another. Third, MAUT also allows stakeholders' perspectives and insights to be considered for large amounts of data from across the three dimensions of sustainability. This is important as stakeholder involvement is increasingly recognized as an essential element of successful sustainability assessment. In particular, MAUT is flexible in that it can use any kind of numerical data (such as nominal, ordinal, interval and ratio). Fourth, the results of the analysis can be utilized to interpret the importance of the different categories from the overall sustainability scores for each sustainability category as well as for each agricultural system. Finally, while quantifying agricultural sustainability through a large set of indicators can be difficult and the results hard to interpret, MAUT allows aggregation of the various indicator values into a single score/index which covers a range of subject matter and is straightforward to interpret, allows for easier score comparisons and is more attention-grabbing for policymakers and the general public alike (OECD, 2008).

However, there are drawbacks to using this method. First, the aggregate final score can be difficult to interpret because the criteria values and the stakeholder preferences for the criteria in the form of weighting are typically buried in the final scores/numbers (OECD, 2008). However, this also means that if an appropriate set of indicators is developed, there is no need for the further step of aggregating indicators because the weighting process in the aggregating method is context-dependent (Sharpe, 2004). Due to the subjectivity of weighting, the final results of MAUT may create a lack of stability and undesirable discontinuities in the modeling results but can still be a good way to assess sustainability; therefore, sensitivity analysis is essential to overcome this problem (Dantsis et al., 2010). Sensitivity analysis supports the applicability of the proposed weighting concept. The main criticism of the application of multicriteria assessment in decision-making is the assignment of weights and its influence on the final outcome of the assessment

(Alvarez-Guerra et al., 2009; Steele et al., 2009). In this case study, however, the model produces very stable rankings – supported by sensitivity analysis – which are somewhat unaffected to changes in criteria and weights. On the basis of these results, we conclude that stakeholder and expert evaluations can be used to determine the sustainability of different agricultural systems. However, it is important to remember that the weighting of the criteria and performance scoring scales will have to be properly justified and be transparent and robust; otherwise, the final results of the assessment will reflect the stakeholders' biases (Steele et al., 2009). So, while these methods are driven by sound mathematical processes, subjectivity does play a role (Alvarez-Guerra et al. 2009). Therefore, ultimately, sustainability assessment by MAUT should include checks and balances to minimize the effect of weighting.

Second, in MAUT analysis there is general agreement that on a 0-1 scale, 0 is the worst-case outcome and 1 is the best-case outcome (Steele et al., 2009). This indicates that a score close to one represents a system that is more sustainable than a score close to zero. In spite of its simplicity, this method requires substantial technical expertise, local knowledge and an understanding of sustainability principles. Further, while MAUT results represent relative rankings of the sustainability of agricultural systems, they are not absolute ratings (Dantsis et al., 2010:262).

Another criticism is that the final ranking is the outcome of poor and good performance of the sustainability criterion where the poor performance of any sustainability criterion is compensated by a good performance of another (OECD, 2008). In spite of these criticisms, assessing agricultural sustainability using MAUT can facilitate learning, debate and consensus building among the stakeholders. Another important aspect is that MAUT emphasizes that all comparisons are relative, and the best value may or may not be a good value.

4.4.2 Assessing PROMETHEE

The PROMETHEE methodology calculates rankings and levels of sustainability by comparing different agricultural systems and can also indicate weak and strong scores of the sustainability criteria within the total. PROMETHEE also aggregates the preference values into an individual score so the results are easy to compare from one agricultural system to another. As mentioned before Like MAUT, it can be used for learning and discussion for stakeholders.

In spite of these advantages, this approach comes with many limitations. For one, as it does not structure a decision problem this can result in difficulties viewing the criteria in a structured way for sustainability assessment. As well, there are no formal guidelines for weighting. And third, the final ranking is hard to explain to the non-specialist (PROMETHEE 1.4 Manual, 2013). Nevertheless, the PROMETHEE methodology seems to be adequate to assess agricultural sustainability because it models preferences within its procedures in a flexible manner.

4.4.3 Assessing the Elimination Method

Applying MCDA to agricultural sustainability assessment is complex as many criteria need to be considered. As discussed in the previous sections on the MAUT and PROMETHEE methods, weighting criteria is very subjective. To avoid this, eliminating criteria based on objective reference values defined in terms of a case study is a useful alternative.

One drawback to this is that successive elimination can cause the method to lose fundamental properties of the original criteria as part of the overall final ranking (Munda, 2008). The research and Elimination analysis reported in this thesis offer insights for future researchers as they define their categories and collect data to test the Elimination method in the context of agricultural and other types of sustainability assessment. Like MAUT and PROMETHEE, Elimination can also facilitate learning, debate and consensus building among the stakeholders for agricultural sustainability. Adopting Elimination for agricultural sustainability assessment can be a positive step in understanding and comparing multiple dimensions of sustainability.

4.4.4 Comparing MAUT, PROMETHEE and Elimination methods

The merits and drawbacks associated with the MAUT, PROMOTHEE and Elimination methods based on the case study assessing agricultural sustainability in coastal Bangladesh are summarized and compared in Table 4.5. From this table it seems that MAUT is the best method for assessing agricultural sustainability since it fulfills many components of model (soundness), results, and feasibility of Table 4.5. However, each of these methods can be used according to the purpose of the assessment. For example, PROMETHEE may be the best if the assessment is only based on pairwise comparison of the indicators values, while MAUT may be best if the assessment is based on stakeholders' weighting, indicator values and desire for a final ranking by combining indicators' values. A general observation is that all three MCDA methods are flexible tools that are able to handle and bring together a wide range and different forms of data and thus provide a useful tool to map out the sustainability of agricultural systems. MAUT and PROMETHEE are able to explicitly incorporate stakeholders' values/perspectives in aggregating an increasing volume of complementary information. This is an asset as most of the agricultural sustainability assessment methods are not able to aggregate information in a manner that considers stakeholders' perspectives through criteria weighting.

Overall, this study highlighted the broad potential of MAUT, PROMETHEE and Elimination as useful, systematic analytical tools to support the emerging and complex field of sustainability assessment. This thesis uses a case study to test the three methods, all of which provide both integrative and interdisciplinary assessments of the sustainability of the agricultural systems. The step-by-step approach of the three MCDA methods serves as a useful MCDA application for agricultural sustainability assessment. The comparative analysis of the three MCDA tools indicates that they are all suitable approaches to rank agricultural sustainability. These assessment methods can provide guidance that will help decision-makers to act in a more structured and strategic way.

Table 4.5: Overview of the compatibility of MAUT, PROMETHEE and Elimination in ASA

Sustainability assessment		MCDA methods		
Main components	Sub components	MAUT	PROMETHEE	Elimination
Model (soundness)	Structures (creates hierarchies) sustainability criteria	+	-	-
	Considers stakeholder weighting of the criteria	+	-	-
	Addresses all dimensions of sustainability	+	+	+
	Capable of handling compensatory and non-compensatory data	+	+	+
	Capable of handling commensurable and incommensurable data	+	+	+
	Includes mechanisms to address uncertainty (sensitivity analysis)	+	~	-
	Integrates all information	+	-	-
	Transparent process	~ +	~ +	+
	Addresses interdisciplinary considerations	+	+	+
Results	Ranking of sustainability	+	+	+
	No rank reversal is possible for sustainability	+	-	+
	Aggregate scores of the criteria and weighting	+	-	-
	Graphic visualization of results	+	+	-
	Sensitivity analysis depending on weighting option	+	+	-
	Clear conclusion	+	+	+
Feasibility	Enables discussion	+	+	+
	Easy to understand results and methodological process	~ +	~ +	+
	Easy to interpret	~ +	~ +	+
	Software support	+	+	-

Note: "+" = Fulfills the component; "~" = Moderately fulfills the component; "-" = Does not fulfill the component

The MAUT method of MCDA can be easily applied to agricultural sustainability assessment because it is structured and transparent, can break down complex problems, facilitates discussion and produces a systematic and visual presentation of the perspectives of diverse stakeholders (Batstone et al., 2010; Linkov & Moberg, 2011). Though it has some limitations, PROMETHEE also takes a holistic approach, is a useful framework for ranking and could support decision-making about agricultural sustainability. While the Elimination method of MCDA is easy to implement, it reduces complex problems to a singular metric and thus can result in an oversimplified and often overly linear presentation of the problem.

Each method has its own limitations, particularities, assumptions and benefits. There is no way to decide whether one method makes more sense than another in a specific problem situation. For example, the Elimination method could be well-suited to community level decision-making if the right data are or could be available, as it is simple to apply. The data and the parameters of the methods and consequently the modeling effort along with looking at the outcomes and their granularity will be deciding factors in choosing which MCDA methods to use for agricultural sustainability assessment (Guitouni et al., 1999). If the criteria values and preference of the stakeholders for the criteria need to be considered in assessment, then MAUT would be highly preferred. If the indifference and preference thresholds need to be considered but preference of the stakeholder does not, then PROMETHEE would be a good option. If only the comparison of reference values needs to be considered, then Elimination can be a good choice for sustainability assessment.

For a robust analysis by MCDA, appropriate and transparent measures are necessary for selecting, scoring and creating reference values of the criteria. Although the three methods to assess agricultural sustainability were applied to coastal farming in Bangladesh in this thesis, there is the potential for it to be tested in other contexts and used for other agricultural sectors and other countries as well. To make the technique useful in other situations, additional study is required, and the selection of indicators and respective weighting must be carefully carried out in the context of individual situations. It is worth noting that the similarity in the resulting rankings seems to indicate that there is consistency among methods and perhaps even that they are quite robust tools. More testing is needed to see if this holds for other data sets.

However, others can use these methods to study agricultural sustainability by identifying their own set of indicators. For example, indicators for the sustainability assessment of agricultural systems that are subject to sudden stress and vulnerability will be different from those in this study. Indicators that are related to stress and vulnerability may be identified in more detail or given more weight. Another important point is that indicators can be correlated. This possibility was not tested in this study due to time and budget constraints. Nevertheless, identifying correlation among indicators will make the assessment more robust.

A small set of indicators is manageable in the MAUT and PROMETHEE framework, so 15 composite indicators were developed using 50 indicators. These 15 composite indicators carry all the weight of the values of these 50 indicators. Elimination can handle large data since it is carried out manually, so 50 indicators directly applied for analysis in Elimination. The similar results of MAUT, PROMETHEE and Elimination methods indicate that there is no significant difference between using 15 composite indicators and 50 indicators.

Chapter Five: Conclusion

5.0 Introduction

Current agricultural systems are facing tremendous pressure due to declining natural resources, environmental pollution, over-utilization of fertilizers and agro chemicals, rapid land use and land cover change and climate change impacts. At the same time, these systems will have to feed the world population equitability, healthfully and sustainably (FAO, 2012; Godfray et al., 2010; IPCC, 2007; Tilman et al., 2002). Given the convergence of these pressures, sustainable agriculture has the potential to offer much needed solutions. Sustainable agriculture practices can lead to increased agricultural productivity, ensure food security and healthier ecosystems, help to increase social and ecological resilience, contribute to climate change adaptation, support rural development, and support the achievement of community, regional and national development goals (FAO, 2011; Talukder, 2012; FAO, 2013a). Sustainability assessment is a first and necessary step to ensure, benchmark and track sustainable agriculture and to develop plans and policies for sustainable agricultural systems at farm, national, and regional levels.

As a result, the status of agricultural sustainability is being examined around the world. As identified in Chapter Two, there are many sustainability assessment methods available to organizations and practitioners, each with various advantages and disadvantages (Ciegis et al., 2015). After reviewing eight selected methods, it was determined that MCDA-based agricultural sustainability assessment offers many benefits. MCDA as a decision-making tool has many features, but not all of them are appropriate for assessing agricultural sustainability and so this method needs to be applied carefully. To address this gap, this study set out to assess and compare the applicability of three MCDA methods (i.e., MAUT, PROMETHEE and Elimination) for agricultural sustainability assessment using indicators from five different coastal agricultural systems in Bangladesh (Talukder, 2012).

This thesis fulfills the broader goal stated in Chapter One to apply and test the MAUT, PROMETHEE and Elimination methods of MCDA in order to develop a holistic assessment tool and to test for sustainability in five agricultural systems. This thesis is among the first attempts to apply and test PROMETHEE (see also Lairez et al., 2015) and is the first to apply and test Elimination methods for agricultural sustainability assessment. It also provides a better understanding of the conceptual and methodological frameworks of MAUT, PROMETHEE and Elimination for use in agricultural sustainability assessment.

5.1 Contribution to sustainability assessment methodology

The following are the main contributions of this thesis to sustainability assessment:

- MAUT, PROMETHEE and Elimination-based sustainability assessment frameworks provide systematic guiding principles which can be applied for sustainability assessment of other agricultural systems and other sectors. For example, the guiding principles in Chapters Three and Four can be applied to sustainability assessment for organic farming, urban agriculture, agro forestry, poultry farming, dairy farming, supply chain management, wetland management, water management, green energy management and corporate sustainability assessment among others.
- The proposed framework for developing composite indicators through proportionate normalization and hybrid aggregation techniques (arithmetic and geometric mean) for developing composite indicators can be very useful in developing composite indicators in other sectors. For example, this method can be useful for developing indexes for

vulnerability assessment, resilience assessment, adaptation strategies, food security assessment, low carbon society initiatives, smart city initiative, and early warning systems.

- FAO (2013) noted that considering sustainability dimensions as a coherent whole remains a major challenge in sustainability assessment, but it can be solved if agricultural sustainability is assessed using any MAUT-, PROMETHEE- or Elimination-based frameworks, as these methods allow for the incorporation of indicators from social, economic and environmental dimensions of sustainability to generate overall scores which can represent a range of sustainability considerations.

5.2 Contribution of the research to policy making

From a policy-making perspective, the following conclusions can be drawn from this thesis:

- The case study that is used in this thesis allows a review and facilitates comparisons of the sustainability of five different agricultural systems. From this case study it appears that integrated agricultural systems are the best in terms of selected sustainability criteria. This finding can be used to formulate evidence-based policy promoting the implementation of this system as a way to increase the sustainability of agriculture in coastal Bangladesh. This case study determined that Integrated (I) agricultural systems are more sustainable than mono-culture type systems such as shrimp-only production systems. This is consistent with the analysis in Talukder (2012) and supports the call for diversifying small-holder agricultural systems. This case study also confirms the need to support agro-ecological initiatives by small-holder farmers in the face of climate change pressures (Altieri, 2015).
- This case study shows possible future trends for agricultural sustainability in the coastal agriculture of Bangladesh and so could be helpful for specific policy changes to improve

any unsatisfactory performances. For example, the sustainability performance of shrimp-related agriculture is poor. Given that shrimp farming is promoted as an important means for coastal farmers in Bangladesh to generate foreign currency (Christensen & Tull, 2014), this finding suggests that other policy approaches may be warranted. The sustainability analysis suggests that for the long-term sustainability of coastal agriculture, shrimp farming practices need to change. Integrated agriculture systems offer a more viable option for the long term when all sustainability categories are considered. While acknowledging that this would require a trade-off of specific economic benefits in the shorter term for sustainability in the longer term, the findings from this thesis suggest this may be worth considering for overall resilience.

- This thesis also facilitates the analysis and monitoring of the performance of the agricultural policies and programs in coastal Bangladesh. This provides a benchmark for future performance and also points to gaps in the data that could help to understand more about sustainability moving forward.

5.3 Contribution of the research for local agricultural offices, agricultural extension workers and farmers in coastal Bangladesh

The results from this thesis can help local agricultural officers, extension workers and farmers to promote sustainable agriculture in coastal Bangladesh in the following ways:

- Ranking agricultural systems using MAUT, PROMETHEE and Elimination-based frameworks can provide guidance for local agricultural offices, agricultural extension workers and farmers to act in more structured and strategic ways for sustainable agricultural planning and programing. For example, the indicators and final results can help decision makers to understand the importance of different indicators. From the performance of the indicators in overall ranking, the local agricultural offices, agricultural extension workers and farmers can make decisions about what initiatives they should take to make unsustainable agriculture more sustainable.

- The results of the assessment provide diagnostic information regarding productivity, efficiency, stability, durability, compatibility, and equity to local agricultural offices, agricultural extension workers and farmers that will help them understand the problems and prospects of different agricultural systems in terms of sustainability. This research presents a set of sustainability issues for local officials and farmers that need further investigation. Coastal communities of Bangladesh practice a kind of agriculture that creates impacts particularly in the context of ecological degradation, climate change and population increase. The sustainability of coastal agriculture is very significant for future adaptation and sustainability planning, and the findings from this research help to point toward more or less sustainable options.
- The findings of this research can contribute to the debate within communities about what might need to change to achieve sustainability in the various agriculture systems of coastal Bangladesh. As referred to earlier, in particular, shrimp cultivation has become a hotly debated issue. “The prevailing global trends in agriculture support the growth of monocultures, which are often seen as unsustainable” (ILEIA, 2000:1). The findings of this research can be used by communities and farmers to recommend that shrimp cultivation be converted into the more sustainable integrated agricultural systems.
- Sustainability rankings can sound a warning about the sustainable performance of agricultural systems. This warning can help local agricultural offices, agricultural extension workers and farmers to take appropriate actions to ensure the sustainability of the agriculture of coastal Bangladesh and elsewhere. For example, by understanding the environmental, economic and social problems of shrimp cultivation, local agricultural

offices and extension workers can raise awareness among local farmers about the negative effects of shrimp farming and suggest that they convert their agriculture to integrated agricultural systems since these are adaptive and show enhanced performance in terms of sustainability.

- Assessing the level of sustainability allows for a comparison among agricultural practices which produces a useful summary of productivity, stability, efficiency, durability, compatibility and equity issues (see Table 3.5: Selected indicators, justification of selection and their characteristics and values) as well as identifying learning opportunities for local agricultural offices, agricultural extension workers and farmers in Bangladesh.
- The indicators that are used in this thesis promote understanding about sustainability issues and indicate the status of local agricultural sustainability. These indicators can help local officials and farmers since they are measurable and manageable. Indicators also help decision makers to understand the link with sustainability and can motivate them to take action (Ciegis et al., 2015).
- By looking at the performance of each indicator in terms of social, economic and environmental issues of agricultural systems, the practitioner or researcher cam make decisions about which indicator needs improvement or which agricultural system should be promoted for the sustainability of the agricultural systems in coastal areas.

5.4 Contributions to global sustainability initiatives

This thesis responds to the calls of the UN and FAO for agricultural sustainability assessment. After Agenda 21, many nations and international organizations like UNEP, OECD, World Bank, ADB, IUCN, FAO and UNDP developed and used sustainability assessment[1] methodologies. In Bangladesh, the Poverty Reduction Strategy Paper (PRSP), Millennium Development Goals (MDGs) and National Sustainable Development Strategy (NSDS) urged sustainability assessment.

Recently, the UN introduced indicator-based sustainable development goals (SDGs), which include a call for "a robust follow-up and review mechanism for the implementation of the new 2030 Agenda for Sustainable Development [that] will require a solid framework of indicators and statistical data to monitor progress, inform policy and ensure accountability of all stakeholders" (UN, 2016:1). This important process offers the possibility to develop a meaningful approach so that the "design and implementation of a solid framework of indicators will provide meaningful and reliable information to ensure a sustainable future with lives in dignity for all" (UN-SDG, 2015:1). SDG frameworks will need to integrate social, economic and environmental indicators and "provide guidance for humanity to prosper in the long term" (David et al., 2013). The MCDA-based assessment framework that is proposed and tested in this thesis has the capacity to integrate indicators and could be a methodological option or template for monitoring and comparing the unified progress of the SDGs (David et al., 2013). However, this would require a test case to see if the proposed framework is appropriate for monitoring and comparing SDGs among countries.

To monitor the progress of SDGs within and among countries, combination of the sustainability indicator under the seventeen goals could be converted into common matrices by applying MAUT- or PROMETHEE-based assessment frameworks. These matrices could help to understand and monitor the progress of SDGs of the countries. MAUT could provide levels and comparisons of SDGs by aggregating indicators, whereas PROMETHEE could provide ranking and comparison of

[1] "Sustainability assessment: An umbrella term that encompasses a range of equivalent terms such as sustainability impact assessment and strategic impact assessment for assessment approaches that are used to integrate or inter-relate the environmental, social and economic pillars of sustainability into decision making on proposed initiatives at all levels, from policy to projects and particularly within or against a framework of sustainability principles, indicators or strategies" (OECD, 2006:151).

SDGs through pairwise comparison of the indicators. Using a MAUT framework, a multidimensional index could also be created for each goal by aggregating various indicators under different sustainable development goals. A PROMETHEE-based framework could be used for ranking countries in terms of sustainability indicators. This ranking could help compare and monitor the progress of countries in terms of SDGs. If reference values can be created for the indicators under the goals, then an Elimination-based framework could be applied to compare the progress and monitor the SDGs within and among countries. The framework for developing composite indicators applied in this thesis could also be helpful for developing composite indicators for SDGs.

While recognizing that agricultural systems are complex and that assessing them through quantitative methods does not capture the richness of these systems, it is widely acknowledged that properly developed metrics can provide benchmarks for comparison within and between systems as well as indicate the extent of progress over time (Singh et al., 2012). Ensuring that these metrics are comprehensive and community-relevant is a critical part of this work. The sustainability analysis of integrated agricultural systems developed by local people using local knowledge in coastal Bangladesh shows that integrated systems produce more crops and protein by ensuring diversity of local crops, vegetables and fisheries. These systems are also considered a local adaptation strategy by local people in coastal Bangladesh and involve women in variety of agricultural activities (Talukder, 2012). These findings can set an example for how targets under SGD 2 (end hunger, achieve food security and improved nutrition, and promote sustainable agriculture) could be achieved using local varieties of crops, local knowledge and local agricultural systems instead of international prescriptions. This also suggests that local community knowledge can act as the basis for indicator development as well as data gathering.

As agricultural sustainability indicators can be used to guide sustainability initiatives and contribute to the formulation of effective sustainability goals for agriculture around the world, there is a need for continuous improvement and regular reporting of agricultural sustainability indicators into the future. This thesis can help countries and practitioners develop representative indicators and assessment frameworks for periodic monitoring of agricultural sustainability through national, international and private initiatives around the world. The proposed framework of these thesis can be used as a model for other assessment processes including early warning systems for hazards by assessing risk, monitoring and predicting risk, communicating potential risk information and responding to the risk through policy planning and awareness education (UNEP, 2012).

5.5 Recommendations for future research

While this thesis applied the three MCDA methods to coastal farming in Bangladesh, there is the potential to test these methods in other agricultural sectors as well as in other countries. To make the technique useful in other situations, additional study is required, and the selection of indicators and respective weighting must be carefully carried out in the context of individual situations.

To overcome the challenge resulting from the subjectivity of many indicators and weightings of the indicators, MCDA and fuzzy set theory (Kahraman, 2008) can be combined in future research on the analysis of agricultural sustainability. Agriculture will be affected by many uncertainties due to climate change impacts, so techniques like risk analysis, probability and conflict resolution methods can be applied to develop indicators that will acknowledge and lessen the tensions among different stakeholders as well as to understand the political and economic priorities for agricultural sustainability.

MCDA, especially MAUT and PROMETHEE, requires considerable mathematical knowledge for calculation, which makes the methods challenging for users. The proposed Elimination method offers a solution to this problem, but setting reference values for analysis in Elimination requires considerable time as well as reliable data. These challenges may motivate other researchers to collect more compatible indicators with which to apply the Elimination method to sustainability assessment and to discover ways to use this method more easily. The application of MAUT, PROMETHEE and Elimination depends on the type of the sustainability assessment and the requirements of the researcher/policy makers. It will be interesting to investigate how different advantages of MAUT, PROMETHEE and Elimination can be combined for future agricultural sustainability assessment.

Sustainability is a continuous process. The suggested indicators should be monitored in future projects to understand the long-term sustainability of the selected agricultural systems. The sustainability of the agricultural systems in the case study presented in this thesis will continue to be affected by climate change in the future. Issues related to resilient diverse crops (cereal, fish) in terms of increased salinity and heat, water management, livestock management, and adaptive agriculture (e.g., floating gardens, hanging gardens) will have to be considered when developing indicators in future research on assessing the sustainability of those agricultural systems.

Appendix I: Questionnaire

[Important note: This questionnaire restructured from Talukder (2012)]

Question No: **Date:**

GPS information:

Part 1: General information

1.1 Code:

1.2 Age: ☐

1.3 Address:

Village: Union: Upazila: District:

1.4 Sex: Female ☐ Male ☐

1.5 Marital status: Unmarried ☐ Married ☐ Widow ☐ Widower ☐

1.6 Educational level of the respondent:

Education level		Please tick
General education	Can write name	
	Can read and write	
	Primary	
	Secondary	
	Diploma	
	SSC	
	HSC	
	Bachelors	
	Honours	
	Masters	
	Other	
Madrasha education	Can write name	
	Can write and read	
	Elementary	
	Alim (grade 12)	
	Fazil (grade 14)	
	Kamil (grade 16)	
	Other	

1.7 Number of family members:

1.8 Structure of the family: Joint family ☐ Single family ☐

1.9 Age of the children:

Children No. and sex	1		2		3		4		5		6		7		8		9		10	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
Age (in years)																				

Note: M = male, F = female

1.10 Educational status of the children:

Children No. & sex			Education level																	
			General education											Madrasha education						
No.	M	F	CWN	CR&W	P	S	D	SSC	HSC	B	H	M	O	CWN	CW&R	E	A	F	K	O

Note: CWN = Can Write Name; CR&W = Can Read and Write; P = Primary; S = Secondary; D = Diploma; B = Bachelor; H = Honours; M = Masters; O = Other; E = Elementary; A = Alim; F = Fazil; and K = Kamil

1.11 Occupation:

Family member	Occupation
Household head	
Wife	
1st child	
2nd child	
3rd child	
4th child	
5th child	
6th child	
Other	

1.12 Usual food intake (by family members):

Time	Items
Morning	
Noon	
Night	
Other	

1.13 Information about disease among family members:

Name of the disease(in last one year)	Effected person's age	Sex	
		M	F
Diarrhoea			
Stomach pain			
Cholera			
Lose motion			
Decentre			
Hookworm infection			
Ringworm			
Itchy			
Allergic reaction			
Skin disease			
Cold			
Influenza			
Fever			
Malaria			
Typhoid			
Dengue			
High blood pressure			
Low blood pressure			
Heart disease			
Tuberculosis			
Diabetes			
Jaundice (Hepatitis)			
Arsenicosis			
Anaemia			
Lead poisoning			
Malnutrition			

Polio			
Scabies			
Blindness			
Cataract			
Drowsiness			
Other diseases (agro chemical-related disease)			

1.14 Sources of drinking, household use and irrigation water:

Sl. No.	Name of the sources	Uses		
		Household	Dinking	Irrigation
	Tube well			
	Deep tube well			
	Open well			
	Shallow well			
	Protected well			
	Hand pump/paddle pump			
	River			
	Pond			
	Wetlands			
	Rain water			
	Other			

1.15 Land area of homestead (in local unit[1]): ☐

1.16 Area of agriculture land (in local unit): ☐

1.17 Number of Gher: ☐

1.18 Area of Gher: ☐

1.19 Number of ponds: ☐

1.20 Area of ponds: ☐

1.21 Total family income (in a year): ☐

[1] ***1 Acre = 100 Decimals, 1 Bigha = 33 Decimals, 1 Kattha = 720 sq.ft., 1 Bigha = 20***

1.22 Assets:

Name of the assets	Number	Prices (In Tk[2])
TV		
Radio		
Van		
Mobile phone		
Bicycle		
Cow/Buffalo Carts		
Furniture		
Other		

1.23 Housing materials:

No. of house	Materials used																			
	Wall					Roof					Structure					Floor				
	B	T	M	P	O	B	T	M	P	O	B	T	M	P	O	B	T	M	P	O

Note: B = bamboo, T = Tin, P = Plastic, M = Mud, O = Other

1.24 What is the sharing mechanism of agriculture production?

Share	Amount of production
Farmer share	
Land Owner share	
Other Information	

4.16: Is there any migration among family members. If yes, who migrated and why and where? How long ago? What are the ages of the migrants?

[2] Tk = Bangladeshi taka, code: BDT

Part 2: Information about crop production

2.1 Total amount of rice production in 2010 and 2011:

Season	Sl. No.	2010				2011			
		Land area	Type of the rice	Total amount (in Mon[3])	Market value (in Tk)	Land area	Type of the rice	Total amount (in Mon)	Market value (in Tk)
Kharif-1	1.								
	2.								
	3.								
	4.								
	5.								
	6.								
	7.								
	8.								
Kharif-2	1.								
	2.								
	3.								
	4.								
	5.								
	6.								
	7.								
	8.								
Rabi	1.								
	2.								
	3.								
	4.								
	5.								
	6.								
	7.								
	8.								
Additional information:									

[3] Bengali measure of weight = 0.933 kg

2.2 Total amount of fish (shrimp/prawn/other fish) production in 2010 and 2011:

Season	Sl.No.	2010					2011				
		Pond area	Gher area	Fish name	Total amount (in Mon)	Market value (in Tk)	Pond area	Gher area	Fish name	Total amount (in Mon)	Market value (in Tk)
Summer	1										
	2										
	3										
	4										
	5										
	7										
Winter	1										
	2										
	3										
	4										
	5										
	6										

Additional information: (How much fish can they catch from river, wetlands and sea? Type of caught fishes, catching cost and market value, etc.)

2.3 Total amount of other crop production in 2010 and 2011:

Season	Sl.No	2010				2011			
		Land area	Crop type Name	Total amount (in Mon)	Market value (in Tk)	Land area	Crop type Name	Total amount (in Mon)	Market value (in Tk)
Kharif-1	1								
	2								
	3								
	4								
	5								
	6								
Kharif-2	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
Rabi	1								
	2								
	3								
	4								
	5								
	6								
Additional information:									

2.4 Total amount of poultry production in 2010 and 2011:

Poultry	2010		2011	
	Total number	Market value (in Tk)	Total number	Market value (in Tk)
Hen for meat				
Hen for egg				
Duck for egg				
Duck for meat				
Pigeon for meat				
Additional information:				

2.5 Total amount of cattle production in 2010 and 2011:

Cattle	2010				2011			
	Total number	Market value (in Tk)			Total number	Market value (In Tk)		
		Milk	Meat	Other (skin, cow dung etc.)		Milk	Meat	Other (skin, cow dung etc.)
Cow for milk/plough								
Cow for meat/plough/ cart								
Goat/ Ram								
Buffalo for milk								
Buffalo for meat/plough/ cart								
Additional information:								

2.6 Total amount of vegetable production in 2010 and 2011:

Season	Sl.No	2010				2011			
		Land area	Vegetable type	Total amount (in Mon)	Market value (in Tk)	Land area	Vegetable name	Total amount (in Mon)	Market value (In Tk)
Kharif-1	1								
	2								
	3								
	4								
	5								
	6								
Kharif-2	1								
	2								
	3								
	4								
	5								
	6								
Rabi	1								
	2								
	3								
	4								
	5								
	6								

Additional information:

2.7 Total amount of homestead production in 2010 and 2011:

Sl.No	2010				2011			
	Land area	Crops/ vegetable/ fruits/ vegetation name	Total Amount/ number	Market value	Land area	Crops/ vegetables /fruits/ vegetation Name	Total Amount/ number	Market value
1								
2								
3								
4								
5								
6								
7								
8								

Additional information (Type of trees in the homestead area):

Part 3: Information related to crop production cost

3.1 Cost of seeds:

Season	2010			2011		
	Name of the seeds/seedlings	Total amount of seeds	Total cost (in Tk)	Name of the seeds/seedlings	Total amount of seeds	Total cost (in Tk)
Kharif-1						
Kharif-2						
Rabi						
Additional information:						

3.2 Cost of fertilizer:

Season	2010				2011			
	Name of the fertilizer		Total amount (in kg)	Total Cost (in Tk)	Name of the fertilizer		Total amount (in kg)	Total cost (in TK)
	Commercial	Chemical			Commercial	Chemical		
Kharif-1								
Kharif-2								
Rabi								

Additional information (Organic fertilizer):

3.3 Cost of pesticide:

Season	2010				2011			
	Name of the insecticide		Total amount (in kg/ litter)	Total Cost (in Tk)	Name of the insecticide		Total Amount (in kg/ litter)	Total cost (in Tk)
	Commercial	Chemical			Commercial	Chemical		
Kharif-1								
Kharif-2								
Rabi								

Additional information:

3.4 Cost of irrigation:

Season	2010			2011		
	Source of Irrigation	Total amount (in litter)	Total Cost (in Tk)	Source of irrigation	Total Amount (in litter)	Total cost (in Tk)
Kharif-1						
Kharif-2						
Rabi						
Additional information:						

3.5 Cost of labour:

Season	2010				2011			
	Name of the crops	Number of labour	Total working days	Total cost (in Tk)	Name of the crops	Number of labour	Total working days	Total cost (in Tk)
Kharif-1								
Kharif-2								
Rabi								
Additional information:								

3.6 Cost of electricity or diesel:

2010				2011			
Total unit of electricity used	Total cost (in Tk)	Total diesel used	Total cost (in Tk)	Total unit of electricity used	Total cost (in Tk)	Total diesel used	Total cost (in Tk)
Additional information:							

3.7 Transport cost of agriculture production (from field to home):

2010		2011	
Means of transport	Total cost (in Tk)	Means of transport	Total cost (in Tk)
Additional information:			

3.8 Cost of agriculture equipment (for ploughing, irrigation, liquid insecticide spraying etc.):

Name of the equipment	2010	2011
	Total cost (in Tk)	Total cost (in Tk)
Additional information:		

3.9 Cost related to fish/shrimp cultivation:

Items		2010		2011	
		Amount/number	Total cost	Amount/number	Total cost
Pond preparation					
Gher preparation					
Chemical use					
Commercial name	Scientific name				
Medicine					
Security					
Fish feed					
Labour					
Transport cost (source to market)					
Additional information:					

3.10 Cost of shrimp fry:

2010				2011			
Source place	Type	Amount	Total cost (in Tk)	Source place	Type	Amount	Total cost (in Tk)
Additional information (transport cost):							

3.11 Cost related to cattle cultivation:

Items		2010		2011	
		Amount/number	Total cost	Amount/number	Total cost
Chemical use					
Commercial name	Scientific name				
Medicine					
Security					
Cattle feed					
Labour					
Cattle housing					
Additional information:					

3.12 Cost related to poultry cultivation:

<table>
<tr><td colspan="2" rowspan="2">Items</td><td colspan="2">2010</td><td colspan="2">2011</td></tr>
<tr><td>Amount/ number</td><td>Total Cost (in Tk)</td><td>Amount/ number</td><td>Total Cost (in Tk)</td></tr>
<tr><td colspan="2">Chemical use</td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Commercial name</td><td>Scientific name</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Medicine</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Poultry feed</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Labour</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Transport cost</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Poultry house</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Security</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">Additional information:</td></tr>
</table>

3.13 Cost of horticulture:

Type of the horticulture	2010		2011	
	Total number	Total cost (in Tk)	Total number	Total cost (in Tk)
Additional information:				

3.14 Locally produced manures

Name of the Manure	Materials used	Amount of production	Production cost	Market value	Production places
Additional information:					

3.15 Poultry and fish feed

Name of the feed		Materials used	Amount of production	Production Cost	Market value	Production places
Fish	Poultry					
Additional information:						

Part 4: Other information

4.1 How many hours do the women work inside and outside (agriculture field/pond/Gher etc.) of the home?

At Home	Outside Home			
	Field	Gher	Pond	Homestead

4.2 What roles do women play in agricultural production?

4.3 Do you produce your own seeds? If yes, where do you produce them? If no, from where do you buy your seeds?

4.4 What seeds are not available? What do you do when seeds are not available?

4.5 How do you preserve your seeds?

4.6 Do you have any access to common resources? If yes, where do you have this access? What do you do there? How much is produced from these common resources? What is the cost of the collected goods? What is the market value of the collected goods?

4.7 Where do you sale your products? Is there a market for your products?

Sl.No	Name of the products	2010	2011	Availability of Market	
		Sale place/people	Sale place/people	Yes	No
Additional information:					

4.8 How do you preserve your agricultural products[4]?

4.9 Do you have any agriculture loans? If yes, from where did you get that loan and what was the purpose of the loan?

Sources:	
Amount:	
Purpose:	

4.10 Do you have any micro credit? If yes, from where did you get that credit? What is the purpose of taking the credit?

[4] Preservation of agricultural products (fish, seed, crops, vegetables etc.)

4.11 Are you involved with any NGO activities? If yes, which ones?

4.12 Are you a member of any NGO? If yes, which one(s)?

4.13 Do you take any suggestions from NGOs/block supervisor for your agricultural activities?

4.14 Do you take any kind of government support for your agricultural activities? If yes, what types and from which agencies?

4.15 What do you do for recreation[5]?

4.16 Where do you go for your health care?

[5] Recreation source = Recreation (TV, dish antenna, radio, cinema, local cultural programme, sports etc.)

4.17 What safety measures do you maintain or take in using fertilizer or spreading pesticide?

4.18 What do you know about climate change impacts on agriculture?

4.19 Do you know about any awareness programme regarding adaptation of agriculture in climate change? If yes, what? Who organized the programme(s)?

Appendix – II

Table A2-1: List of methods for measuring different indicators

Productivity	Formula	Unit	Description
Weighted yield of rice[1] (main staple crop)	$WY = M_P/A$	t/ha	Where, WY = Weighted yield, M_P = Total mass of the crop (rice) / year in tons, A = Total area of the crop in a year in hectares
Net income from the agro-ecosystem	$NIA = \sum \frac{(I \times A_c)}{A_t}$	US$/ha	Where, NIA = Net income from agricultural systems, I = Net income per hectare of each crop grown in US$, A_c= Area of each crop in hectare, A_t = Total land area of agricultural systems in hectare
Protein yield from agro-ecosystem	$PYA = \sum P_t/A_t$	kg/ha	Where, PYA = Protein yield from agricultural systems, P_T = Total protein from different crops of agro-ecosystem in kg, A_t = Total land area of agricultural systems in hectare
Note: Indicators of stability were collected from secondary information			
Efficiency	**Formula**	**Unit**	**Description**
Money input and output in the agro-ecosystem	$MIOA = AO_{t\$} \div AI_{t\$}$	Ratio of monetary output to input'	Where, $MIOA$ = Money input and output in the agricultural systems, $AO_{t\$}$ = Total dollar output from the agricultural systems, $AI_{t\$}$ = Total dollar input in the agricultural systems
Overall energy efficiency	$OEF = T_{eo} \div T_{ei}$	Ratio of energy output to input	Where, OEF = Overall energy efficiency of agricultural systems, T_{eo} = Total energy output of crops produced in a year, T_{ei} = Total energy input for all crops produced in a year
Non-renewable energy efficiency	$NREF = T_{ep} \div T_{nre}$	Ratio of energy output to input	Where, $NREF$ = Non-Renewable energy efficiency of agricultural systems, T_{ep} = Total energy content of primary product in calories, T_{nre} = Total non-renewable energy input in calorie for all crops production
Durability	**Formula**	**Unit**	**Description**
Chemical response to pest stress	$CRPT = PF_{ncp} \div 10$	Binary yes/no response	Where, $CRPT$ = Chemical response to pest stress in the agricultural systems, PF_{ncp} = Percentage of farmers reporting not using chemical pesticide for agriculture, 10 indicates highest value of farmers who do not use chemical pesticide for agriculture by converting percentage of farmers to a 0 to 10 scale
Water availability at transplanting stage of rice	$WATS = PF_{wt} \div 10$	Binary yes/no response	Where, $WATS$ = Water availability at transplanting stage of rice, PF_{wt} = Percentage of farmers reporting availability of water at transplanting stage, 10 indicates highest value of water availability reported by farmers by converting percentage of farmers to a 0 to 10 scale
Water availability at flowering stage of rice	$WAFS = PF_{wf} \div 10$	Binary yes/no response	Where, WAFS = Water availability at flowering stage of rice, PF_{wf} = Percentage of farmers reporting availability of water, 10 indicates highest value of water availability in flowering stage reported by farmers by converting percentage of farmers to a 0 to 10 scale

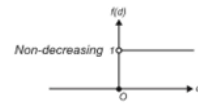
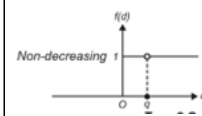
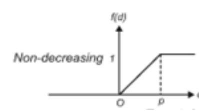
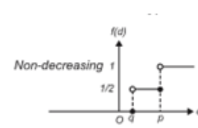
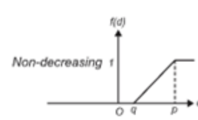
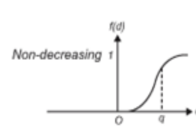
Farm management[2]	$FM = PF_{fm} \div 10$	Binary yes/no response	Where, FM = Farm Management, PF_{fm} = Percentage of farmers who apply farm management, 10 indicates highest value of farmers who follow farm management by converting percentage of farmers to a 0 to 10 scale
Good product price	$GPP = PF_{pp} \div 10$	Binary yes/no response	Where, GPP = Good product price, PF_{pp}= Percentage of farmers getting good product price, 10 indicates highest value of farmers who get a good price for their agricultural products by converting percentage of farmers to a 0 to 10 scale
Availability of seeds	$AS = PF_{ras} \div 10$	Binary yes/no response	Where, AS = Availability of seed, PF_{ras}= Percentage of farmers reporting availability of seed, 10 indicates highest value of farmers who said seeds are available by converting percentage of farmers to a 0 to 10 scale
Availability of markets[3]	$AM = PF_{ram} \div 10$	Binary yes/no response	Where, AM = Availability of market for agricultural product(s), PF_{ram} = Percentage of farmers who reported availability of market, 10 indicates highest value of farmers who had access to markets, converted percentage of farmers into a 0 to 10 scale
Agricultural training	$AT = PF_{rat} \div 10$	Binary yes/no response	Where, AT = Received agricultural training, PF_{rat} = Percentage of farmers who reported receiving agricultural training, 10 indicates highest value of farmers who received agricultural training by converting percentage of farmers to a 0 to 10 scale
Climate change awareness	$CCA = PF_{racci} \div 10$	Binary yes/no response	Where, CCA = Have awareness of climate change impacts on agriculture, PF_{racci} = Percentage of farmers who reported an awareness of climate change impacts on agriculture, 10 indicates highest value of farmers who reported an awareness about climate change impacts by converting percentage of farmers to a 0 to 10 scale
Advice from agricultural extension workers or NGO	$AAEWN = PF_{rsbn} \div 10$	Binary yes/no response	Where, $AAEWN$ = Take suggestion from agricultural extension workers or NGO, PF_{rsbn}= Percentage of farmers who reported taking suggestions from agricultural extension workers or NGO for agricultural activities, 10 indicates highest value of farmers reported take suggestion from block supervisor by converting percentage of farmers into a 0 to 10 scale
Compatibility	**Formula**	**Unit**	**Description**
Drinking water quality[4]	$PWS = PF_{apw} \div 10$	Binary yes/no response	Where, PWS = Protected water supply, PF_{apw} = Percentage of people with access to protected water. 10 indicates highest value of farmers who reported having a supply of protected drinking water by converting percentage of farmers into a 0 to 10 scale
Illness from drinking water	$DWQ = (20 - PF_{peirt})/2$	Binary yes/no response	Where, DWQ = Drinking water-related illness, PF_{peirt} = Percentage of people who experienced illness and required treatment in past year, 20% is the poorest goalpost and 0 is the best goalpost
Overall biodiversity condition: percentage of non-crop area	$OBC = -\sum A_i \times \ln A_i$ $SOBC = 10 \times OBC/2$	%	Where, OBC = Overall biodiversity condition, A_i = Fractional area occupied by an individual crop or land use, $\ln A_i$ = natural logarithm (ln) of A_i $SOBC$ = Scaling overall biodiversity condition, OBC = Overall biodiversity condition, “10” is the best score in 0 to 10 scale

Overall biodiversity condition: crop richness	$CRI = N_c$	Count	Where, CRI = Crop richness, N_c = Number of crops produced by farmers in a year
Overall biodiversity condition: crop rotation	$CR = N_{cr}$	Count	Where, CR = Crop rotation, N_c = Number of crop rotations reported by farmers in a year
Ecosystem connectivity	$EC = F_{ec}$	Binary yes/no response	Where, EC = Ecosystem connectivity, F_{ec} = Farmer observation of ecosystem connectivity in terms of yes or no answer
Equity	**Formula**	**Unit**	**Description**
Education of farmers[5]	$EOF = (TS/N \times 100) \div 10$	%	Where, EOF = Education of farmers, TS = Total education score by the responded farmers of the agricultural systems, N = Total number of respondents, "10" is the best score on a 0 to 10 scale
Education status of farmers' male children	Same procedures as above	%	Same procedures as above
Education status of farmers' female children	Same procedures as above	%	Same procedures as above
Access to electronic media	$AEM = PF_{ae} \div 10$	%	Where, AEM = Access to electronic media, PF_{ae} = Percentage of farmers who have access to electronic media, "10" is the best score on a 0 to 10 scale
Farm profitability	$AIAS = \sum TI \div N_f$	$	Where, $AIAS$ = Average income of the agricultural systems in a year, TI =Total income from the whole agricultural systems, N_f = Number of farmers surveyed
Average wage of farm laborer	$AWFL = \sum TI \div N_{fr}$	$/person/day	Where, $AWFL$ = Average wage for farm labour, TI =Total wage, N_{fr} = Number of farmer respondents
Livelihood diversity other than agriculture	$LD = PF_{rso} \div 10$	Count, 0 to 5	Where, LD = Livelihood diversity, PF_{rso} = Percentage of farmers reporting secondary occupation other than agricultural activities, 10 indicates highest value of farmers reporting livelihood diversity by converting percentage of farmers into a 0 to 10 scale
Years of economic hardship[6]	$YEH = 10 - N$	Number of years	Where, YEH = Years of economic hardship, N = Number of years of economic hardship out of 10 years
Road network (establishing farm roads and access roads)	$RN = PF_{rn} \div 10$	Access/no access	Where, RN = Road network, PF_{rn} = Percentage of farmers reported about good road network, 10 indicates highest value of farmers who reported livelihood diversity by converting percentage of farmers into a 0 to 10 scale
Settings where treatment is taken or public health	$ST = \sum X_i N_i \div N_t$	%	Where, ST = Settings where treatment is available, $X_i N_i$ = Treatment to attain a score X_i; these are summed and averaged for all treatments, N_t = Total number of individuals
Sanitation or public health	$TF = \sum X_i N_i \div N_t$	%	Where, TF = Toilet Facilities, $X_i N_i$ = Number of Toilet facilities to attain a score X_i,; N_t = Total number of toilet facilities

Women's involvement in decision making about agricultural activities	$WPAA = PW_{aa} \div 10$	%	Where, $WPAA$ = Women's participation in agricultural activities, PW_{aa}= Percentage of women who participate in agricultural activities, "10" is the best score into a 0 to 10 scale
Gender-based wage differentials	$GBWD = (30 - D)/3$	$/person/day	Where, $GBWD$ = Gender-based wage differentials, D = Wage difference in percentage terms between men and women's labor, "30" is the per cent differential as the poorest value

Note: [1]Weighted yield is calculated by summing total production of rice in the corresponding field sizes in a year and dividing by the sum of all the areas (vanLoon et al., 2005); [2]Includes soil tests, pest management, land management, soil fertility management; [3]related to market diversification; [4]protected water; [5]Illiterate (cannot write and read) = 0, Primary schooling (from grade 1-5) = 0.5, Secondary schooling (from grade 6-10) = 1, tertiary schooling (grade 11 to upper study) =2; [6]Economic hardship is defined as lack of capital for doing agriculture. Source: Reconstructed from Talukder, 2012.

Table A2-2: Preference functions in PROMETHEE

Type of preference	Description of the preference	Graphical presentation	Analytical definition
I: True/Usual criterion	When the value of the criteria of alternative a exceeds alternative b, then there is a strict preference and the preference value is 1. In case of equal value of the criteria, there is no preference and the preference value is 0.		$f(d) = \begin{cases} 1 & \text{if} \quad 0 < d \\ 0 & \text{if} \quad d \leq 0 \end{cases}$
II: Threshold criterion	The decision-maker defines the indifference threshold value of the criteria. If the value of the criteria of alternative a exceeds that of alternative b by an amount q, greater than or equal to the indifference value (q), then a is preferred over b.		$f(d) = \begin{cases} 1 & \text{if} \quad q < d \\ 0 & \text{if} \quad d \leq q \end{cases}$
III: Linear with threshold criterion	If the criteria value of alternative a is closer to the absolute preference than alternative b, then alternative a is better than alternative b. If the difference of the criteria of alternative a reaches the absolute preference, then alternative a is absolutely better than alternative b.		$f(d) = \begin{cases} 1 & \text{if} \quad p < d \\ \frac{d}{p} & \text{if} \quad 0 < d \leq p \\ 0 & \text{if} \quad d \leq 0 \end{cases}$
IV: Linear over range criterion	First, an indifference value of the criteria is determined. When the difference of the criteria values of alternatives a and b moves from a value 0 to a value p, the preference function increases linearly from 0 to 1 over that range of differences. If the criteria value of alternative a passes the difference of threshold value of 0, then a is preferred to b.		$f(d) = \begin{cases} 1 & \text{if} \quad p < d \\ \frac{d-q}{p-q} & \text{if} \quad q < d \leq p \\ 0 & \text{if} \quad d \leq q \end{cases}$
V: Stair step/ Level criterion	For this method, an absolute preference value and an indifference value are determined. If the criteria value of alternative a is less than the absolute preference value that gives a preference of 0, the difference between the absolute preference value and indifference value gives a preference of 1/2, and a difference greater than the absolute preference value gives a preference of 1.		$f(d) = \begin{cases} 1 & \text{if} \quad d > p \\ \frac{1}{2} & \text{if} \quad q < d \leq p \\ 0 & \text{if} \quad d \leq q \end{cases}$
Vi: Gaussian criterion	The s threshold value is somewhere between the q_j indifference threshold and the q_j preference threshold and it follows normal distribution. This preference function is less often used due to difficulty in parameters.		$f(d) = \begin{cases} 1 - \exp(\frac{-d^2}{2\sigma^2}) & \text{if} \quad 0 < d \\ 0 & \text{if} \quad d \leq 0 \end{cases}$

Legend: d = the difference between two criteria a and b, p = the strict preference threshold, q = the indifference threshold, s = the standard deviation in Gaussian distribution. Source: Based on Diakoulaki and Koumoutsos, 1991.

Appendix – III

Table A3.1: Indicators used to assess agricultural sustainability (literature review)

Component	Parameters
Ecological	Improve water resource management[15,16,4]; usage of pesticides, herbicides and fungicides[12,16,9]; usage of animal/organic manures[16]; usage of green manures[3]; physical yield[12,6]; physical inputs and efficient use of input[6]; cropdiversification[12,9,11]; crop rotation[12]; use of alternative crop[16]; usage of fallow system[12,16,11]; cropping pattern[12,10]; trend of change in climatic conditions[15,16]; usage of chemical fertilizer[16]; conservational tillage (no/minimum tillage)[16,7]; control erosion[15,12,16,4]; energy[16,11]; microbial biomass with in the soil[15,9] ; cover crop/mulch[12,7]; depth of groundwater table[15,14]; integrated pest[16]; energy consumption[16]; water use[16]; waste[3]; agro-diversity[5, 2]; biodiversity[18].
Economic	Average of crop production[12,9]; expenses for input[16,13]; monetary income from outside the farm[15,16]; monetary income from the farm[15,10]; economic efficiency[15,10]; profitability[12,16,8,17,4]; the salaries paid to farm workers[16]; employment opportunities[12,16]; market availability[15,16]; land ownership[15,16,10]; soil management[15, 12,16,14]; stability of the agricultural enterprise[3]; crop productivity[16,1]; local economy[3]; vulnerability[3], GDB contribution[5]; holding size[2]; machinery[2,18].
Social	Education level of the household members[15,16]; housing facilities[3]; work study[3]; nutritional/health status of the family members[15,12,16]; improved decision making[12,7,16]; improved the quality of rural life[15,16]; working and living conditions[15]; participation/social capital[15,16]; social equity[12,16,13]; social or community well-being[16,1]; food sufficiency[16]; equity[16,3]; governance[3]; human right[3]; accountability[3]; labour[5,18] .

Source: [1]DFID, 2004; [2]Dantsis et al., 2010; [3]FAO, 2012b; [4]Gafsi et al., 2006; [5]Gomez-Limon & Riesgo, 2009; [6]Herzog & Gotsch, 1998; [7]Horrigan et al., 2002; [8]De koeijer et al., 2002; [9]Nambiar et al., 2001; [10]Nijkamp & Vreeker, 2000; [11]Pannell & Glenn, 2000; [12]Rasul &Thapa, 2004; [13]Rigby & Caceres, 2001; [14]Sands & Podmore, 2000; [15]Van Cauwenbergh et al., 2007; [16]vanLoon et al., 2005; [17]Van Passel et al., 2007; [18]Vecchione, 2010.

Table A3.2: Basic steps for developing sustainability indicators under two methodological paradigms

Steps	**Methodological paradigms**	
	Top-down	**Bottom-up**
Step 1: Establish context	Conceptualize the context of the system boundaries in which indicators are developed, such as a watershed or agricultural system.	Context is established through local community consultation to identify strengths, weaknesses, opportunities and threats for specific systems.
Step 2: Establish sustainability goals and strategies	Natural and social scientists identify key socio-ecological conditions that they feel must be maintained to ensure system integrity.	Multi-stakeholder processes identify sometimes competing visions, end-stage goals and scenarios for sustainability.
Step 3: Identify, evaluate and select indicators	Based on expert knowledge, researchers identify indicators that are widely accepted in the scientific community and select the most appropriate indicators using a list of pre-set evaluation criteria.	Communities identify potential indicators, evaluate them against their own (potentially weighted) criteria and select indicators they can use.
Step 4: Collect data to monitor progress	Indicators are used by experts to collect quantitative data which they analyse to monitor socio-ecological change.	Indicators are used by communities to collect quantitative or qualitative data they can analyse to monitor progress towards their sustainability goals.

Source: Adapted and modified from Reed et al., 2006:409.

Table A3.3: Phases in MCDA methods

Phases	Name of the Phases	Description
1st Phase	Structuring of the decision problem	In this phase the stakeholders of the decision problems are identified. The objectives and the criteria of the decision are verified. The alternatives decisions are specified and selected. The problems in alternatives are also clarified.
2nd Phase	Articulating and modeling the preferences	In this phase the preference model is formulated and validated to include all the relevant information of the decision making preferences. The preference function may be a proportionate score (that is, a linear preference function), or a utility value (that is, a nonlinear preference function).
3rd Phase	Aggregating the alternative evaluations (preferences)	In this phase MCDA tools assesses the alternatives by evaluation and comparison based on the requirements of the decision making. Assign weights are applied to the preference measures for the different criteria[6]. The weighting function may be linear and additive or of some other form. The weighting methods of criteria are classified into three categories: subjective weighting, objective weighting and combination weighting methods. The final value or merit is determined by using a simplistic weighted average of the scores, with the option providing the highest weighted score being the one that is "best". But more sophisticated techniques might be used for more complex situations.
4th Phase	Making recommendations	On the phase of the final result recommendations are made for detailed guidelines and further analysis

Sourer: Based on Sadok et al., 2009; Wang et al., 2009.

[6] "Sets of criteria that reflect the diversity of views and values amongst stakeholders can be elicited through facilitated discussion and drawn from a variety of other sources including research and policy documentation. Each criterion should be clearly defined to avoid ambiguity in understanding the differing views" (HUNT:2016:1)

Table A3.4: Strength and weakness of MCDA methods

Perspective	Strength	Weakness
Expert	A complex problem is broken down into workable units (e.g., options, criteria, weights and preferences are made explicit) in MCDA process.[1, 2, 4]	Finding quantitative and/or accurate information on many criteria is difficult.[1,2]
	It inspires transparency of logic (valued by stakeholders) and provides a useful structure for communicating decisions.[1]	Difficulties with identifying or agreeing scale descriptors for assessment[1].
	The MCDA framework assists in transparent structuring preparations and deliberation processes.[1]	Methodological challenges arise, when it is not clear whether the method has dealt appropriately with compromises involving compensation of one factor loss by another factor gain[1].
	MCDA processes result in a good combination of agreed facts and social values.[1,5]	Over the assumption that preferences for different criteria are assumed to be independent of each other.[1]
	Citizens are involved to make comparative values judgments in a long-term perspective.[1,5]	Through a double-counting problem when chosen criteria are either redundant or non-exhaustive[1].
	Citizen juries can be used to aggregate multiple individual preference weights through deliberation to achieve consensus.[1,3,5]	Interactions between analyst and decision makers can become difficult if the analyst is taking on dual roles of science expert and process facilitator.[1,2] Stakeholder engagement processes need to be 'fit for purpose' within the constraints of the resourcing available.[1,2]
Stakeholder/ participant	Giving citizens increased understanding of different points of view.[1, 2, 3,5]	The need to balance complexity/simplicity with cognitive capacity; complex MCDA methods can be perceived by non-experts as "black box" approaches; too many objectives/criteria can overload individual's thinking and analysis.[1,2]
	Enabling the group to learn and 'move forward.[1,2,5]	Citizens can become overwhelmed by expert contributions in some situations - distracting them from their long-term focus.[1]
	Encouraging participants to focus more on the preferences and weightings for the criteria than on the final outcome.[1,2,5]	The differences between scientific knowledge and practical knowledge and the different ways of thinking about a real/abstract situation or problem.[1]
	Framing of citizen deliberations to favor social values -- the format did not preclude voicing of individual interests.[1]	Having experts/interest group representatives select criteria risks missing some criteria considered important by individual citizens.[1]

Source: Adapted and modified from [1]Batstone et al., 2010:7-9; [2]Diakoulaki & Grafakos, 2004; [3]Omann, 2000; [4]Hobbs & Horn, 1997; [5]Linkov et al., 2006.

Table A3.5: Classification schemes of MCDA techniques

Name of the classification	Techniques Includes	References
Outranking methods	Elimination Et Choix Traduisant la Realite´ (ELECTRE) family, Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) I and II methods and Regime Method Analysis	Polatidis et al., 2006
Value or utility function-based methods	Multi-Attribute Utility Theory (MAUT), Simple Multi-Attribute Rated Technique (SMART), Analytical Hierarchy Process (AHP), Simple Additive Weighting (SAW)	
Other methods	Novel Approach to Imprecise Assessment and Decision Environment (NAIADE), Flag Model, Stochastic Multiobjective Acceptability Analysis (SMAA)	
Multi-criteria value functions	MAUT	Hajkowicz & Collins, 2007
Outranking approaches	PROMETHEE, ELECTRE	
Distance to ideal point methods	Compromise Programming (CP) and TOPSIS	
Pairwise comparisons	AHP	
Fuzzy set analysis.	Buckley (1984) presented an implementation framework where each DM provides a fuzzy membership value for each alternative on each criterion.	
Tailor methods	A tailored method usually extends or adapts a fundamental methodology to a particular application.	
General utility analysis	AHP	Browne et al., 2010
Outranking methodologies	PROMETHEE and ELECTRE	
Social multi-criteria evaluation (SMCE)	NAIADE	

Table A3.6: Prerequisites of MCDA techniques for Agricultural Sustainability Assessment

Prerequisites of MCDA techniques	**Justification**
Weights elicitation	To provide preference information among the sustainability criteria
Critical threshold values	To operationalize the assimilative capacity of the environmental, economic and social aspects
Comparability	To perform an integrated comparison among the between the agricultural systems
Qualitative and quantitative information	To handle the mixed information usually associated with agricultural sustainability assessment
Rigidity	To give robust results
Stakeholders involvement	To include a diverse audience of stakeholders
Graphical representation	To render the outcome understandable
Ease of use	To familiarize the stakeholder and assessors with the assessment process
Sensitivity analysis	To enhance the transparency of the procedure
Variety of alternatives	To incorporate all possible courses of action
Large number of evaluation criteria	To embrace all different aspects of agricultural sustainability
Consensus seeking procedures	To reach up a global compromise
Incorporation of intangible aspects	To be capable of taking into account "hidden" dimensions of the assessment
Incommensurability	To keep the decision criteria in their original units and provide a better decomposition of the issue
Treatment of uncertainty	To explicitly treat the imperfect data (uncertain, imprecise, missing, erroneous, etc.)
Partial compensation	To operationalize a strong sustainability conception
Hierarchy of scale	To decrease the ambiguities and provide for explicit consistency
Concrete meaning for parameters used	To improve the reliability of the process
Learning dimension	To acknowledge and accept new information revealed during the evolution of the procedure
Temporal aspects	To consider the emergency of the situation and clarify long- and short-term concerns

Source: Based on Polatidis et al., 2006

Table A3.7: Checklist for building a composite indicator

Steps	Description	Why it is needed
1st: Theoretical framework	Provides the basis for the selection and combination of variables into a meaningful composite indicator under a fitness-for-purpose principle (involvement of experts and stakeholders is envisioned in this step).	▪ To get a clear understanding and definition of the multidimensional phenomenon to be measured. ▪ To structure the various sub-groups of the phenomenon (if needed). ▪ To compile a list of selection criteria for the underlying variables, *e.g.*, input, output, process.
2nd: Data selection	Should be based on the analytical soundness, measurability, country coverage, and relevance of the indicators to the phenomenon being measured and their relationship to each other. The use of proxy variables should be considered when data are scarce (involvement of experts and stakeholders is envisioned in this step).	▪ To check the quality of the available indicators. ▪ To discuss the strengths and weaknesses of each selected indicator. ▪ To create a summary table of data characteristics, e.g., availability (across country, time), source, type (hard, soft or input, output, process).
3rd: Imputation of missing data	Is needed in order to provide a complete dataset (e.g., by means of single or multiple imputation).	▪ To estimate missing values. ▪ To provide a measure of the reliability of each imputed value so as to assess the impact of the imputation on the composite indicator results. ▪ To discuss the presence of outliers in the dataset.
4th: Multivariate analysis	Should be used to study the overall structure of the dataset, assess its suitability, and guide subsequent methodological choices (e.g., weighting, aggregation).	▪ To check the underlying structure of the data along the two main dimensions, namely individual indicators and countries (by means of suitable multivariate methods, e.g., principal components analysis, cluster analysis). ▪ To identify groups of indicators or groups of countries that are statistically "similar" and provide an interpretation of the results. ▪ To compare the statistically determined structure of the dataset to the theoretical framework and discuss possible differences.
5th Normalization	Should be carried out to render the variables comparable.	▪ To select suitable normalization procedure(s) that respects both the theoretical framework and the data properties.

		▪ To discuss the presence of outliers in the dataset as they may become unintended benchmarks. ▪ To make scale adjustments, if necessary. ▪ To transform highly skewed indicators, if necessary.
6th: Weighting and aggregation	Should be done along the lines of the underlying theoretical framework.	▪ To select appropriate weighting and aggregation procedure(s) that respects both the theoretical framework and the data properties. ▪ To discuss whether correlation issues among indicators should be accounted for. ▪ To discuss whether compensability among indicators should be allowed.
7th: Uncertainty and sensitivity analysis	Should be undertaken to assess the robustness of the composite indicator in terms of the mechanism for including or excluding an indicator, the normalization scheme, the imputation of missing data, the choice of weights, the aggregation method, and so forth.	▪ To consider a multi-modelling approach to build the composite indicator and alternative conceptual scenarios for the selection of the underlying indicators if available. ▪ To identify all possible sources of uncertainty in the development of the composite indicator and accompany the composite scores and ranks with uncertainty bounds. ▪ To conduct sensitivity analysis of the inference (assumptions) and determine what sources of uncertainty are more influential in the scores and/or ranks.
8th: Back to the data	Is needed to reveal the main drivers of overall good or bad performance. Transparency is primordial to good analysis and policymaking.	▪ To profile country performance at the indicator level so as to reveal what is driving the composite indicator results. ▪ To check for correlation and causality (if possible). ▪ To identify whether the composite indicator results are overly dominated by a few indicators and to explain the relative importance of the sub-components of the composite indicator.

Source: OECD, 2008:20-22

Table A3.8: Overall result of MAUT analysis in Web-HIPRE software

Value Tree

0 Ag_Sustainability

1 Productivity 0.200

2 Productivity 1.000

3 S 0.233

3 SR 0.533

3 I 1.000

3 T 0.467

3 R 1.000

1 Stability 0.200

2 Landsca_stab 0.350

3 S 0.636

3 SR 0.818

3 I 0.955

3 T 1.000

3 R 0.909

2 Soil health 0.350

3 S 0.682

3 SR 0.955

3 I 0.682

3 T 1.000

3 R 0.955

2 Water quality 0.300

3 S 0.379

3 SR 0.621

3 I 0.759

3 T 1.000

3 R 0.621

1 Efficiency 0.200

2 Monetary_effi 0.500

3 S 0.233

3 SR 0.326

3 I 1.000

3 T 0.349

3 R 0.419

2 Energy_effi 0.500

3 S 0.233

3 SR 0.533

3 I 1.000

3 T 0.467

3 R 1.000

1 Durability 0.100

2 Resist_pest_ st 0.300

3 S 0.889

3 SR 1.000

3 I 0.667

3 T 0.444

3 R 0.704

2 Resist_eco_st 0.350

3 S 1.000

3 SR 0.800

3 I 0.800

3 T 0.680

3 R 0.760

2 Resist_clim_ch 0.350

3 S 0.733

3 SR 0.900

3 I 1.000

3 T 0.333

3 R 0.367

1 Compatibility 0.150

2 Human_com 0.500

3 S 0.240

3 SR 0.880

3 I 1.000

3 T 0.960

3 R 0.960

2 Biophysical_co 0.500

3 S 0.345

3 SR 0.448

3 R 1.000

1 Equity 0.150

2 Education 0.350

3 S 0.769

3 SR 0.846

3 I 1.000

3 T 0.462

3 R 0.769

2 Economic 0.350

3 S 0.739

3 SR 1.000

3 I 0.957

3 T 0.739

3 R 0.913

2 Health 0.200

3 S 0.654

3 SR 0.808

3 I 1.000

3 T 0.692

3 R 0.692

2 Gender 0.100

3 S 0.531

3 SR 0.594

3 I 1.000

3 T 0.188

3 R 0.813

Composite Priorities

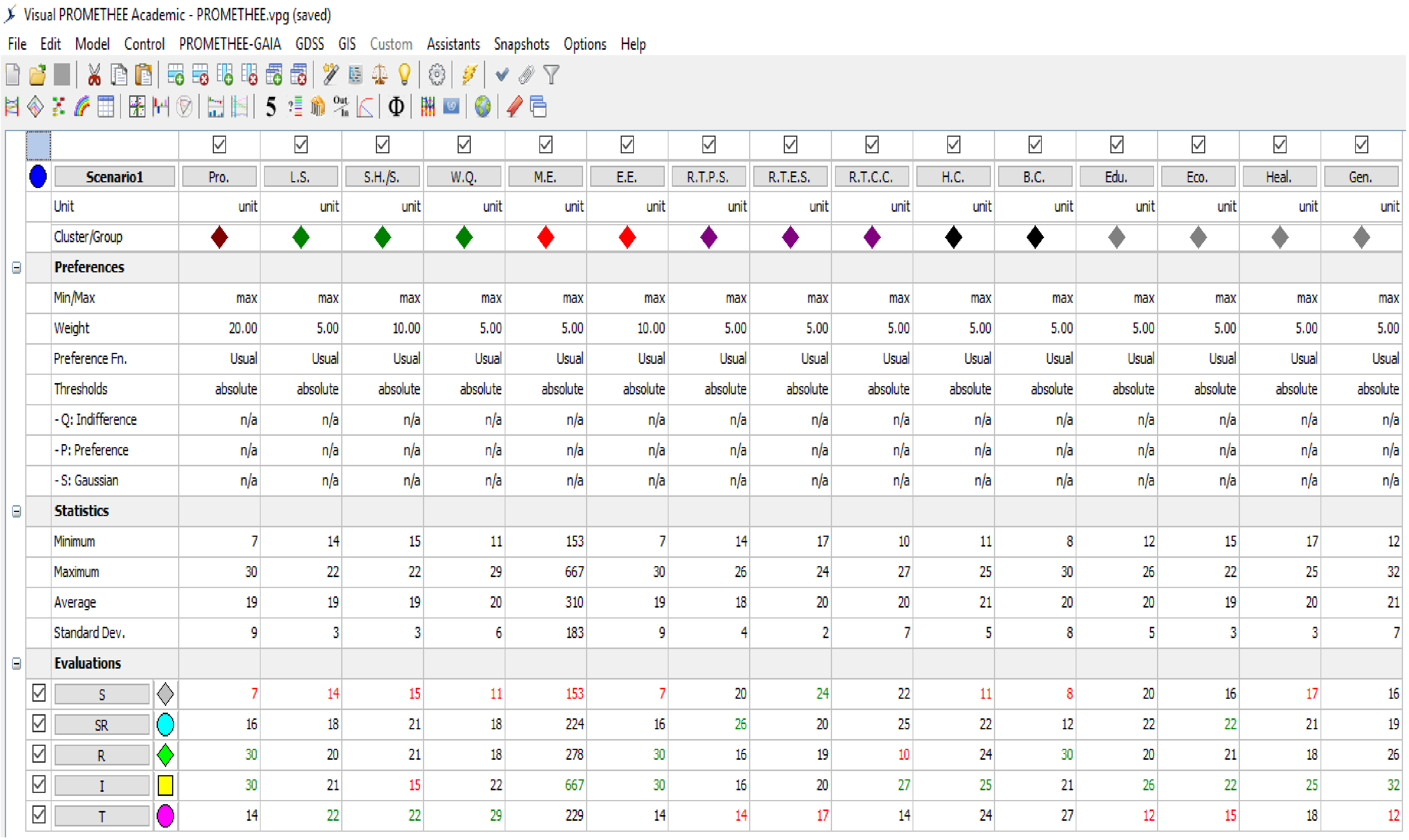
	S	SR	R	I	T
Productivi	0.047	0.107	0.200	0.200	0.093
Stability	0.115	0.161	0.168	0.160	0.200
Efficiency	0.047	0.086	0.142	0.200	0.082
Durability	0.087	0.090	0.061	0.083	0.049
Compatibil	0.044	0.100	0.147	0.075	0.072
Equity	0.107	0.130	0.121	0.148	0.087
Overall	0.446	0.673	0.838	0.866	0.582

Figure A3.1: Composite priorities of MAUT analysis in Web-HIPRE software

Table A3.9: Evaluation matrix for agricultural systems for all criteria in PROMETHEE

A.S.	Pro.	L.S	S.H./S	W.Q.	M.E.	E.E.	R.T.P.S.	R.T.E.S.	R.T.C.S.	H.C.	B.C.	Edu.	Eco.	Hlth.	Gen.
S	7	14	15	11	153	7	20	24	22	11	8	20	16	17	16
SR	16	18	21	18	224	16	26	20	25	22	12	22	22	21	19
R	30	20	21	18	278	30	16	19	10	24	30	20	21	18	26
T	30	21	15	22	667	30	16	20	27	25	21	26	22	25	32
I	14	22	22	29	229	14	14	17	14	24	27	12	15	18	12

Here: Red numbers indicate lowest point and green numbers represent highest point



Scenario1	Pro.	L.S.	S.H./S.	W.Q.	M.E.	E.E.	R.T.P.S.	R.T.E.S.	R.T.C.C.	H.C.	B.C.	Edu.	Eco.	Heal.	Gen.
Unit	unit	unit	unit	unit	unit	unit	unit	unit	unit	unit	unit	unit	unit	unit	unit
Cluster/Group															
Preferences															
Min/Max	max	max	max	max	max	max	max	max	max	max	max	max	max	max	max
Weight	20.00	5.00	10.00	5.00	5.00	10.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Preference Fn.	Usual	Usual	Usual	Usual	Usual	Usual	Usual	Usual	Usual	Usual	Usual	Usual	Usual	Usual	Usual
Thresholds	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute
- Q: Indifference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
- P: Preference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
- S: Gaussian	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Statistics															
Minimum	7	14	15	11	153	7	14	17	10	11	8	12	15	17	12
Maximum	30	22	22	29	667	30	26	24	27	25	30	26	22	25	32
Average	19	19	19	20	310	19	18	20	20	21	20	20	19	20	21
Standard Dev.	9	3	3	6	183	9	4	2	7	5	8	5	3	3	7
Evaluations															
S	7	14	15	11	153	7	20	24	22	11	8	20	16	17	16
SR	16	18	21	18	224	16	26	20	25	22	12	22	22	21	19
R	30	20	21	18	278	30	16	19	10	24	30	20	21	18	26
I	30	21	15	22	667	30	16	20	27	25	21	26	22	25	32
T	14	22	22	29	229	14	14	17	14	24	27	12	15	18	12

Figure A3.2: Snapshot of PROMETHEE spreadsheet for data analysis.

Table A3.10: Hypothetical table for calculation of strict preference of PROMETHEE

Indicator	Agricultural Systems A	Agricultural Systems B	Agricultural Systems C	Weight
Productivity (t/ha)	10	12	7	30
Soil stability (score)	5	7	3	30
Ecosystem services (score)	10	7	14	30
Governance (score)	3	3	9	5
Education rate (%)	75	45	90	5

Table A3.11. Example of the calculation of strict preference of PROMETHEE (Hypothetical)

Agricultural Systems	Indicators	Pairwise Comparison		Score	Total Score	Weight	Score*Weight	Total Weight
A		A-B	A-C					
	Pro	0	1	1	4	0.3	0.3	0.95 (Most Sustainable)
	S.S.	0	1	1		0.3	0.3	
	E.S.	1	0	1		0.3	0.3	
	Gov.	0	0	0		0.05	0.00	
	E.R.	1	0	1		0.05	0.05	
B		B-A	B-C					
	Pro	1	0	1	3	0.3	0.3	0.9
	S.S.	1	0	1		0.3	0.3	
	E.S.	0	1	1		0.3	0.3	
	Gov.	0	0	0		0.05	0.00	
	E.R.	0	0	0		0.05	0.00	
C		C-A	C-B					
	Pro	0	0	0	6	0.3	0.00	0.80
	S.S.	0	0	0		0.3	0.00	
	E.S.	1	1	2		0.3	0.6	
	Gov.	1	1	2		0.05	0.1	
	E.R.	1	1	2		0.05	0.1	

Table A3.12: Submitted/Proposed papers and contribution of the candidate

Papers	Proposed title	Contribution of candidate
1	Comparison of the Selected Methodological Approaches to Assessment of Agricultural Sustainability	80%, the candidate led the experimental design, programming, experimental testing, data analysis, and manuscript preparation.
2	Developing composite indicators for agricultural sustainability assessment: Effect of normalization and aggregation techniques	80%, the candidate led the experimental design, programming, experimental testing, data analysis, and manuscript preparation.
3	Multi Utility Value Theory (MUVT): A Multi-Criteria Decision Analysis (MCDA) Technique for Assessing Sustainability of Agriculture Systems	80%, the candidate led the experimental design, programming, experimental testing, data analysis, and manuscript preparation.
4	Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) a Novel Approach to Assess Agricultural Sustainability	80%, the candidate led the experimental design, programming, experimental testing, data analysis, and manuscript preparation.
5	Elimination Method of Multi-Criteria Decision Analysis (MCDA): A Simple Methodological Approach for Assessing Agricultural Sustainability	80%, the candidate led the experimental design, programming, experimental testing, data analysis, and manuscript preparation.
6	Testing and Comparing Applicability of MAUT, PROMETHE and Elimination Methods of MCDA for Agricultural Sustainability Assessment	80%, the candidate led the experimental design, programming, experimental testing, data analysis, and manuscript preparation.
7	Energy Efficiency of Agricultural Systems in the South-west Coastal Zone of Bangladesh	80%, the candidate led the experimental design, programming, experimental testing, data analysis, and manuscript preparation.

Table A3.13: Conference papers from PhD project

Papers	Title
1	Talukder, B., Blay-Palmer, A., vanLoon, G., Hipel, K. Milne R. (2015). Assessing Sustainability of Agricultural Systems Using Multi-Criteria Decision Analysis. Inauguration workshop of Locally Embedded, Globally Engaged (FLEdGE) Partnership project. 8 September, 2015. Balsillie School of International Affairs, Waterloo, Canada.
2	Talukder, B., Blay-Palmer, A., vanLoon, G., Hipel, K. Milne R. (2015). Multi-Criteria Decision Analysis (MCDA) Technique a Tool for Assessing and Comparing Sustainability of Climate Smart and Conventional Agricultural Systems. Our Common Future under Climate Change" International Scientific Conference, 7-10 July 2015 Paris, France.
3	Talukder, B., Blay-Palmer, A., vanLoon, G., Hipel, K. Milne R. (2015). Multi-Criteria Decision Analysis (MCDA) Technique a Tool for Assessing Sustainability of Agriculture Systems, Ph.D. Dissertation Workshop in Environment and Resources, Balsillie School of International Affairs, Waterloo, Ontario, Canada.
4	Talukder, B., Blay-Palmer, A., vanLoon, G. (2015). Rain water-based integrated agricultural system: A model for ensuring food security and adaptation in coastal Bangladesh. Climate-Smart Agriculture 2015, Global Science Conference, Mach 16-18, 2015, Le Corum, Montpellier, France.
5	Talukder, B., Blay-Palmer, A., vanLoon, G., & Hipel, K. (2014). Application of PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) for assessing sustainability of agricultural system: A case study from coastal Bangladesh. Fourth International Conference on Food Studies, 20-21 October 2014, Monash University Prato Centre, Prato, Italy.
6	Talukder, B., Blay-Palmer, A., vanLoon, G., & Hipel, K. (2013). Multi-Criteria Decision Analysis (MCDA) in assessing sustainability of the coastal agriculture of Bangladesh. Presented in Third Food Studies: An Interdisciplinary Conference, 15-16 October 2013, Texas University, USA.
2	Talukder, B., & Blay-Palmer, A. (2013). Incorporating system thinking in assessments of food and agriculture system sustainability. Presented in the Graduate Student Workshop of Waterloo Food Issues Group (WatFIG), 18 April 2013, Waterloo University, Canada.

References

1. Acosta-Alba, I., & Van der Werf, H. M. (2011). The use of reference values in indicator-based methods for the environmental assessment of agricultural systems. *Sustainability*, *3*(2), 424-442.

2. ADB, & IFPRI. (2009). *Building climate resilience in the agriculture sector in Asia and the Pacific*. Asian Development Bank and International Food Policy Research Institute. Retrieved on May 10 2015 from http://www.adb.org/sites/default/files/pub/2009/Building-Climate-Resilience-Agriculture-Sector.pdf

3. Adger, W. N. (2006). Vulnerability. *Global environmental change*, *16*(3), 268-281.

4. Aguirre, B. E. (2002). “Sustainable development” as collective surge. *Social Science Quarterly*, *83*(1), 101-118.

5. Akasie, G. (2010). Accounting Essentials: Concepts, Terms and Meaning. Author House.

6. Alencar, L. H., & Almeida, A. T. D. (2010). A model for selecting project team members using multicriteria group decision making. *Pesquisa Operacional*, *30*(1), 221-236.

7. Alexandratos, N. & Bruinsma, J. (2012). *World agriculture towards 2030/2050: the 2012 revision.* ESA Working paper No. 12-03. Rome, FAO. Retrieved on September 10 2015 from http://large.stanford.edu/courses/2014/ph240/yuan2/docs/ap106e.pdf

8. Allen, P., Van Dusen, D., Lundy, J., & Gliessman, S. (1991). Integrating social, environmental, and economic issues in sustainable agriculture. *American Journal of Alternative Agriculture*, *6*(1), 34-39.

9. Altieri, M. A. (1995). *Agroecology: the science of sustainable agriculture* (No. 2. Edition). Westview Press.

10. Altieri, M. A. (2004). Linking ecologists and traditional farmers in the search for sustainable agriculture. *Frontiers in Ecology and the Environment*, *2*(1), 35-42.

11. Alvarez-Guerra, M., Viguri, J. R., & Voulvoulis, N. (2009). A multicriteria-based methodology for site prioritisation in sediment management. *Environment International*, *35*(6), 920-930.

12. Amekawa, Y. (2010). Rethinking sustainable agriculture in Thailand: a governance perspective. *Journal of sustainable agriculture*, *34*(4), 389-416.

13. Anand, S., & Sen, A. (2000). Human development and economic sustainability. *World development*, *28*(12), 2029-2049.

14. Anielski, M., & Wilson, J. (2010). Environmental Footprinting for Agriculture in Alberta: Literature Review and Analysis. *Anielski Management Inc., Prepared for Alberta Agriculture and Rural Development, Edmonton, Alberta*.

15. Antunes, P., Santos, R., Videira, N. & Colaço, F. (2012). *Approaches to integration in sustainability assessment of technologies. Guidelines for the application of mca-tools for the sustainability assessment of technologies in participatory contexts and weighing factors for environmental, economic, and social indicators*. Report prepared within the EC 7th framework project. Retrieved on August 15 2015 from http://www.prosuite.org/c/document_library/get_file?uuid=c378cd69-f785-40f2-b23e-ae676b939212&groupId=12772

16. Apse, M. P., & Blumwald, E. (2002). Engineering salt tolerance in plants. *Current Opinion in Biotechnology*, *13*(2), 146-150.

17. Asenso-Okyere, K., Davis, K., & Aredo, D. (2008). *Advancing agriculture in developing countries through knowledge and innovation: Synopsis of an international conference*. Intl Food Policy Res Inst.

18. Astier, M., García-Barrios, L., Galván-Miyoshi, Y., González-Esquivel, C. E., & Masera, O. R. (2012). Assessing the Sustainability of Small Farmer Natural Resource Management Systems. A Critical Analysis of the MESMIS Program. *Ecology and society*, *17*(3), 25.

19. BARC. (1996). Agro-ecological zone of Bangladesh. Bangladesh Agricultural Research Council. BARC/UNDP/FAO GIS project BGD/95/006.

20. BARC. (2000). Map of Pre-Kharif Drought Prone Areas. BARC/UNDP/FAO GIS project BGD/95/006. Bangladesh Agricultural Research Council, Dhaka.

21. Batstone, C. J., Baines, J. M., Goodwin, E., Morgan, B., & Cnard, T. (2010). *Methods for developing sustainability indicator systems for freshwater and estuarine receiving bodies of urban storm-water.* Cawthron Report No. 1874. New Zealand: Cawthron Institute. Retrieved on October 10 2015 from https://www.niwa.co.nz/sites/niwa.co.nz/files/upsw3.pdf

22. Battisti, D. S., & Naylor, R. L. (2009). Historical warnings of future food insecurity with unprecedented seasonal heat. *Science*, *323*(5911), 240-244.

23. Baumol, W. J., & Oates, W. E. (1971). The use of standards and prices for protection of the environment. *Swedish Journal of Economics*, *73*(1), 42-54.

24. Beddington, J. (2010). Food security: contributions from science to a new and greener revolution. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1537), 61-71.

25. Behzadian, M., Kazemzadeh, R. B., Albadvi, A., & Aghdasi, M. (2010). PROMETHEE: A comprehensive literature review on methodologies and applications. *European Journal of Operational Research*, *200*(1), 198-215.

26. Bell, S., & Morse, S. (2008). *Sustainability indicators: measuring the immeasurable?*. Earthscan.

27. Belton, V., & Stewart, T. (2002). *Multiple criteria decision analysis: an integrated approach*. Springer Science & Business Media.

28. Benini, A. (2012). Composite measures: their use in rapid needs assessments: conceptual background and technical guidance. Version 17. Retrieved on April 10 2015 from http://aldo-benini.org/Level2/HumanitData/ACAPS_CompositeMeasures_Note_120517AB.pdf

29. Berardi, G., Green, R., & Hammond, B. (2011). Stability, sustainability, and catastrophe: Applying resilience thinking to US agriculture. *Human Ecology Review*, *18*(2).

30. Berkes, F., & Folke, C. (1994). Investing in cultural capital for sustainable use of natural capital. *Investing in natural capital: the ecological economics approach to sustainability. Island Press, Washington DC*, 128-149.

31. BFH-HAFL. (2016, February 10). Retrieved on November 20 2015 from https://www.hafl.bfh.ch/en/home.html

32. BGS & DPHE. (2001). Arsenic Contamination of Groundwater in Bangladesh. Kinniburgh, D.G. and Smedley, P. L. (Editors). Volume 2: Final report. British Geological Survey Report *WC/00/19.* British Geological Survey, Keyworth. Retrieved on October 05 2015 from http://www.bgs.ac.uk/arsenic/bangladesh/

33. Binder, C. R., Feola, G., & Steinberger, J. K. (2010). Considering the normative, systemic and procedural dimensions in indicator-based sustainability assessments in agriculture. *Environmental impact assessment review*, *30*(2), 71-81.

34. Binder, C. R., & Feola, G. (2013). Normative, systemic and procedural aspects: a review of indicator-based sustainability assessments in agriculture. In *Methods and Procedures for Building Sustainable Farming Systems*. Springer Netherlands, 33-46.

35. Blanc, I., Friot, D., Margni, M. & Jolliet, O. (2008): Towards a new index for environmental sustainability based on a DALY weighting approach. *Sustainable development*, *16*, 251-260.

36. Blay-Palmer, A. (Ed.). (2010). *Imagining sustainable food systems: theory and practice*. Ashgate Publishing, Ltd.

37. Bockstaller, C., & Girardin, P. (2003). How to validate environmental indicators. *Agricultural systems*, *76*(2), 639-653.

38. Bockstaller, C., Guichard, L., Keichinger, O., Girardin, P., Galan, M. B., & Gaillard, G. (2009). Comparison of methods to assess the sustainability of agricultural systems: a review. In *Sustainable Agriculture*. Springer Netherlands, 769-784.

39. Booysen, F. (2002). An overview and evaluation of composite indices of development. Social indicators research, 59(2), 115-151.

40. Bossel, H. (1999). *Indicators for sustainable development: theory, method, applications*. Winnipeg: International Institute for Sustainable Development.

41. Bossel, H. (2003). Assessing viability and sustainability: a systems-based approach for deriving comprehensive indicator sets. *Integrated Natural Resource Management: Linking Productivity, the Environment and Development*, 247-266.

42. Brans, J.P. (1982). L'ingénierie de la décision. Elaboration d'instruments d'aide à la décision. Méthode PROMETHEE. In: Nadeau, R., Landry, M. (Eds.), L'aide à la Décision: Nature, Instrument set Perspectives D'avenir. Presses de Université Laval, Québec, Canada, 183–214.

43. Brans, J.P. & Mareschal, B. (2005). Promethee Methods, In: Multiple Criteria Decision Analysis. State of the Art Survey, J.R. Figueira, S. Greco and M. Ehrgott (Eds.). Springer, New York, USA, 112-131.

44. Brand, D. A., Saisana, M., Rynn, L. A., Pennoni, F., & Lowenfels, A. B. (2007). Comparative analysis of alcohol control policies in 30 countries. *PLoS Medicine*, 4(4), 752.

45. Brentrup, F., Küsters, J., Kuhlmann, H., & Lammel, J. (2004). Environmental impact assessment of agricultural production systems using the life cycle assessment method: I. Theoretical concept of a LCA method tailored to crop production. *European Journal of Agronomy*, *20*(3), 247-264.

46. Briassoulis, H. (2001). Sustainable development and its indicators: through a (planner's) glass darkly. *Journal of Environmental Planning and Management*, *44*(3), 409-427.

47. Brinkhoff, P. (2011). Multi-Criteria Analysis for Assessing Sustainability of Remedial Actions Applications in Contaminated Land Development. A Literature Review. Department of Civil and Environmental Engineering. Chalmers University of Technology. Göteborg, Sweden. Retrieved August 10 2015 from http://publications.lib.chalmers.se/records/fulltext/150656.pdf

48. Browne, D., O'Regan, B., & Moles, R. (2010). Use of multi-criteria decision analysis to explore alternative domestic energy and electricity policy scenarios in an Irish city-region. *Energy*, *35*(2), 518-528.

49. Burney, J. A., Davis, S. J., & Lobell, D. B. (2010). Greenhouse gas mitigation by agricultural intensification. *Proceedings of the national Academy of Sciences*, *107*(26), 12052-12057.

50. Byerlee, D., De Janvry, A., & Sadoulet, E. (2009). Agriculture for development: Toward a new paradigm. *Annual Review of Resource Economics*, *1*(1), 15-31.

51. Bylin, C., Misra, R., Murch, M., & Rigterink, W. (2004). *Sustainable Agriculture: Development of an On-farm Assessment Tool: a Project Submitted in Partial Fulfillment... for the Degree of Master of Science/Master of Forestry/Master of Landscape Architecture...* University of Michigan. Retrieved on April 14 2015 from http://css.snre.umich.edu/css_doc/CSS04-03.pdf

52. Cabell, J. F., & Oelofse, M. (2012). An Indicator Framework for Assessing Agroecosystem Resilience. *Ecology & Society*, *17*(1).

53. Caporali, F., & Onnis, A. (1992). Validity of rotation as an effective agroecological principle for a sustainable agriculture. *Agriculture, ecosystems & environment*, *41*(2), 101-113.

54. Carpenter, S., Walker, B., Anderies, J. M., & Abel, N. (2001). From metaphor to measurement: resilience of what to what? *Ecosystems*, *4*(8), 765-781.

55. Carson, R. (1962). *Silent Spring*. A Crest Reprint Fawcett Publications, Inc., Greenwich, Conn. Member Of American Book Publishers Council, Inc. Retrieved December 10 2014 from http://library.uniteddiversity.coop/More_Books_and_Reports/Silent_Spring-Rachel_Carson-1962.pdf

56. Cash, D. W., Adger, W. N., Berkes, F., Garden, P., Lebel, L., Olsson, P., ... & Young, O. (2006). Scale and cross-scale dynamics: governance and information in a multilevel world. *Ecology and society*, *11*(2), 8.

57. Castoldi, N., & Bechini, L. (2010). Integrated sustainability assessment of cropping systems with agro-ecological and economic indicators in northern Italy. *European journal of agronomy*, *32*(1), 59-72.

58. Cavallaro, F. (2013). *Assessment and Simulation Tools for Sustainable Energy Systems: Theory and Applications* (Vol. 129). Springer Science & Business Media.

59. CCA (Council of Canadian Academies). (2014). Aboriginal Food Security in Northern Canada: An Assessment of the State of Knowledge, Ottawa, ON. The Expert Panel on the State of Knowledge of Food Security in Northern Canada, Council of Canadian Academies.

60. Ciegis, R., Ramanauskiene, J., & Startiene, G. (2015). Theoretical reasoning of the use of indicators and indices for sustainable development assessment.*Engineering Economics*, *63*(4).

61. Chambers, R. (1992). Sustainable livelihoods: the poor's reconciliation of environment and development. Chapter 7 in Paul Ekins and Manfred Max-Neef eds., Real-Life Economics: Understanding Wealth Creation, New York: Routledge. Retrieved on August 15 2014 from http://opendocs.ids.ac.uk/opendocs/bitstream/handle/123456789/141/rc175.pdf?sequence=2

62. Chapin, F. S., Carpenter, S. R., Kofinas, G. P., Folke, C., Abel, N., Clark, W. C., ... & Berkes, F. (2010). Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends in Ecology & Evolution*, *25*(4), 241-249.

63. Charles, A. T. (2004). Sustainability and resilience in natural resource systems: policy directions and management institutions. *Encyclopaedia of Life Support Systems. Oxford, UK: UNESCO and Eolss Publishers*.

64. Cherchye, L., Moesen, W., Rogge, N., & Van Puyenbroeck, T. (2007). An introduction to 'benefit of the doubt' composite indicators. *Social Indicators Research*, 82(1), 111-145.

65. Christensen, J., & Tull, M. (2014). Introduction: Historical Perspectives of Fisheries Exploitation in the Indo-Pacific. In *Historical Perspectives of Fisheries Exploitation in the* Indo-Pacific (pp. 1-12). Springer Netherlands.

66. Ciegis, R., Ramanauskiene, J., & Martinkus, B. (2009). The concept of sustainable development and its use for sustainability scenarios. *Inzinerine Ekonomika-Engineering Economics*, *2*(62), 28-37.

67. Cinelli, M., Coles, S.R. & Kirwan, K. (2013). *Use of multi criteria decision analysis to support life cycle sustainability assessment: an analysis of the appropriateness of the available methods*. The 6th International Conference on Life Cycle Management in Gothenburg 2013. Retrieved on September 25 2014 from http://conferences.chalmers.se/index.php/LCM/LCM2013/paper/viewFile/665/263

68. Cinelli, M., Coles, S. R., & Kirwan, K. (2014). Analysis of the potentials of multi criteria decision analysis methods to conduct sustainability assessment. *Ecological Indicators*, *46*, 138-148.

69. Ciuffo, B., Miola, A., Punzo, V., & Sala, S. (2012). Dealing with uncertainty in sustainability assessment. Report on the application of different sensitivity analysis techniques to field - specific simulation models. EU. Retrieved on October 10 2015 from http://publications.jrc.ec.europa.eu/repository/bitstream/JRC68035/lbna25166enn.pdf

70. Chen, Y. (2006). *Multiple criteria decision analysis: classification problems and solutions.* Doctoral dissertation, University of Waterloo, Waterloo, Canada.

71. Colantonio, A., & Dixon, T. (2008). Urban social sustainability: North-South perspectives. In *UN-Habitat 4th World Urban Forum,* 3-6.

72. Colantonio, A. (2011). *Social sustainability: exploring the linkages between research, policy and practice* (p: 35-57). Springer Berlin Heidelberg.

73. Convertino, M., Baker, K.M., Vogel, J.T., Lu, C., Suedel, B., Linkov, I. (2013). Multi-criteria decision analysis to select metrics for design and monitoring of sustainable ecosystem restorations. Ecol. Indic. 26, 76–86.

74. Conway, G. R., & Barbier, E. B. (2013). *After the green revolution: sustainable agriculture for development*. Routledge.

75. Conway, G. R., & Pretty, J. N. (2013). *Unwelcome harvest: agriculture and pollution*. Routledge.

76. Costanza, R. (2003). The early history of ecological economics and the international society for ecological economics (ISEE). *ISEE, Internet Encyclopaedia of Ecological Economics*. Retrieved on May 10 2015 from http://isecoeco.org/pdf/costanza.pdf

77. Cribb, J. (2010). *The coming famine: the global food crisis and what we can do to avoid it*. University of California Press.

78. DAE. (2016). Vision & Mission of Department of Agricultural Extension. Department of Agricultural Extension. Ministry of Agriculture, Bangladesh. Retrieved on January 10 2016 from http://www.dae.gov.bd/site/page/f1ba9e63-2535-4704-b458-9506085dee2b/Vision-&-Mission-of-DAE

79. Daly, H.E. (1990). Towards Some Operational Principals of Sustainable Development. *Ecological Economics*, *2*(1), 1-6.

80. Dailey, G. (2000, October-December). Normalizing census data in ArcView. ArcUser Online, 44-45. Retrieved on January 10 2016 from https://www.esri.com/news/arcuser/1000/files/normalize.pdf

81. Dinshaw, A. (2014). What Is the Role for Transformation in Adaptation? World Resource Institute. Retrieved on February 18 2015 from http://www.wri.org/blog/2014/04/what-role-transformation-adaptation

82. Dantsis, T., Douma, C., Giourga, C., Loumou, A., & Polychronaki, E. A. (2010). A methodological approach to assess and compare the sustainability level of agricultural plant production systems. *Ecological Indicators*, *10*(2), 256-263.

83. Darnhofer, I. (2010). Strategies of family farms to strengthen their resilience. *Environmental Policy and Governance*, *20*(4), 212-222.

84. Darnhofer, I., Fairweather, J., & Moller, H. (2010). Assessing a farm's sustainability: insights from resilience thinking. *International journal of agricultural sustainability*, *8*(3), 186-198.

85. Dasgupta, S. & Roy, I. (2011). Good agricultural Governance: *A resource guide focused on smallholder crop production.* FAO, Regional Office For Asia And The Pacific, Bangkok. Retrieved on February 10 2014 from http://www.fao.org/docrep/015/ba0113e/ba0113e00.pdf

86. David, G., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M. C., Shyamsundar, P., ... & Noble, I. (2013). Sustainable development goals for people and planet. *Nature: international weekly journal of science*, *495*.

87. Decancq, K., & Lugo, M. A. (2008). Setting weights in multidimensional indices of well-being. Retrieved on June 10 2014 from http://www.ophi.org.uk/wp-content/uploads/ssDecancq-Lugo-2008.pdf

88. De Koeijer, T. J., Wossink, G. A. A., Struik, P. C., & Renkema, J. A. (2002). Measuring agricultural sustainability in terms of efficiency: the case of Dutch sugar beet growers. *Journal of environmental management*, *66*(1), 9-17.

89. de Onis, M. (2006). WHO child growth standards: length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age. WHO. Retrieved on August 06 2014 from file:///C:/Users/Byomkesh/Desktop/New%20folder%20(7)/924154693X_eng.pdf

90. De Mey, K., K. D'Haene, F. Marchand, M. Meul, and L. Lauwers. (2011). Learning through stakeholder involvement in the implementation of MOTIFS: an integrated assessment model for sustainable farming in Flanders. *International Journal of Agricultural Sustainability* 9(2), 350-363.

91. De Montis, A., De Toro, P., Droste-Franke, B., Omann, I., & Stagl, S. (2004). Assessing the quality of different MCDA methods. In: Getzner, M., Spash, C. and S. Stagl (eds.) *Alternatives to environmental valuation*. Routledge, London. 99-133.

92. Delbaere, B., & Serradilla, A. N. (Eds.). (2004). *Environmental risks from agriculture in Europe: Locating environmental risk zones in Europe using agri-environmental indicators*. European Centre for Nature Conservation. Retrieved on May 10 2014 from http://www.ecnc.glemma.nl/file_handler/documents/original/view/41/2004--enriskpdf.pdf

93. Derissen, S., Quaas, M., & Baumgärtner, S. (2009). *The relationship between resilience and sustainable development of ecological-economic systems* (No. 146). University of Lüneburg Working Paper Series in Economics.

94. Devuyst, D. (2001). Introduction to sustainability assessment at the local level. In Devuyst, D., Hens, L., & De Lannoy, W. (Eds.). (2001). *How green is the city?: sustainability assessment and the management of urban environments*. Columbia University Press.

95. DFID, Department for International Development-UK. (2003). *Sustainable agriculture. Key sheet*. Retrieved on March 10 2014 from http://www.odi.org.uk/sites/odi.org.uk/files/odi-assets/publications-opinion-files/3143.pdf

96. DFID (2004). *Agricultural sustainability: Working / Supporting Paper*. England. Retrieved on May 10 2013 from http://dfid-agriculture consultation.nri.org/summaries/wp12.pdf.

97. DFID. (2005). *Growth and poverty reduction: the role of agriculture. A DFID Policy Paper.* London. Retrieved on March 20 2014 from http://dfid-agriculture-consultation.nri.org/launchpapers/roleofagriculture.pdf

98. Diamond, J. (2002). Evolution, consequences and future of plant and animal domestication. *Nature*, *418*(6898), 700-707.

99. Diakoulaki, D. and Koumoutsos, N. (1991). Cardinal ranking of alternative actions: extension of the PROMETHEE method. *European Journal of Operational Research*, 53(3), 337-347.

100. Diakoulaki, D. & Grafakos, S. (2004). *Externe-pol, externalities of energy*: extension of accounting framework and policy applications. National Technical University Athens, Greece. Retrieved on April 15 2014 from http://www.externe.info/externe_2006/expolwp4.pdf

101. Diakoulaki, D., Antunes, C. H., & Martins, A. G. (2005). MCDA and energy planning. In *Multiple criteria decision analysis: state of the art surveys* (p: 859-890). Springer New York.

102. Diaz, R. J., & Rosenberg, R. (2008). Spreading dead zones and consequences for marine ecosystems. *Science*, *321*(5891), 926-929.

103. Dirzo, R., & Raven, P. H. (2003). Global state of biodiversity and loss. *Annual Review of Environment and Resources*, *28*(1), 137-167.

104. Doumpos, M., & Zopounidis, C. (2002). *Multicriteria decision aid classification methods* (Vol. 73). Springer.

105. Downing, T. E., & Patwardhan, A. (2005). Assessing vulnerability for climate adaptation. *Adaptation policy frameworks for climate change: Developing strategies, policies and measures*, 67-90. Retrieved on April 10 2014 from http://www4.unfccc.int/nap/Country%20Documents/General/apf%20technical%20paper03.pdf

106. Drexhage, J., & Murphy, D. (2010). Sustainable development: from Brundtland to Rio 2012. *Background Paper for the High Level Panel on Global Sustainability, United Nations, New York*. Retrieved on April 10 2014 from http://www.un.org/wcm/webdav/site/climatechange/shared/gsp/docs/GSP1-6_Background%20on%20Sustainable%20Devt.pdf

107. Dubey, A., & Lal, R. (2009). Carbon footprint and sustainability of agricultural production systems in Punjab, India, and Ohio, USA. *Journal of crop improvement*, *23*(4), 332-350.

108. Duffy, P. (1998). Environmental impact assessment training for sustainable agriculture and rural development: A case in Kenya. Retrieved on August 12 2014 from *http://www. fao. org/sd/epdirect/epan0012. htm*.

109. Eagles, P. F., McCool, S. F., & Haynes, C. D. (2002). *Sustainable tourism in protected areas: Guidelines for planning and management* (No. 8). IUCN.

110. Ebert, U. & Welsch, H. (2004): Meaningful environmental indices: a social choice approach. *Journal of environmental economics and management*, *47*, 270-283.

111. EC. (2015, October 10). Tool #57: multi-criteria analysis. European Commission. Retrieved on February 07 2014 from http://ec.europa.eu/smart-regulation/guidelines/tool_57_en.htm

112. EESC (European Economic and Social Committee). (2013). *Agricultural resilience in the face of crises and shocks*. Brussels Policy Briefing no. 30. Retrieved on June 10 2015 from http://eudevdays.eu/sites/default/files/cta-reader-30_agricultural-resilience-eng-rev-21.pdf

113. Ekins, P., Simon, S., Deutsch, L., Folke, C., & De Groot, R. (2003). A framework for the practical application of the concepts of critical natural capital and strong sustainability. *Ecological economics*, *44*(2), 165-185.

114. El-Zein, A., & Tonmoy, F. N. (2015). Assessment of vulnerability to climate change using a multi-criteria outranking approach with application to heat stress in Sydney. *Ecological Indicators*, *48*, 207-217.

115. Elbehri, A., Liu, A., Segerstedt, A., Liu, P., Babilonia Estrada, R., Hölldobler, B. W., ... & Benítez, M. L. (2013). *Biofuels and the sustainability challenge: a global assessment of sustainability issues, trends and policies for biofuels and related feedstocks* (No. FAO E37). FAO, Roma (Italia). Retrieved on November 20 2015 from http://www.fao.org/docrep/017/i3126e/i3126e.pdf

116. EU, European Union. (2010). *The economics of ecosystems and biodiversity*. Retrieved on July 15 2014 from http://ec.europa.eu/environment/nature/biodiversity/economics/

117. EU. (2012). *Sustainable agriculture for the future we want*. European Commission. Retrieved on July 08 2014 from http://ec.europa.eu/agriculture/events/2012/rio-side-event/brochure_en.pdf

118. Elkington, J. (2004). Enter the triple bottom line. In A. Henriques & J. Richardson (Eds) *The triple bottom line, does it all add up? Assessing the sustainability of business and CSR,* London: Earthscan Publications Ltd, 1-16.

119. Ercin, A. E., & Hoekstra, A. Y. (2012). Carbon and Water Footprints. Concepts, Methodologies and Policy Responses. United Nations World Water Assessment Programme.

120. Ericksen, P. J. (2008). Conceptualizing food systems for global environmental change research. *Global Environmental Change*, *18*(1), 234-245.

121. Eriksson, I. S., Elmquist, H., & Nybrant, T. (2005). SALSA: A simulation tool to assess ecological sustainability of agricultural production. *AMBIO: A Journal of the Human Environment*, *34*(4), 388-392.

122. ESRI. (2015). ArcGIS Software. ESRI, Canada

123. Esquinas-Alcazar, J. (2005). Protecting crop genetic diversity for food security: political, ethical and technical challenges. *Nature Reviews Genetics*, *6*(12), 946-953.

124. Evenson, R. E., & Gollin, D. (2003). Assessing the impact of the Green Revolution, 1960 to 2000. *Science*, *300*(5620), 758-762.

125. Fan, S., Ringler, C., Nkonya, E., & Stein, A. J. (2012). *Ensuring food and nutrition security in a green economy*. International Food Policy Research Institute. Retrieved on April 02 2014 from http://www.ifpri.org/sites/default/files/publications/bp21.pdf.

126. FAO. (1992). *FAO's definition on sustainable agriculture and rural development in 1992 Earth Summit in Rio de Janeiro*. Retrieved on July 05 2014 from www.fao.org/wssd/Sard/index-en.htm

127. FAO. (1998). *The Right to Food: In theory and in practice. Rome.* Retrieved on August 07 2014 from http://www.fao.org/docrep/016/ah189e/ah189e.pdf

128. FAO. (2007). Stakeholder Analysis. Food Security Information for Action Food Security Information Systems and Networks. Annex to the lesson "Improving Food Security Information Systems". Retrieved on April 15 2015 from http://www.fao.org/elearning/course/F2/en/pdf/trainerresources/annex0206_05.pdf

129. FAO. (2009).*Global agriculture towards 2050*. High Level Expert Forum - How to Feed the World in 2050. Retrieved on April 20 2015 from http://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf

130. FAO. (2010). *Food comes first, FAO and the eight millennium development goals*. FAO, Italy. Retrieved on January 20 2015 from http://www.fao.org/fileadmin/user_upload/mdg/doc/booklet_mdg_en.pdf

131. *FAO. (2011).Global Food Losses and Food Waste. Rome, FAO*

132. FAO. (2012). *The state of food insecurity in the world, economic growth in necessary but not sufficient to accelerate reduction of hunger and malnutrition*. Rome, FAO. Retrieved on January 10 2015 from http://www.fao.org/docrep/016/i3027e/i3027e.pdf

133. FAO. (2012a). Sustainable Agricultural Productivity Growth and Bridging the Gap for Small-Family Farms. *Interagency Report to the Mexican G20 Presidency, with contributions by Biodiversity International, CGIAR, FAO, IFAD, IFPRI, IICA, OECD, UNCTAD, UN-HLTF, WFP, the World Bank and WTO*. Retrieved from August 20 2015 from https://library.cgiar.org/bitstream/handle/10947/2702/Sustainable_Agricultural_Productivity_Growth_and_Bridging_the_Gap_for_Small-Family_Farms.pdf?sequence=1

134. FAO. (2012b). *Sustainability assessment of food and agriculture systems (SAFA) guidelines*. Natural Resources Management and Environment Department. FAO, Rome. Retrieved on September 20 2014 from http://www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/Reflections_SAFA_E_Forum_2012_final.pdf

135. FAO. (2013, August 2015). *Sustainability path way*. Retrieved on January 20 2015 from http://www.fao.org/nr/sustainability/en/

136. FAO. (2013a). Healthy people depend on healthy food systems Sustainable Food Systems for Food Security and Nutrition. World Food Day• 16 October 2013. FAO. Retrieved on October 23 2014 from http://www.fao.org/fileadmin/templates/getinvolved/images/WFD_issues_paper_2013_web_EN.pdf

137. FAO, IFAD and WFP. (2015). The State of Food Insecurity in the World 2015. Meeting the 2015 international hunger targets: taking stock of uneven progress. Rome, FAO. Retrieved on October 01 2014 from http://www.fao.org/3/a-i4646e.pdf

138. FAO. (2014).*World Food Situation*. Retrieved on October 25 2015 from http://www.fao.org/worldfoodsituation/csdb/en/

139. FAO. (2015). FAO and the 17 Sustainable Development Goals. Retrieved on February 14 2015 from http://www.fao.org/3/a-i4997e.pdf

140. Fash, W. L. (1994). Changing perspectives on Maya civilization. *Annual review of anthropology*, *23*(1), 181-208.

141. Federico, G. (2005). *Feeding the world: an economic history of agriculture, 1800-2000*. Princeton University Press.

142. Freudenberg, M. (2003): Composite indicators of country performance: a critical assessment. OECD Science, Technology and Industry Working Papers, 2003/16. Paris: OECD Publishing.

143. Fereres, E., & Soriano, M. A. (2007). Deficit irrigation for reducing agricultural water use. *Journal of Experimental Botany*, *58*(2), 147-159.

144. Field observation by Talukder (2011).

145. Figueira, J., Greco, S., & Ehrgott, M. (Eds.). (2005). *Multiple criteria decision analysis: state of the art surveys* (Vol. 78). Springer.

146. Foa, R., & Tanner, J. (2012). Methodology of the indices of social development (No. 2012-04). ISD Working Paper Series. Retrieved on June 10 2014 from http://www.indsocdev.org/resources/ISD%20Working%20Paper%202012-4.pdf

147. Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C. S., & Walker, B. (2002). Resilience and sustainable development: building adaptive capacity in a world of transformations. *AMBIO: A journal of the human environment*, *31*(5), 437-440.

148. Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience thinking: Integrating resilience, adaptability and transformability. *Ecology & society*, *15*(4).

149. Francis, C., Lieblein, G., Gliessman, S., Breland, T. A., Creamer, N., Harwood, R., ... & Poincelot, R. (2003). Agroecology: the ecology of food systems. *Journal of sustainable agriculture*, *22*(3), 99-118.

150. Fraser, E. D., Dougill, A. J., Mabee, W. E., Reed, M., & McAlpine, P. (2006). Bottom up and top down: Analysis of participatory processes for sustainability indicator identification as a pathway to community empowerment and sustainable environmental management. *Journal of environmental management*, *78*(2), 114-127.

151. Gafsi, M., Legagneux, B., Nguyen, G., & Robin, P. (2006). Towards sustainable farming systems: Effectiveness and deficiency of the French procedure of sustainable agriculture. *Agricultural Systems*, *90*(1), 226-242.

152. Gafsi, M. & Favreau, L.J. (2010). Appropriate method to assess the sustainability of organic farming systems. WS2.1 – Methods and procedures for building sustainable farming systems. 9th European IFSA Symposium, 4-7 July 2010, Vienna (Austria). Retrieved on July 01 2015 from http://ifsa.boku.ac.at/cms/fileadmin/Proceeding2010/2010_WS2.1_Gafsi.pdf

153. Galan, M.B., Peschard, D. & Boizard H. (2007). ISO 14 001 at the farm level: Analysis of five methods for evaluating the environmental impact of agricultural practices, J. Environ. Manage. 82, 341–352.

154. Galford, G. L., Soares-Filho, B., & Cerri, C. E. (2013). Prospects for land-use sustainability on the agricultural frontier of the Brazilian Amazon. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *368*(1619), 20120171.

155. Gavade, R. K. (2014). Multi-criteria decision making: An overview of different selection problems and methods. *International Journal of Computer Science and Information Technologies, 5*(4), 5643-5646.

156. Geldermann, J., & Rentz, O. (2001). Integrated technique assessment with imprecise information as a support for the identification of best available techniques (BAT). *OR-Spektrum*, *23*(1), 137-157.

157. Geneletti, D., & van Duren, I. (2008). Protected area zoning for conservation and use: A combination of spatial multicriteria and multiobjective evaluation. *Landscape and Urban Planning*, *85*(2), 97-110.

158. Gibson, R. B. (2006). Beyond the pillars: Sustainability assessment as a framework for effective integration of social, economic and ecological considerations in significant decision-making. *Imperial College Press, 8(3),* 259–280.

159. Gibson R.B. (2012). Why sustainability assessment. In Bond, A. J., Morrison-Saunders, A., & Howitt, R. (Eds.). (2012). *Sustainability assessment: pluralism, practice and progress*. Routledge.

160. Gill, G. J. (1993). *OK, the Data's Lousy, But It's All We've Got (being a critique of conventional methods)*. London: IIED. Retrieved on October 20 2015from http://pubs.iied.org/pdfs/6052IIED.pdf

161. Giovannucci, D., Scherr, S., Nierenberg, D., Hebebrand, C., Shapiro, J., Milder, J., & Wheeler, K. (2012). Food and agriculture: The future of sustainability. *The sustainable development in the 21st century (SD21) Report for Rio*, *20*. Retrieved on October 10 2015 from https://sustainabledevelopment.un.org/content/documents/agriculture_and_food_the_future_of_sustainability_web.pdf

162. GIRA. (2016, February 10). Retrieved on July 01 2014 from http://www.gira.org.mx/

163. GIZ. (2012*). What is sustainable agriculture*. German Federal Ministry for Economic Development and Cooperation (BMZ). Division Rural Development and Global Food Security. Retrieved on May 12 2014 from http://www.giz.de/Themen/en/dokumente/giz2012-en-sustainable-agriculture.pdf

164. Glomsaker, K. (2012).Systems thinking and sustainable urban development - How to improve the planning of sustainable cities. Norwegian University of Life Sciences - UMB, School of Economics and Business, Master Thesis 30 credits 2012. Retrieved on August 27 2014 from http://brage.bibsys.no/umb/retrieve/3682/Glomsaker_Mthesis.pdf

165. Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., ... & Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. *Science*, *327*(5967), 812-818.

166. Goldberger, J. R. (2011). Conventionalization, civic engagement, and the sustainability of organic agriculture. *Journal of Rural Studies*, *27*(3), 288-296.

167. Golafshani, N. (2003). Understanding reliability and validity in qualitative research. *The qualitative report*, *8*(4), 597-607.

168. Gomez-Limon, J. A., & Sanchez-Fernandez, G. (2010). Empirical evaluation of agricultural sustainability using composite indicators. *Ecological Economics*, *69*(5), 1062-1075.

169. Gómez-Limón, J. A., & Riesgo, L. (2009). Alternative approaches to the construction of a composite indicator of agricultural sustainability: An application to irrigated agriculture in the Duero basin in Spain. *Journal of environmental management*, *90*(11), 3345-3362.

170. Gomez-Limon, J. A., & Riesgo, L. (2010). A Composite Indicator to Measure Agricultural Sustainability: Alternative Approaches. *Decision Support Systems in Agriculture, Food and the Environment: Trends, Applications and Advances*, 219.

171. Gonzalez, C. G. (2004). Trade liberalization, food security, and the environment: The neoliberal threat to sustainable rural development. *Transnational Law & Contemporary Problems*, *14*(2), 419-498.

172. Gordon, B. (1993). Aristotelian economic analysis and the medieval schoolmen. *History of Economics Review*, *20*, 1-12.

173. Grenz, J., Thalmann, C., Schoch, M., Stämpfl, A. & Studer, C. (2011). RISE (Response-Inducing Sustainability Evaluation), version 2. 0. Swiss College of Agriculture, Zollikofen, Switzerland.

174. Grober, U. (2007). *Deep roots: A conceptual history of'sustainable development'(Nachhaltigkeit)* (No. P 2007-002). WZB Discussion Paper. Retrieved on April 26 2014 from https://www.econstor.eu/dspace/bitstream/10419/50254/1/535039824.pdf

175. Guijt, I., & Moiseev, A. (2001). Resource kit for sustainability assessment. *IUCN, Gland, Switzerland and Cambridge, UK*.

176. Guitouni, A., & Martel, J. M. (1998). Tentative guidelines to help choosing an appropriate MCDA method. *European Journal of Operational Research*, *109*(2), 501-521.

177. Gupta, A. K. (2004). Origin of agriculture and domestication of plants and animals linked to early Holocene climate amelioration. *Current Science*, *87*(1), 54-59.

178. Gurr, G. M., Wratten, S. D., & Luna, J. M. (2003). Multi-function agricultural biodiversity: pest management and other benefits. *Basic and Applied Ecology*, *4*(2), 107-116.

179. Gustavsson, J., Cederberg, C., Sonesson, U., Van Otterdijk, R., & Meybeck, A. (2011). Global food losses and food waste. *Food and Agriculture Organization of the United Nations, Rome*. Retrieved on May 15 2014 from http://www.fao.org/fileadmin/user_upload/suistainability/pdf/Global_Food_Losses_and_Food_Waste.pdf

180. Haigh, M. (2010). Education for a Sustainable Future: Strategies of the New Hindu Religious Movements. *Sustainability*, *2*(11), 3500-3519.

181. Hajkowicz, S. A., McDonald, G. T., & Smith, P. N. (2000). An evaluation of multiple objective decision support weighting techniques in natural resource management. *Journal of Environmental Planning and Management*, *43*(4), 505-518.

182. Hajkowicz, S., & Collins, K. (2007). A review of multiple criteria analysis for water resource planning and management. *Water resources management*, *21*(9), 1553-1566.

183. Hajkowicz, S., Negra, C., Barnett, P., Clark, M., Harch, B., & Keating, B. (2012). Food price volatility and hunger alleviation–can Cannes work?. *Agriculture & Food Security*, *1*(8), 1-12.

184. Hani, F., Braga, F., Stämpfli, A., Keller, T., Fischer, M., & Porsche, H. (2003). RISE, a tool for holistic sustainability assessment at the farm level. *International Food and Agribusiness Management Review*, *6*(4), 78-90.

185. Hardin, G. (1968). The tragedy of the commons. *Science*, *162*(3859), 1243-1248.

186. Hayashi, K. (2000). Multicriteria analysis for agricultural resource management: a critical survey and future perspectives. *European Journal of Operational Research*, *122*(2), 486-500.

187. Hayati, D., Ranjbar, Z., & Karami, E. (2010). Measuring agricultural sustainability. In *biodiversity, biofuels, agroforestry and conservation agriculture* (pp. 73-100). Springer Netherlands.

188. Heller, C.M., & Keoleian, A.G. (2006).*life cycle-based sustainability indicators for assessment of the U.S. Food system*. Report of the Center for Sustainable Systems. Report No. CSS00-04.University of Michigan. Retrieved on May 15 2015 from http://css.snre.umich.edu/css_doc/CSS00-04.pdf

189. Herath, G. (2004). Incorporating community objectives in improved wetland management: the use of the analytic hierarchy process. *Journal of environmental management*, *70*(3), 263-273.

190. Herath, G., & Prato, T. (Eds.). (2006). *Using multi-criteria decision analysis in natural resource management*. Ashgate Publishing, Ltd.

191. Herbert, L. (2009). *Centenary history of waste and waste managers in London and south east England*. The Chartered Institute of Waste Management. Retrieved on May 12 2014 from http://www.ciwm.co.uk/web/FILES/About_CIWM/100_yrs_London_and_SE_centre.pdf

192. Herzog, F., & Gotsch, N. (1998). Assessing the sustainability of smallholder tree crop production in the tropics: a methodological outline. *Journal of sustainable agriculture*, *11*(4), 13-37.

193. Hipel, K. W., Fang, L., & Heng, M. (2010). System of systems approach to policy development for global food security. *Journal of Systems Science and Systems Engineering*, *19*(1), 1-21.

194. Hipel, K. H. (2013). *Multiple participant multiple criteria decision making*. SYDE 433. Fall 2013. Courseware. Waterloo University, Canada.

195. Hobbs, B. F., & Horn, G. T. (1997). Building public confidence in energy planning: a multimethod MCDM approach to demand-side planning at BC gas. *Energy policy*, *25*(3), 357-375.

196. Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual review of ecology and systematics*, 1-23.

197. Holling, C. S. (2001). Understanding the complexity of economic, ecological, and social systems. *Ecosystems*, *4*(5), 390-405.

198. Holling, C. S., & Walker, B. (2003). Resilience defined. Entry prepared for the Internet encyclopedia of ecological economics. Retrieved on May 10 2014 from http://isecoeco.org/pdf/resilience.pdf

199. Horlings, L. G., & Marsden, T. K. (2011). Towards the real green revolution? Exploring the conceptual dimensions of a new ecological modernisation of agriculture that could 'feed the world'. *Global Environmental Change*, *21*(2), 441-452.

200. Horrigan, L., Lawrence, R. S., & Walker, P. (2002). How sustainable agriculture can address the environmental and human health harms of industrial agriculture. *Environmental health perspectives*, *110*(5), 445.

201. Hossain, M. S., Uddin, M. J., & Fakhruddin, A. N. M. (2013). Impacts of shrimp farming on the coastal environment of Bangladesh and approach for management. *Reviews in Environmental Science and Bio/Technology*, *12*(3), 313-332.

202. Hrebicek, J., Valtinyová, S., Křen, J., Hodinka, M., Trenz, O., & Marada, P. (2013). Sustainability indicators: development and application for the agriculture sector. In *Sustainability Appraisal: Quantitative Methods and Mathematical Techniques for Environmental Performance Evaluation* (pp. 63-102). Springer Berlin Heidelberg.

203. Hu, H., & Xiong, L. (2014). Genetic engineering and breeding of drought-resistant crops. *Annual Review of Plant Biology*, *65*, 715-741.

204. Huang, J., Pray, C., & Rozelle, S. (2002). Enhancing the crops to feed the poor. *Nature*, *418*(6898), 678-684.

205. Huang, I. B., Keisler, J., & Linkov, I. (2011). Multi-criteria decision analysis in environmental sciences: ten years of applications and trends. *Science of the total environment*, *409*(19), 3578-3594.

206. Hudrlikova, L., & Kramulova, J. (2013). Do transformation methods matter? The case of sustainability indicators in Czech regions. *Advances in Methodology & Statistics/Metodoloski zvezki,* 10(1), 31-48.

207. Hudrlikova, L. (2013). Composite indicators as a useful tool for international comparison: the Europe 2020 example. Prague Econ Pap, 4, 459-473.

208. HUNT. (2006). Best practice recommendation: Participatory multi-criteria decision analysis. HUNT is an interdisciplinary international research project, financed by the EU's 7th Framework program, looking into the wider meaning of hunting in the 21st century. Retrieved from http://fp7hunt.net/Portals/HUNT/Reports/hunt%20best%20practice-4.pdf

209. Hyde, K., Maier, H. R., & Colby, C. (2003). Incorporating uncertainty in the PROMETHEE MCDA method. Journal of Multi-Criteria Decision Analysis, 12(4-5), 245-259.

210. IAASTD, International Assessment of Agricultural Knowledge, Science and Technology for Development (2009). *Global report*. Island Press, Washington, US. Retrieved on June 10 2013 from http://www.une:org/dewa/agassessment/reports/IAASTD/EN/Agriculture%20at%20a%20Crossroads_Global%20Report%20(English).pdf

211. IAIA. (1999). Principles of Environmental Impact Assessment Best Practice. Institute of Environmental Assessment, Uk. Retrieved on December 10 2014 from https://www.eianz.org/document/item/2744

212. ILEIA .(2015). Monocultures towards sustainability – Editorial. LEISA Magazine, 16(4), 1-2. Retrieved on December 20 2015 from http://www.agriculturesnetwork.org/magazines/global/monocultures-towards-sustainability/monocultures-towards-sustainability-editorial

213. Information Resources Management Association. (2014). Sustainable Practices: Concepts, Methods, Tools and Applications. E-book, Hershey, Pennsylvania.

214. IPCC. (2007). Agriculture, in Climate Change 2007: Mitigation. Working Group III Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

215. IUCN (International Union for Conservation of Nature). (1980). *World Conservation Strategy: Living resources for Sustainable Development*. Gland, Switzerland. Retrieved on June 17 2014 from http://data.iucn.org/dbtw-wpd/edocs/WCS-004.pdf

216. Jackson-Smith, D. (2010). Toward Sustainable Agricultural Systems in the 21st Century. National Academies Press.

217. Jackson, T. (2011). Prosperity without growth: Economics for a finite planet. Routledge. Earthscan, UK. Retrieved on June 18 2014 from http://www.ipu.org/splz-e/unga13/prosperity.pdf

218. Jacobs, R., Smith, P. & Goddard, M.K. (2004): Measuring performance: an examination of composite performance indicators: a report for the Department of Health. York: Centre of Health Economics, University of York. Retrieved on July 17 2014 from http://www.york.ac.uk/che/pdf/tp29.pdf

219. Jencks, S.F., Huff, E.D., & Cuerdon, T. (2003): Change in the quality of care delivered to Medicare beneficiaries, 1998-1999 to 2000-2001. *The journal of the American Medical Association*, 289, 305-312.

220. Jeon, C. M., Amekudzi, A. A., & Guensler, R. L. (2010). Evaluating plan alternatives for transportation system sustainability: Atlanta metropolitan region. *International Journal of Sustainable Transportation*, *4*(4), 227-247.

221. Kahraman, C. (Ed.). (2008). *Fuzzy multi-criteria decision making: theory and applications with recent developments* (Vol. 16). Springer Science & Business Media.

222. Kasemir, B. (Ed.). (2003). *Public participation in sustainability science: a handbook*. Cambridge University Press.

223. Kassab, M. (2006). *Integrated decision support system for infrastructure privatization under uncertainty using conflict resolution*. Doctoral dissertation, University of Waterloo, Waterloo, Canada.

224. Kates, R. W., Parris, T. M., & Leiserowitz, A. A. (2005). What is sustainable development? Goals, indicators, values, and practice. *Environment (Washington DC)*, *47*(3), 8-21.

225. Keeney, R. L., & Raiffa, H. (1993). *Decisions with multiple objectives: Preferences and value trade-offs*. England: Cambridge University Press.

226. Khalili, N. R., & Duecker, S. (2013). Application of multi-criteria decision analysis in design of sustainable environmental management system framework. *Journal of Cleaner Production*, *47*, 188-198.

227. Khush, G. S. (2001). Green revolution: the way forward. *Nature Reviews Genetics*, *2*(10), 815-822.

228. Koksalan, M. M., Wallenius, J., & Zionts, S. (2011). *Multiple criteria decision making: from early history to the 21st century*. World Scientific.

229. Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World map of the Koppen-Geiger climate classification updated. Meteorologische Zeitschrift, 15(3), 259-263.

230. Lairez, J., Feschet, P., Aubin, J., Bockstaller, C., & Bouvarel, I. (2015).*Agriculture et développement durable: Guide pour l'évaluation multicritère*. Quae.

231. Lal, R. (1991). Tillage and agricultural sustainability. *Soil and Tillage Research*, *20*(2), 133-146.

232. Layard, R. (2005). *Happiness: Lessons from a new science*. London: Allen Lane.

233. Layard, R. (2010). Measuring subjective well-being. *Science, 327*, 534-535.

234. Lerch, A., & Nutzinger, H. G. (2002). Sustainability: economic approaches and ethical implications. *Journal of Economic and Social Policy*, *6*(2), 2.

235. Lerche, N., Schmehl, M., & Geldermann, J. (2014). Sustainability Assessment of Concepts for Energetic Use of Biomass: A Multi-Criteria Decision Support Approach. In *Operations Research Proceedings 2012* (77-82). Springer International Publishing.

236. Levy, J. K., Hipel, K. W., & Kilgour, D. M. (1998). Systems for sustainable development: challenges and opportunities. *Systems Engineering*, *1*(1), 31-43.

237. Linkov, I., Satterstrom, F. K., Kiker, G., Batchelor, C., Bridges, T., & Ferguson, E. (2006). From comparative risk assessment to multi-criteria decision analysis and adaptive management: recent developments and applications. *Environment International*, *32*(8), 1072-1093.

238. Linkov, I., Moberg, E. (2011). Multi-Criteria Decision Analysis: Environmental Applications and Case Studies. CRC Press.

239. Loken, E. (2007). Use of multicriteria decision analysis methods for energy planning problems. *Renewable and Sustainable Energy Reviews*, *11*(7), 1584-1595.

240. Lopez-Ridaura, S., Masera, O., & Astier, M. (2002). Evaluating the sustainability of complex socio-environmental systems. The MESMIS framework. *Ecological indicators*, *2*(1), 135-148.

241. Lopez-Ridaura, S., Van Keulen, H., Van Ittersum, M. K., & Leffelaar, P. A. (2005). Multi-scale sustainability evaluation of natural resource management systems: Quantifying indicators for different scales of analysis and their trade-offs using linear programming. *The International Journal of Sustainable Development & World Ecology*, *12*(2), 81-97.

242. Lubin, D. A., & Esty, D. C. (2010). The sustainability imperative. *Harvard Business Review*, *88*(5), 42-50.

243. Lutteken, A., & Hagedorn, K. (1999). Concepts and Issues of Sustainability in Countries in Transition-an Institutional Concept of Sustainability as a Basis for the Network. In *Central and Eastern European Sustainable Agriculture Network First Workshop Proceedings. Rome: REU Technical Series,* 61, 26-36.

244. Ma, J., Hipel, K. W., De, M., & Cai, J. (2008). Transboundary water policies: assessment, comparison and enhancement. *Water Resources Management*, *22*(8), 1069-1087.

245. MacCrimmon, K. R. (1973). An overview of multiple-objective decision-making. In J. L.Cochrance & M. Zeleny (Eds.), *Multiple-criteria decision-making* (pp. 18-44). Columbia: University of South Carolina Press.

246. Macharis, C., Springael J., De Brucker, K., Verbeke, A. (2004). PROMETHEE and AHP: The design of operational synergies in multicriteria analysis. Strengthening PROMETHEE with ideas of AHP. European Journal of Operational Research 153: 307−317.

247. Muthu, S. S. (2014). Assessing the environmental impact of textiles and the clothing supply chain. Elsevier.

248. Malthus, T. (1789). *An essay on the principle of population: An essay on the principle of population, as it affects the future improvement of society* with remarks on the speculations of Mr. Godwin, M. Condorcet, and Other Writers. Printed for J. Johnson, in St. Paul's Church-Yard. Retrieved on December 10 2015 from http://www.es:org/books/malthus/population/malthus.pdf

249. Maletta, H. E. (2014). Land and farm production: Availability, use, and productivity of agricultural land in the world. *Use, and Productivity of Agricultural Land in the World.* Retrieved on May 19 2014 from http://ssrn.com/abstract=2484248 orhttp://dx.doi.org/10.2139/ssrn.2484248

250. Mann, W., Lipper, L., Tennigkeit, T., McCarthy, N., Branca, G., & Paustian, K. (2009). Food Security and Agricultural Mitigation in Developing Countries: Options for Capturing Synergies. *Rome: FAO*.

251. Marchand, F., L. Debruyne, L. Triste, C. Gerrard, S. Padel, and L. Lauwers. (2014). Key characteristics for tool choice in indicator based sustainability assessment at farm level. *Ecology and Society*, *19*(3), 46.

252. Marie, M., Srour, G., Ziki, B., Abi Saab, S., Yakhlef, H., & Ghozlane, F. (2009). Multi-criteria evaluation of small ruminant farming systems sustainability in Lebanon and Algeria. In *Options Méditerranéennes. Séries A. Mediterranean Seminars* (Vol. 91). CIHEAM-IAMZ.

253. Markulev, A. & Long, A. (2013). *On sustainability: an economic approach*. Productivity Commission Staff Research Note. Commonwealth of Australia. Retrieved on January 20 2015 from http://www.pc.gov.au/__data/assets/pdf_file/0018/123372/sustainability.pdf

254. Marta-Costa, A. A., & Silva, E. (2012). *Methods and procedures for building sustainable farming systems: Application in the European context*. Springer Science & Business Media.

255. Marttunen, M., & Hämäläinen, R. P. (2008). The decision analysis interview approach in the collaborative management of a large regulated water course. *Environmental management*, *42*(6), 1026-1042.

256. Mazziotta, M., & Pareto, A. (2015). Comparing two non-compensatory composite indices to measure changes over time: a case study. STATISTIKA, 95 (2), 44-53. Retrieved on May 25 2015 from https://www.czso.cz/documents/10180/20550317/32019715q2044.pdf/693ab726-62b8-4163-8569-f47b4841245d?version=1.0

257. Martin-Breen, P., & Anderies, J. M. (2011). Resilience: A literature review. *Rockefeller Foundation, September*, *18*, 45-46.

258. MEA. (2005). *Ecosystems and human well-being: Synthesis.* Millennium Ecosystem Assessment, Island Press, Washington, DC. Retrieved on May 10 2015 from http://www.millenniumassessment.org/documents/document.356.aspx.pdf

259. Meadows, D. H., Meadows, D., Randers, J., & Behrens III, W. W. (1972). The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind (New York: Universe).

260. Mei, Z., & Grummer-Strawn, L. M. (2007). Standard deviation of anthropometric Z-scores as a data quality assessment tool using the 2006 WHO growth standards: a cross country analysis. *Bulletin of the World Health Organization*, 85(6), 441-448.

261. Mekonnen, M. M., & Hoekstra, A. Y. (2012). A global assessment of the water footprint of farm animal products. *Ecosystems*, *15*(3), 401-415.

262. Mendoza, G. A., & Martins, H. (2006). Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. *Forest ecology and management*, *230*(1), 1-22.

263. Meul, M., Van Passel, S., Nevens, F., Dessein, J., Rogge, E., Mulier, A., & Van Hauwermeiren, A. (2008). MOTIFS: a monitoring tool for integrated farm sustainability. *Agronomy for sustainable development*, *28*(2), 321-332.

264. Mirza, M.M.Q. (1997). Hydrological changes in the Ganges system in Bangladesh in the post-Farakka period. *Hydrological Sciences Journal,* 42(5), 613–631.

265. Mitchell, H. B. (2012). Data fusion: concepts and ideas. Springer Science & Business Media.

266. Moffett, A., & Sarkar, S. (2006). Incorporating multiple criteria into the design of conservation area networks: a minireview with recommendations. *Diversity and Distributions*, *12*(2), 125-137.

267. Morais, D. C., de Almeida, A. T., Alencar, L. H., Clemente, T. R. N., & Cavalcanti, C. Z. B. (2015). PROMETHEE-ROC Model for assessing the readiness of technology for generating energy. *Mathematical Problems in Engineering*. Hindawi, *2015,* 1-11.

268. Morawiecki, T. (2011). *A Consultancy Approach to Sustainable Agriculture: Creating Meaning through Engagement, Communities of Practice, and Holistic Systems Thinking* (Doctoral dissertation, University of Minnesota).

269. Munda, G., & Nardo, M. (2005). Constructing consistent composite indicators: the issue of weights. EUR 21834 EN.

270. Nardo, M., Saisana, M., Saltelli, A., & Tarantola, S. (2005). Tools for composite indicators building. European Commission, Ispra.

271. Munda, G., & Saisana, M. (2011). Methodological considerations on regional sustainability assessment based on multicriteria and sensitivity analysis. Regional studies, 45(2), 261-276.

272. Munda, G. (2008). The issue of consistency: basic discrete multi-criteria "Methods". Social Multi-Criteria Evaluation for a Sustainable Economy. Springer, Heidel-berg, Berlin. 85–109.

273. Mustajoki, J., & Hamalainen, R. P. (2000). Web-HIPRE: Global decision support by value tree and AHP analysis. Infor Information Systems and Operational Research, *38*(3), 208-220.

274. Mustajoki, J., Hämäläinen, R. P., & Marttunen, M. (2004). Participatory multicriteria decision analysis with Web-HIPRE: a case of lake regulation policy. *Environmental Modelling & Software*, *19*(6), 537-547.

275. Nambiar, K. K. M., Gupta, A. P., Fu, Q., & Li, S. (2001). Biophysical, chemical and socio-economic indicators for assessing agricultural sustainability in the Chinese coastal zone. *Agriculture, ecosystems & environment*, *87*(2), 209-214.

276. Nardo, M., Saisana, M., Saltelli, A., Tarantola, S., Hoffman, A., & Giovannini, E. (2005). *Handbook on constructing composite indicators: method and user guide* (No. 2005/3). OECD publishing. Retrieved on May 29 2015 from http://www.oecd-ilibrary.org/docserver/download/5lgmz9dkcdg4.pdf?expires=1457237251&id=id&accname=guest&checksum=59A7F51D1E1E25A5EE1595B8020194A8

277. Nardo, M., Saisana, M., Saltelli, A., Tarantola, S., Hoffman, H. & Giovannini, E. (2009): Handbook on constructing composite indicators: methodology and user guide. Paris: Organisation for Economic Co-operation and Development.

278. Nasiri, H., Alavipanah, S.K., Matinfar, H.R., Azizi, A., Hamzeh, M. (2012). Implementation of Agricultural Ecological Capability Model Using Integrated Approach of PROMETHEE II and Fuzzy-AHP in GIS Environment (Case Study: Marvdasht county). *Journal of Environmental Studies*, 38(3), 28-30.

279. Nedea, P. S. (2012). The Evolving Concept of Sustainable Agriculture. *Anale. Seria Stiinte Economice. Timisoara*, *18*, 64-69.

280. Neef, A., & Neubert, D. (2011). Stakeholder participation in agricultural research projects: a conceptual framework for reflection and decision-making. *Agriculture and Human Values*, *28*(2), 179-194.

281. Ness, B., Urbel-Piirsalu, E., Anderberg, S., & Olsson, L. (2007). Categorising tools for sustainability assessment. *Ecological economics*, *60*(3), 498-508.

282. Niemeijer, D., & de Groot, R. S. (2008). A conceptual framework for selecting environmental indicator sets. *Ecological indicators*, *8*(1), 14-25.

283. Nijkamp, P., & Vreeker, R. (2000). Sustainability assessment of development scenarios: methodology and application to Thailand. *Ecological Economics*, *33*(1), 7-27.

284. North, D. W. (1968). A tutorial introduction to decision theory. *Systems Science and Cybernetics, IEEE Transactions on*, *4*(3), 200-210.

285. OECD. (1999). Environmental Indicators for Agriculture. Volume 1: Concepts and Framework. Paris, France. Retrieved on July 20 2015 from http://www.oecd.org/greengrowth/sustainable-agriculture/40680795.pdf

286. OECD. (2006). DAC Guidelines and Reference Series Applying Strategic Environmental Assessment Good Practice Guidance for Development Co-operation: Good Practice Guidance for Development Co-operation. OECD.

287. OECD. (2008). Handbook on constructing composite indicators. methodology and user guide. Joint Research Centre-European Commission. Paris: Author.

288. Ogola A.F.P. (2007). *Environmental Impact Assessment General Procedures*. Presented at Short Course II on Surface Exploration for Geothermal Resources, organized by UNU-GTP and KenGen, at Lake Naivasha, Kenya, 2-17 November, 2007. GEOTHERMAL TRAINING PROGRAMME . United Nations University. Retrieved on May 29 2014 from http://www.os.is/gogn/unu-gtp-sc/UNU-GTP-SC-05-28.pdf

289. Omann, I. (2000). How can Multi-criteria Decision Analysis contribute to environmental policy making? A case study on macro-sustainability in Germany. paper for the *Third International Conference of the European Society for Ecological Economics,* Vienna. Retrieved on May 10 2014 from http://seri.at/wp-content/uploads/2010/05/Multi_criteria_Decision_Analysis_contribute_to_environmental_policy_making.pdf

290. Palme, U. (2011). History and Definitions of Sustainable Development. TOSCA sustainability framework. Retrieved on July 20 2015 from http://lee.schoolwires.net/cms/lib03/NC01001912/Centricity/Domain/701/History%20and%20Definitions%20of%20Sustainable%20Development.pdf

291. Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *365*(1554), 3065-3081.

292. Pattberg, P. (2007). Conquest, domination and control: Europe’s mastery of nature in historic perspective. *Journal of Political Ecology*, *14*(1), 9.

293. Paustian, K., Antle, J. M., Sheehan, J., & Paul, E. A. (2006). Agriculture's role in greenhouse gas mitigation.

294. Payraudeau, S., & van der Werf, H. M. (2005). Environmental impact assessment for a farming region: a review of methods. *Agriculture, Ecosystems & Environment*, *107*(1), 1-19.

295. Pannell, D. J., & Glenn, N. A. (2000). A framework for the economic evaluation and selection of sustainability indicators in agriculture. *Ecological economics*, *33*(1), 135-149.

296. Perrings, C. (2006). Resilience and sustainable development. *Environment and Development Economics*, *11*(4), 417-427.

297. Perry, L. W. (2012). *Thank Evolution for God*. Xlibris Corporation.

298. Pezzey, J., & Toman, M. A. (2002). *The economics of sustainability: a review of journal articles*. Washington, DC: Resources for the Future.

299. Pinter, L., Hardi, P., Martinuzzi, A., & Hall, J. (2012). Bellagio STAMP: Principles for sustainability assessment and measurement. *Ecological Indicators*, *17*, 20-28.

300. Pisano, U. (2012). Resilience and Sustainable Development: Theory of resilience, systems thinking. Retrieved on August 28 2014 from http://www.sd-network.eu/quarterly%20reports/report%20files/pdf/2012-September-Resilience_and_Sustainable_Development.pdf

301. Polatidis, H., Haralambopoulos, D. A., Munda, G., & Vreeker, R. (2006). Selecting an appropriate multi-criteria decision analysis technique for renewable energy planning. *Energy Sources, Part B*, *1*(2), 181-193.

302. Pomerol, J. C., & Barba-Romero, S. (2012). Multicriterion decision in management: principles and practice (Vol. 25). Springer Science & Business Media.

303. Pomerol, J. C., & Barba-Romero, S. (2012). Multicriterion decision in management: principles and practice (Vol. 25). Springer Science & Business Media.

304. Pope, J., Annandale, D., & Morrison-Saunders, A. (2004). Conceptualising sustainability assessment. *Environmental impact assessment review*, *24*(6), 595-616.

305. Pope, J. (2006). Editorial: What's so special about sustainability assessment?. *Journal of Environmental Assessment Policy and Management*, *8*(03), v-x.

306. Poppe, K. J., Termeer, C. J. A. M., & Slingerland, M. (Eds.). (2009). *Transitions towards sustainable agriculture and food chains in peri-urban areas*. Wageningen Academic Pub.

307. Porsche, H., Fischer, M., Braga, F., & Häni, F. (2004). Introduction of the sustainability assessment tool RISE into Canadian agriculture. *J. Univ. Guelph*, *11*(1), 11-19.

308. Power, A. G. (2010). Ecosystem services and agriculture: tradeoffs and synergies. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *365*(1554), 2959-2971.

309. Prato, T., & Herath, G. (2007). Multiple-criteria decision analysis for integrated catchment management. *Ecological Economics*, *63*(2), 627-632.

310. Pretty, J. (1999). Can sustainable agriculture feed Africa? New evidence on progress, processes and impacts. *Environment, Development and Sustainability*, *1*(3-4), 253-274.

311. Pretty, J. N., & Hine, R. (2001). *Reducing food poverty with sustainable agriculture: A summary of new evidence*. Colchester: University of Essex.

312. Pretty, J. N., Morison, J. I., & Hine, R. E. (2003). Reducing food poverty by increasing agricultural sustainability in developing countries. *Agriculture, ecosystems & environment*, *95*(1), 217-234.

313. Pretty, J. (2003a). Social capital and the collective management of resources. *Science*, *302*(5652), 1912-1914.

314. Pretty, J. (2008). Agricultural sustainability: concepts, principles and evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), 447-465.

315. Pretty, J. N., Noble, A. D., Bossio, D., Dixon, J., Hine, R. E., Penning de Vries, F. W. T., & Morison, J. I. L. (2006). Resource-conserving agriculture increases yields in developing countries. *Environmental science & technology*, *40*(4), 1114-1119.

316. PROMETHEE 1.4 Manual. (2013). Retrieved on August 20 2014 from http://www.promethee-gaia.net/visual-promethee.html

317. Radford, K. J. (1989). *Individual and small group decisions*. New York, NY: Springer-Verlag.

318. Rahman, M. & Roy, I. B. (2006). *Effect of system of rice intensification (SRI) on rice yield in Bangladesh, Boro season, 2005-2006*. Action Aid Bangladesh. Retrieved on May 20 2013 from http://sri.ciifad.cornell.edu/countries/bangladesh/index.html#reports

319. Rahman, S., & Barmon, B. K. (2012). Energy productivity and efficiency of the ‘gher’(prawn-fish-rice) farming system in Bangladesh. Energy, 43(1), 293-300.

320. Rashid, H. (1991). *Geography of Bangladesh,* pp. 87-88. Dhaka: University Press.

321. Rasul, G., & Thapa, G. B. (2004). Sustainability of ecological and conventional agricultural systems in Bangladesh: an assessment based on environmental, economic and social perspectives. *Agricultural systems*, *79*(3), 327-351.

322. Rasul, G. (2009). Ecosystem services and agricultural land-use practices: a case study of the Chittagong Hill Tracts of Bangladesh. *Sustainability: Science, Practice and Policy*, *5*(2).

323. Roy, R., & Chan, N. W. (2012). An assessment of agricultural sustainability indicators in Bangladesh: review and synthesis. *The Environmentalist*, *32*(1), 99-110.

324. Ray, D. K., Mueller, N. D., West, P. C., & Foley, J. A. (2013). Yield trends are insufficient to double global crop production by 2050. *PLOS one*, *8*(6), e66428.

325. Redman, C. L. (2014). Should sustainability and resilience be combined or remain distinct pursuits. *Ecology and Society*, *19*(2), 37.

326. Reed, M. S., Fraser, E. D., & Dougill, A. J. (2006). An adaptive learning process for developing and applying sustainability indicators with local communities. *Ecological Economics*, *59*(4), 406-418.

327. Rees, W. E., & Wackernagel, M. (1992). *Ecological footprints and appropriated carrying capacity: measuring the natural capital requirements of the human economy*. University of British Columbia, School of Community and Regional Planning.

328. Rees, W. E. (1996). Revisiting carrying capacity: area-based indicators of sustainability. *Population and environment*, *17*(3), 195-215.

329. Renn, O. (2003). Social assessment of waste energy utilization scenarios. *Energy,* 28, 345-1357.

330. Rennings, K. (2000). Redefining innovation—eco-innovation research and the contribution from ecological economics. *Ecological economics*, *32*(2), 319-332.

331. Richmond, B. (1993). Systems thinking: critical thinking skills for the 1990s and beyond. *System dynamics review*, *9*(2), 113-133.

332. Rigby, D., Woodhouse, P., Young, T., & Burton, M. (2001). Constructing a farm level indicator of sustainable agricultural practice. *Ecological Economics*, *39*(3), 463-478.

333. Rigby, D., & Cáceres, D. (2001). Organic farming and the sustainability of agricultural systems. *Agricultural systems*, *68*(1), 21-40.

334. Robertson, G. P., & Swinton, S. M. (2005). Reconciling agricultural productivity and environmental integrity: a grand challenge for agriculture. *Frontiers in Ecology and the Environment*, *3*(1), 38-46.

335. Rodrigues, G. S., Campanhola, C., & Kitamura, P. C. (2003). An environmental impact assessment system for agricultural R&D. *Environmental Impact Assessment Review*, *23*(2), 219-244.

336. Ross, J. (1995). *Dimensions of need: an atlas of food and agriculture*. T. Loftas (Ed.). Food & Agriculture Org.

337. Rosegrant, M. W., Ringler, C., Benson, T., Diao, X., Resnick, D., Thurlow, J., ... & Orden, D. (2006). Agriculture and achieving the millennium development goals. Washington, DC: The World Bank.

338. Rosset, P., Collins, J., & Lappe, F. M. (2000). Lessons from the Green Revolution. *Third World Resurgence*, 11-14. Retrieved on February 25 2014 from http://www.soc.iastate.edu/sapp/greenrevolution.pdf

339. Rotmans, J., Kemp, R., and Van Asselt, M. (2001). More evolution than revolution: Transition management in public policy. *Foresight, 03*(01), 17.

340. Rozman, Č., Potočnik, M., Pažek, K., Borec, A., Majkovič, D., & Bohanec, M. (2009). A multi-criteria assessment of tourist farm service quality. *Tourism Management*, *30*(5), 629-637.

341. Sadok, W., Angevin, F., Bergez, J. É., Bockstaller, C., Colomb, B., Guichard, L., ... & Doré, T. (2009). Ex ante assessment of the sustainability of alternative cropping systems: Implications for using multi-criteria decision-aid methods – A review. In *Sustainable Agriculture* (pp. 753-767). The Netherlands: Springer.

342. Saisana, M., & Tarantola S. (2002): State-of-the-art report on current methodologies and practices for composite indicator development. Ispra: Institute for the Protection and the Security of the Citizen Technological and Economic Risk Management Unit.

343. Saisana, M., Tarantola, S., Schulze, N., Cherchye, L., Moesen, W., & Van Puyenbroeck, T. (2005). State-of-the-art report on composite indicators for the knowledge-based economy. Work-package, 5.

344. Saisana, M. S. A., & Saltelli, A. (2011). Rankings and ratings: instructions for use. Hague journal on the rule of law, 3(2), 247-268.

345. Saltelli, A., Nardo, M., Saisana, M., & Tarantola, S. (2005). Composite indicators: the controversy and the way forward. *Statistics, Knowledge and Policy Key Indicators to Inform Decision Making: Key Indicators to Inform Decision Making*, OECD. 359-372. Retrieved on October 27 2014 from http://www.ingentaconnect.com/content/oecd/16843134/2005/00002005/00000035/3005062e?crawler=true#page=359

346. Saltelli, A. (2007). Composite indicators between analysis and advocacy. Social indicators research, 81, 65-77.

347. Salzman, J. (2003). Methodological choices encountered in the construction of composite indices of economic and social well-being. Center for the Study of Living Standards.

348. Sajeva, M., Gatelli, D., Tarantola, S., & Hollanders, H. (2005). Methodology report on European innovation scoreboard 2005. European Trend Chart on Innovation.

349. Sands, G. R., & Podmore, T. H. (2000). A generalized environmental sustainability index for agricultural systems. *Agriculture, Ecosystems & Environment*, *79*(1), 29-41.

350. Sathaye, J., A. Najam, C. Cocklin, T. Heller, F. Lecocq, J. Llanes-Regueiro, J. Pan, ……….Winkler .(2007). *Sustainable development and mitigation. In climate change 2007: Mitigation. Contribution of working group iii to the fourth assessment report of the intergovernmental panel on climate change* [B. Metz, O.R. Davidson, :R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Retrieved on October 29 2014 from http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter12.pdf

351. Saunders, C., Kaye-Blake, W., & Campbell, R. (2010). Capital based sustainability indicators as a possible way for measuring agricultural sustainability. Retrieved on May 01 2014 from http://www.argos.org.nz/uploads/2/3/7/3/23730248/research_report_10_02_capital_based_sustainability_indicators.pdf

352. Sauvenier, X.; Valckx, J.; Van Cauwenbergh, N.; Wauters, E.; Bachev, H.; Biala, K.; Bielders, C.; Brouckaert, V.; Garcia Cidad, V.; Goyens, S.; Hermy, M.; Mathijs, E.; Muys, B.; Vanclooster, M.; Peeters, A. (2006). *Framework for Assessing Sustainability Levels in Belgian Agricultural Systems—SAFE.* Belgian Science Policy: Brussels, Belgium. Retrieved on May 01 2014 from http://www.belspo.be/belspo/home/publ/pub_ostc/CPagr/rappCP28_en.pdf

353. Schiere, J. B., Groenland, R., Vlug, A., & Van Keulen, H. (2004). System thinking in agriculture: an overview. *Emerging challenges for farming systemslessons from Australian and Dutch agriculture. Kingston Act*, *2604*, 57-86.

354. SAIC (Scientific Applications International Corporation) & Curran, M. A. (2006). *Life-cycle Assessment: Principles and Practice*. National Risk Management Research Laboratory, Office of Research and Development, US Environmental Protection Agency. Retrieved on June 01 2014 from http://nepis.epa.gov/Exe/ZyPDF.cgi/P1000L86.PDF?Dockey=P1000L86.PDF

355. Scoones, I. (1998). Sustainable rural livelihoods: a framework for analysis. IDS Working Paper 72. Retrieved on January 10 2015 from http://www.ids.ac.uk/files/dmfile/Wp72.pdf

356. Sebby, K. (2010). The Green Revolution of the 1960's and Its Impact on Small Farmers in India. Environmental Studies Undergraduate Student Theses. Paper 10. Retrieved on January 10 2015 from http://digitalcommons.unl.edu/envstudtheses/10

357. Sen, A. (1985). A sociological approach to the measurement of poverty: a reply to Professor Peter Townsend. *Oxford Economic Papers*, *37*(4), 669-676.

358. Sen, A. K. and Foster, J. (1997). On economic inequality. Oxford: Oxford University Press.

359. Sen, A. (1999). *Development as freedom*. Oxford University Press.

360. Sen, A. (2013). The ends and means of sustainability. *Journal of Human Development and Capabilities*, *14*(1), 6-20.

361. Senge, P. M. (1990). The *fifth discipline: The art & practice of the learning organization*. New York: Currency Doubleday.

362. Shapouri, S., & Rosen, S. L. (1999). Food security assessment: Why countries are at risk. Market and Trade Economics Division. USAID. USA. Retrieved on March 05 2015 from http://pdf.usaid.gov/pdf_docs/Pcaaa880.pdf

363. Shapiro, C., Varian, H. R., Rajgopal, S., Venkatachalam, M., & Kotha, S. (2004). Exploring Network Economics.

364. Sharpe, A. (2004). Literature review of frameworks for macro-indicators (No. 2004-03). Ottawa, Canada: Centre for the Study of Living Standards.

365. Sheu, J. B. (2007). An emergency logistics distribution approach for quick response to urgent relief demand in disasters. *Transportation Research Part E: Logistics and Transportation Review*, *43*(6), 687-709.

366. Shreck, A., Getz, C., & Feenstra, G. (2006). Social sustainability, farm labor, and organic agriculture: Findings from an exploratory analysis. *Agriculture and Human Values*, *23*(4), 439-449

367. Sigrimis, N., Antsaklis, P., & Groumpos, P. P. (2001). Advances in control of agriculture and the environment. *Control Systems, IEEE*, *21*(5), 8-12.

368. Smith, C. S., & McDonald, G. T. (1998). Assessing the sustainability of agriculture at the planning stage. *Journal of Environmental Management*, *52*(1), 15-37.

369. Smith, W. K., Cleveland, C. C., Reed, S. C., & Running, S. W. (2014). Agricultural conversion without external water and nutrient inputs reduces terrestrial vegetation productivity. *Geophysical Research Letters*.

370. Schmidtmann, B., Uskova, G., Uhlemair, H., & Geldermann, J. (2014). A Comparison of Two Visualisation Methods for Decision Support in MCDM Problems. In *Operations Research Proceedings 2012* (83-89). Springer International Publishing.

371. Schoolman, E. D., Guest, J. S., Bush, K. F., & Bell, A. R. (2012). How interdisciplinary is sustainability research? Analyzing the structure of an emerging scientific field. *Sustainability science*, *7*(1), 67-80.

372. Sharpe, A. (2004). *Literature review of frameworks for macro-indicators* (No. 2004-03). Ottawa: Centre for the Study of Living Standards. Retrieved on March 20 2014 from http://www.csls.ca/reports/LitRevMacro-indicators.pdf

373. Singh, R. K., Murty, H. R., Gupta, S. K., & Dikshit, A. K. (2012). An overview of sustainability assessment methodologies. *Ecological Indicators*, *15*(1), 281-299.

374. Spies, A. (2003). The sustainability of the pig and poultry industries in Santa Catarina, Brazil: A framework for change. Retrieved on May 05 2014 from http://espace.library.uq.edu.au/view/UQ:157958

375. SRDI. (2012). Saline Soils of Bangladesh. 2nd ed. Soil Fertility Assessment, Soil Degradation, and its Impacts on Agriculture Program (SFSDP). Soil Resource Development Institute (SRDI), Dhaka, Bangladesh.

376. SRDIa. (2001). Land and Soil Resources Use Guideline. Shyamanagar Upazila, Satkhira District, Government of Bangladesh.

377. SRDIb. (1997). Land and Soil Resources use Guideline. Kaliganj Upazila, Satkhira District, Government of Bangladesh.

378. SRDIc. (1991). Land and Soil Resources Use Guideline. Kalaroa Upazila, Satkhira District, Government of Bangladesh.

379. SRDId. (1993). Land and Soil Resources Use Guideline. Bhola Sadar Upazila, Bhola District, Government of Bangladesh.

380. SRDIe. (2008). Land and Soil Resources Use Guideline. Dumuria Upazila, Khulna District, Government of Bangladesh.

381. Stano, P. (2014). Aggregation rules (I). Compensatory approach. 12th JRC Annual Training on Composite Indicators & Multicriteria Decision Analysis (COIN 2014). European Commission Joint Research Centre Econometrics and Applied Statistics Unit Composite Indicators Research Group (JRC-COIN). Retrieved on May 28 2014 from file:///C:/Users/Byomkesh/Desktop/20140922_JRC_COIN_11_Aggregation(I).pdf

382. Stanujkic, D., Magdalinovic, N., Stojanovic, S., & Jovanovic, R. (2012). Extension of ratio system part of MOORA method for solving decision-making problems with interval data. *Informatica*, *23*(1), 141-154.

383. Steele, K., Carmel, Y., Cross, J., & Wilcox, C. (2009). Uses and misuses of multicriteria decision analysis (MCDA) in environmental decision making. *Risk analysis*, *29*(1), 26-33.

384. Stevens, C. (2005). *Measuring sustainable development. Statistics brief*. OECD. No.10. Retrieved on June 10 2013 from http://www.oecd.org/std/35407580.pdf

385. Studer, C., Haeni, F., Porsche, H., Staempfli, A. & Thalmann, C. (2009). RISE - Response-Inducing Sustainability Evaluation: Model Synopsis. Swiss College of Agriculture, Zollikofen, Switzerland.

386. Su, X. Y., Zhao, Z. H., Zhang, H. J., Li, Z. Q., & Deng, Y. (2011). An integrative assessment of risk in agriculture system. *Journal of Computational Information Systems*, *7*(1), 9-16.

387. Sumner, A., & Tezanos Vázquez, S. (2014). How has the developing world changed since the late 1990s? A dynamic and multidimensional taxonomy of developing countries. Center for Global Development Working Paper, (375). Retrieved on July 10 2013 from file:///C:/Users/Byomkesh/Desktop/New%20folder%20(7)/developing-world-changed-1990s-multidimensional-taxonomy_1.pdf

388. Susarla, A. and Nazareth, K. (2007). *Sustainable development: An introduction*. Internship Series, Volume 1. Centre for Environment Education. Retrieved on May 20 2013 from http://www.sayen.org/Volume-I.pdf

389. Swanson, D.A., J.C. Hiley, H.D. Venema and R. Grosshans (2009). *Indicators of adaptive capacity to climate change for agriculture in the Prairie region of Canada: comparison with field observations*. International Institute for Sustainable Development. Retrieved on May 27 2014 from http://www.iisd.org/pdf/2009/pcr_adaptive_cap_ag.pdf

390. Sydorovych, O., & Wossink, A. (2007). Assessing Sustainability of Agricultural Systems: Evidence from a Conjoint Choice Survey. In *2007 Annual Meeting, February 4-7, 2007, Mobile, Alabama* (No. 34889). Southern Agricultural Economics Association.

391. Sydorovych, O., & Wossink, A. (2008). The meaning of agricultural sustainability: evidence from a conjoint choice survey. *Agricultural Systems*, *98*(1), 10-20.

392. Tainter, J. A. (2006). Social complexity and sustainability. *Ecological Complexity*, *3*(2), 91-103.

393. Tarabusi, E. C., & Guarini, G. (2013). An unbalance adjustment method for development indicators. Social indicators research, 112(1), 19-45.

394. Tate, E. (2012). Social vulnerability indices: a comparative assessment using uncertainty and sensitivity analysis. Natural hazards, 63(2), 325-347.

395. Tester, M., & Langridge, P. (2010). Breeding technologies to increase crop production in a changing world. *Science*, *327*(5967), 818-822.

396. Talukder, B. (2012). Sustainability of Changing Agricultural Systems in the Coastal Zone of Bangladesh. MES thesis. Queen's University, Canada.

397. Talukder, B., & Saifuzzaman, M. (2015). Sustainability of agricultural systems in the coastal zone of Bangladesh. *Renewable Agriculture and Food Systems*, 1-18.

398. Tibor, T., & Feldman, I. (1996). ISO 14000: a guide to the new environmental management standards.

399. Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., ... & Swackhamer, D. (2001). Forecasting agriculturally driven global environmental change. *Science*, *292*(5515), 281-284.

400. Tilman, D., Cassman, K. G., Matson, A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature*, *418*(6898), 671-677.

401. Theodore, R. K., Rajasekar, D. D., Selvaraj, G., & Jawa, D. (2001).*Sustainability of diversified farms in Tambiraparani River command area, Southern India*. Overseas development institute (ODI). Agricultural research & extension network (AgREN). Retrieved on June 30 2014 from http://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/5118.pdf

402. Thrupp, L. A. (2000). Linking agricultural biodiversity and food security: the valuable role of agrobiodiversity for sustainable agriculture. *International affairs*, *76*(2), 283-297.

403. Tofallis, C. (2014). Add or multiply? A tutorial on ranking and choosing with multiple criteria. *INFORMS transactions on education*, *14*(3), 109-119.

404. Tracey, S., & Anne, B. (2008). *OECD Insights Sustainable Development Linking Economy, Society, Environment: Linking Economy, Society, Environment*. OECD Publishing. Retrieved on July 30 2014 from http://www.worldresourcesforum.org/files/file/Full%20book.pdf

405. Triantaphyllou E. 2000. *Multi-Criteria Decision Making Method: A Comparative Study*. Dordrecht, Netherlands: Kluwer Academic Publishers.

406. Tsoutsos, T., Tsouchlaraki, A., Tsiropoulos, M., & Serpetsidakis, M. (2009). Visual impact evaluation of a wind park in a Greek island. *Applied Energy*, *86*(4), 546-553.

407. Turral, H., Burke, J. J., & Faurès, J. M. (2011). *Climate change, water and food security*. Food and Agriculture Organization of the United Nations, Rome.

408. Tsoutsos, T., Drandaki, M., Frantzeskaki, N., Iosifidis, E., & Kiosses, I. (2009). Sustainable energy planning by using multi-criteria analysis application in the island of Crete. *Energy Policy*, 37(5), 1587-1600.

409. Uddin, K.M.A. and Kaudstaa, R. (2003).Delineation of the coastal zone. Working paper (WP005). Program Development Office for Integrated Coastal Zone Management Plan (PDOICZMP). Dhaka, Bangladesh.

410. UN. (1987). Report of the world commission on environment and development: Our common future. Retrieved on January 10 2015 from http://www.un-documents.net/ocf-02.htm.

411. UN. (1992). Agenda 21. *United Nations Conference on Environment & Development*: Rio de Janerio, Brazil, 3 to 14 June 1992. Retrieved on June 30 2013 from http://sustainabledevelopment.un.org/content/documents/Agenda21.pdf

412. UN. (1992b). *Convention on biological diversity*. United Nations. Retrieved on January 15 2015 from http://www.cbd.int/doc/legal/cbd-en.pdf

413. UN. (1995, July 2015). World *summit for social development Copenhagen, 1995*. Retrieved February 10 2015 from http://www.un.org/esa/socdev/wssd/text-version/

414. UN. (2003*). Report on the regional follow-up to the Johannesburg plan of implementation of the world summit on Sustainable development*. United Nations. Retrieved on June 30 2013 from http://www.unesca:org/59/e/E1302e.pdf

415. UN. (2009). United Nations intellectual history project. Briefing note. Number 11. Retrieved on May 20 2014 from http://www.unhistory.org/briefing/11Sustainability.pdf

416. UN. (2012). *Report of the United Nations Conference on Sustainable Development, Rio de Janeiro, Brazil 20–22 June 2012.* United Nations.

417. UN. (2012a). *Building on the MDGs to bring sustainable development to the post-2015 development agenda*. Thematic Think Piece. ECE, ECE, ESCAP, UNDESA, UNEP, UNFCCC. UN system Task Team on the Post-2015 UN Development Agenda. Retrieved on April 05 2014 from http://www.un.org/millenniumgoals/pdf/Think%20Pieces/17_sustainable_development.pdf

418. UN. (2013a).The Millennium Development Goals Report -2013. United Nations. Retrieved on April 25 2014 from http://www.un.org/millenniumgoals/pdf/report-2013/mdg-report-2013-english.pdf

419. UN. (2014). Statistics and indicators for the post-2015 development agenda. Retrieved on April 25 2014 from http://www.un.org/en/development/desa/policy/untaskteam_undf/UNTT_MonitoringReport_WEB.pdf

420. UN. (2016, February). Sustainable Development Goals. Retrieved on April 10 2014 from http://unstats.un.org/sdgs/

421. UNDP. (2011). Human Development Index (HDI) Report, 2011. UNDP.

422. UNDP. (2012). *International guidebook of environmental finance tools: A sectoral Approach, Protected areas, sustainable forest, sustainable agriculture, and pro-poor energy.* Chapter 5: Sustainable Agriculture. UND: Retrieved on May 19 2015 from http://www.und:org/content/dam/undp/library/Environment%20and%20Energy/Environmental%20Finance/Chapter%205.pdf

423. UNDP. (2014). Human Development Index (HDI) Report, 2014. UNDP.

424. UNEP (2002). *Integrating environment and development: 1972–2002*. Global Environment Outlook 3 (GEO-3): Past, Present and Future Perspectives. Retrieved on May 28 2015 from http://www.une:org/geo/geo3/pdfs/Chapter1.pdf

425. UNEP. (2004). Women and desertification: a dynamic relationship-IV. Women and the Environment. UNEP. Nairobi. Retrieved on January 20 2014 from http://www.unep.org/PDF/Women/ChapterFour.pdf

426. UNEP. (2007, July 2015). *The Montreal protocol on substances that deplete the ozone layer*. Retrieved on January 15 2014 from http://ozone.une:org/new_site/en/montreal_protocol.php

427. UNEP. (2011). *GREEN economy: Pathways to sustainable development and poverty eradication*. UNE: Retrieved on February 10 2014 from http://www.une:org/greeneconomy/portals/88/documents/ger/GER_synthesis_en.pdf

428. UNEP. (2012). Early Warning Systems: A State of the Art Analysis and Future Directions. Division of Early Warning and Assessment (DEWA), United Nations Environment Programme (UNEP), Nairobi. Retrieved on June 17 2014 from http://na.unep.net/siouxfalls/publications/early_warning.pdf

429. UNFCC. (2005, November 2015*). Kyoto protocol*. Retrieved on January 04 2014 from http://unfccc.int/kyoto_protocol/items/2830.php

430. UNFCC. (2009, November 2015). *Copenhagen climate change conference – December 2009* . Retrieved on January 04 2014 from https://unfccc.int/meetings/copenhagen_dec_2009/meeting/6295.php

431. UNIFAD. (2010). The Multidimensional Poverty Assessment Tool: Design, development and application of a new framework for measuring rural poverty. International Fund for Agricultural Development: Rome. Retrieved on May 07 2014 from http://www.unep.org/PDF/Women/ChapterFour.pdf

432. UNSCD. (2012, October 2015). *Rio+20 Conferences*. Retrieved on May 09 2014 from http://www.uncsd2012.org/about.html

433. UNCSD. (2011). *Food security and sustainable agriculture*. RIO 2012 Issues Briefs. Retrieved on May 10 2015 from http://www.uncsd2012.org/content/documents/227Issues%20Brief%209%20-%20FS%20and%20Sustainable%20Agriculture%20CLCnew.pdf

434. UN-SDG. (2015, September). Sustainable Development Goal indicators. Retrieved on May 14 2014 from http://unstats.un.org/sdgs/

435. Urbinato, D. (1994). London's historic pea-soupers". *EPA (Environmental Protection Agency) Journal; (United States)*, *20*. Retrieved on January 2015 from http://www2.epa.gov/aboutepa/londons-historic-pea-soupers

436. USAID. (2008). Guide to Focus Group Discussions. Micro REPORT #138. UASID. Retrieved on October 07 2015 from https://www.microlinks.org/sites/default/files/resource/files/ML6294_mr_138_guide_to_focus_group_discussions.pdf

437. USAID. (2012). *Building resilience to recurrent crisis: USAID policy and program guidance*. U.S. Agency for International Development. Retrieved on October 17 2015 from http://www.usaid.gov/sites/default/files/documents/1870/USAIDResiliencePolicyGuidanceDocument.pdf

438. Vaidya, A., & Mayer, A. L. (2013). Use of the participatory approach to develop sustainability assessments for natural resource management. *International Journal of Sustainable Development & World Ecology*, (ahead-of-print), 1-11.

439. Valdez, B., Svolou, A., & Valdez, F. (2008). A Holistic Approach to Process Improvement Using the People CMM and the CMMI-DEV: Technology Process, People, & Culture, The Holistic Quadripartite. *Software Engineering Information Repository. SEI and CMU*.

440. vanLoon, G. W., Patil, S. G., & Hugar, L. B. (2005). Agricultural sustainability: strategies for assessment. *Agricultural sustainability: strategies for assessment*. SAGE Publications. New Delhi.

441. Van Calker, K. J., Berentsen, P. B., Giesen, G. W., & Huirne, R. B. (2005). Identifying and ranking attributes that determine sustainability in Dutch dairy farming. *Agriculture and Human Values*, *22*(1), 53-63.

442. van Calker, K. J., Berentsen, : B., Romero, C., Giesen, G. W. J., & Huirne, R. B. (2006). Development and application of a multi-attribute sustainability function for Dutch dairy farming systems. *Ecological Economics*, *57*(4), 640-658.

443. Van Calker, K. J., Berentsen, : B. M., Giesen, G. W. J., & Huirne, R. B. M. (2008). Maximising sustainability of Dutch dairy farming systems for different stakeholders: A modelling approach. *Ecological Economics*, *65*(2), 407-419.

444. Van Cauwenbergh, N., Biala, K., Bielders, C., Brouckaert, V., Franchois, L., Garcia Cidad, V., ... & Peeters, A. (2007). SAFE—A hierarchical framework for assessing the sustainability of agricultural systems. *Agriculture, ecosystems & environment*, *120*(2), 229-242.

445. Van de Fliert, E. and A. R. Braun. (2002). Conceptualizing integrative, farmer participatory research for sustainable agriculture: from opportunities to impact. *Agriculture and Human Values*, *19*(1), 25-38.

446. Van der Werf, H. M., & Petit, J. (2002). Evaluation of the environmental impact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods. *Agriculture, Ecosystems & Environment*, *93*(1), 131-145.

447. Van Ittersum, M. K., Ewert, F., Heckelei, T., Wery, J., Alkan Olsson, J., Andersen, E., ... & Wolf, J. (2008). Integrated assessment of agricultural systems–A component-based framework for the European Union (SEAMLESS). *Agricultural systems*, *96*(1), 150-165.

448. van Ittersum, M. & Brouwer, F. M. (2010). In F. M. Brouwer & M. van Ittersum (eds). Environmental and Agricultural Modelling. *Integrated Approaches for Policy Impact Assessment.* Springer.

449. Van Passel, S., Nevens, F., Mathijs, E., & Van Huylenbroeck, G. (2007). Measuring farm sustainability and explaining differences in sustainable efficiency. *Ecological economics*, *62*(1), 149-161.

450. Van Passel, S., & Meul, M. (2010). Multilevel sustainability assessment of farming systems: a practical approach. In *Proceedings of the 9th European IFSA Symposium,* 791-800. Retrieved October 19 2015 from http://ifsa.boku.ac.at/cms/fileadmin/Proceeding2010/2010_WS2.1_VanPassel.pdf

451. Van Passel, S., & Meul, M. (2012). Multilevel and multi-user sustainability assessment of farming systems. In: Marta-Costa, A.A., Silva, E. (Eds.), Methods and Procedures for Building Sustainable Farming Systems: Applications in the European Context. Springer, New York, 63-88.

452. Van Pham, L., & Smith, C. (2014). Drivers of agricultural sustainability in developing countries: a review. *Environment Systems and Decisions*, *34*(2), 326-341.

453. van Zeijl-Rozema, A. (2011). *Regional sustainable development: Barriers in practice*. Retrieved on April 23 2014 from http://www.icis.unimaas.info/wp-content/uploads/2011/02/Thesis-Van-Zeijl.pdf

454. Vasey, D. E. (2002). *An Ecological History of Agriculture 10,000 BD to AD 10,000*. Purdue University Press.

455. Vecchione, G. (2010). EU rural policy: proposal and application of an agricultural sustainability index. Retrieved on April 10 2015 from https://core.ac.uk/download/files/153/6837183.pdf

456. Vitousek, P. M., Aber, J. D., Howarth, R. W., Likens, G. E., Matson, : A., Schindler, D. W., ... & Tilman, D. G. (1997). Human alteration of the global nitrogen cycle: sources and consequences. *Ecological applications*, *7*(3), 737-750.

457. Von Braun, J., Ahmed, A., Asenso-Okyere, K., Fan, S., Gulati, A., Hoddinott, J., ... & Von Grebmer, K. (2008). *High food prices: The what, who, and how of proposed policy actions*. Washington, DC: International Food Policy Research Institute.

458. Von Braun, J., & Diaz-Bonilla, E. (2008). *Globalization of food and agriculture and the poor* (No. 52). International Food Policy Research Institute (IFPRI).

459. Vorosmarty, C. J., Green, P., Salisbury, J., & Lammers, R. B. (2000). Global water resources: vulnerability from climate change and population growth.*science*, *289*(5477), 284-288.

460. Von Wiren-Lehr, S. (2001). Sustainability in agriculture—an evaluation of principal goal-oriented concepts to close the gap between theory and practice. *Agriculture, Ecosystems & Environment*, *84*(2), 115-129.

461. Wang, J. J., Jing, Y. Y., Zhang, C. F., & Zhao, J. H. (2009). Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and Sustainable Energy Reviews*, *13*(9), 2263-2278.

462. WARPO. 2006. Coastal Development Strategy. Water Resources Planning Organization, Ministry of Water Resources. Government of the People's Republic of Bangladesh.

463. WB (World Bank). (2009). KEI and KI Indexes (KAM 2009). Retrieved on June 20 2015 from http://info.worldbank.org/etools/kam2/kam_page5.asp

464. WCED. (1987).Our Common Future. World Commission on Environment and Development. Oxford University Press, Oxford.

465. WDR. (2008). *Agriculture for Development*. World Development Report .The World Bank. Washington, DC. Retrieved on July 19 2015 from http://siteresources.worldbank.org/INTWDR2008/Resources/WDR_00_book.pdf

466. Weaver, P. M., & Rotmans, J. (2006). *Integrated sustainability assessment: What? Why? How?* MATISSE working paper. MATISSE (Methods and Tools for Integrated Sustainability Assessment). MATISSE is supported by the 6th Framework Programme of the European Union. Retrieved on March 23 2015 from http://www.matisse-project.net/projectcomm/uploads/tx_article/Working_Paper_1_03.pdf

467. WEF (World Economic Forum). (2013). *Special report: Building national resilience to global risks*. Retrieved on March 24 204 from http://reports.weforum.org/global-risks-2013/view/section-three/special-report-building-national-resilience-to-global-risks/

468. Welch, R. M., & Graham, R. D. (2000). A new paradigm for world agriculture: productive, sustainable, nutritious, healthful food systems. *Food & Nutrition Bulletin*, *21*(4), 361-366.

469. WHO. (1996). The WHO recommended classification of pesticides by hazard and guidelines to classification (Eds.), WHO/PCS/96.3, World Health Organization, International Programme on Chemical Safety (IPCS), Geneva, Switzerland.

470. Williams, D., & Khan, N. A. (2001). Freshwater prawn farming in gher system: indigenous technology developed in south-west Bangladesh. *GOLDA Project, CARE Bangladesh, GPO Box*, (226), 7-51. Retrieved on March 25 2015 from http://www.shrimpfoundation.org/admin_panel/resources_file/84.%20CARE%20GOLDA%20freswater%20prawn%20cultivation%20in%20Bangladesh.PDF

471. Wolfslehner, B., & Seidl, R. (2010). Harnessing ecosystem models and multi-criteria decision analysis for the support of forest management. *Environmental management*, *46*(6), 850-861.

472. Wood, M. D., Bostrom, A., Bridges, T., & Linkov, I. (2012). Cognitive mapping tools: Review and risk management needs. *Risk Analysis*, *32*(8), 1333-1348.

473. WTO. (2011). *Trading into the future*. WTO Publications. Retrieved on October 26 2014 from http://www.wto.org/english/thewto_e/whatis_e/tif_e/understanding_e.pdf

474. WIT. (2008). Famine: Natural or manmade, Special focus. *World Ecological Report.* World information transfer. Retrieved on July 10 2015 from http://worldinfo.org/wp-content/uploads/library/wer/english/2008_Winter_Vol_XX_no_4.pdf

475. WLU. (2014). Wilfrid Laurier University Database. Waterloo, Canada.

476. WWAP (World Water Assessment Programme). (2012). *The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk*. Paris, UNESCO.

477. Yoe, C. (2002). Trade-off analysis planning and procedures guidebook. *US Army Corps of Engineers*, *310*. Retrieved on August 16 2014 from http://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/02-R-2.pdf

478. Zahm, F., Viaux, P., Vilain, L., Girardin, P, & Mouchet, C. (2008). Assessing farm sustainability with the IDEA method–from the concept of agriculture sustainability to case studies on farms. *Sustainable Development*, *16*(4), 271-281.

479. Zietsman, J., Rilett, L. R., & Kim, S. J. (2006). Transportation corridor decision-making with multi-attribute utility theory. *International Journal of Management and decision making*, 7(2), 254-266.