Benefit Cost Analysis and Multi-Criteria Decision Approaches for Assessing Ecological Services: An Economic Perspective

by

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(Under the Direction of Craig E. Landry)

ABSTRACT

Climate change and rapid urbanization have diminished ecosystem service provision, posing serious threats to human welfare and the global environment. Ecosystem-based adaptation measures, such as Green Infrastructure (GI), are recognized as effective solutions, but a lack of comprehensive data on benefits and costs has constrained their growth. Economic valuation of ecosystem services provided by Green Infrastructure, aimed at maximizing social welfare, is crucial. Multi-criteria Decision Analysis (MCDA) is a suitable method to capture the multi-dimensional nature of ecosystem services. However, it may not fully address the three goals of ecosystem services valuation: efficiency, equity, and sustainability. This paper explores different approaches from the perspective of welfare economics to achieve these goals, providing insights into how Green Infrastructure can be integrated into decision-making processes for optimal social welfare.

INDEX WORDS: Green Infrastructure, Multi-Criteria Decision Analysis, Ecosystem Services, Social Welfare

BENEFIT COST ANALYSIS AND MULTI-CRITERIA DECISION APPROACHES FOR ASSESSING ECOLOGICAL SERVICES: AN ECONOMIC PERSPECTIVE

by

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DEDICATION

I want to dedicate this thesis to my parents Mr. Bhumi Raj Khadka and Mrs. Sarda Khadka.

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CHAPTER 1

INTRODUCTION

Over the past several decades, poorly planned and executed development projects have contributed to significant declines in ecological services (Benedict et al., 2002), such as the loss of approximately, 25,000 acres of wetlands each year in the US; diminishing the resilience of natural systems which co-opts societal ability to cope with extreme natural conditions; diminishing ecological services provided by ecosystems, such as flood control, stormwater management, pollution filtration (Lawton & Daily, 1998); and increases in impervious surfaces (rooftops, walkways, patios, driveways, parking lots, roads, bridges) that restrict hydrological flows and resulted in urban flooding (Greiner et al., 2020). Urbanization is transforming ecological systems across the world. Current estimates suggest that two-thirds of the world's population will reside in cities by 2050 (Desa et al., 2014). This trend is anticipated to put increasing pressure on urban ecosystems (Eigenbrod et al., 2011), depressing vital provisioning, regulating, supporting, as well as cultural services provided by natural systems. Urbanization, along with industrialization and transportation, contributes to greenhouse gas emissions and climate change (Ersoy Mirici, 2022). Ecosystem Services are categorized as provisioning, regulating, supporting, and cultural services, and their degradation due to anthropogenic effects, such as industrialization, urbanization, and transportation, has serious implications for human welfare and global eco-security(Xu et al., 2021). Ecosystem services encompass a range of benefits that can be categorized into four main types: provisioning services, which provide necessities such as food, water, and materials; regulating services, which help to control climate, floods, disease, and water quality, as well as manage waste; cultural services, which offer opportunities for recreation, aesthetic appreciation, and spiritual satisfaction; and supporting services, which enable essential processes like soil formation, pollination, and nutrient cycling (Millennium Ecosystem Assessment (Program), 2005). Climate change and urbanization have both had an impact on the ecological environment. As a result, special attention is required for the protection of ecosystem services of urban cities for the well-being of large residing population (Xu et al., 2021). Therefore, green approaches like green infrastructure (GI) providing multiple ecosystem services have gained attention for promoting sustainable urban development. The role of green infrastructure in adapting to climate change, enhancing stormwater management, mitigating the urban heat island effect, reducing environmental pollution, improving socio-cultural facilities, promoting social equality, enhancing aesthetics, and enhancing social well-being has been highlighted in various studies (Coutts & Hahn, 2015; Wang & Banzhaf,2018). Ecosystem-based adaptation strategies that consider ecosystem services beyond traditional approaches offer opportunities for reducing vulnerability to climate change (Ersoy Mirici, 2022). GI is considered as the harmony of coexistence between nature and humans, guaranteeing the maintenance of ecosystem services, promoting biodiversity conservation, improving ecological connectivity, and implementing measures for ecological restoration and plays an active role in coordinating man-made constructions with nature protection, particularly in addressing urban heat island effects, climate change impacts, and the need for open green space after COVID-19(Ersoy Mirici, 2022).

Motivation

Climate change is a pervasive and serious problem that imperils the abundant biodiversity, and ecosystems compromising the ecological benefits of future generation (Sharma & Malaviya, 2023). Recurrent storms and environmental change in combination with growing expanses of impervious surfaces intensify pluvial flooding (Trenberth, 2011; Dong et al., 2020), resulting in significant loss of life and property damages (Cutter et al., 2018). Catastrophic flooding negatively impacts economic and environmental assets, as well as creating physical and mental health problems, and deepening the gulf of social inequalities (Saulnier et al., 2017). Moreover, localized storm flooding is more common and a major concern for communities due to persistent, albeit less impactful, effects than catastrophic floods (Festing et al., 2014; Winters et al., 2015). Adaptation to such conditions requires consideration of an array of infrastructure options including green and hybrid options (Ojea, 2015), which can provide for a better array of environmental, social, and economic performance (Bockarjova et al., 2020). A collection of stormwaters, hydrological, and land management approaches that imitate natural ecological processes (blue-green or hybrid infrastructure) are often found to be effective at controlling localized flooding, mitigating catastrophic flooding, and improving ecological service provision (Maragno et al., 2018; Venkataramanan et al., 2019). Ecosystems produce public good services flows that are rarely assessed rigorously, spatially, or, most significantly, in economic terms (as expected by many investors and government agencies) (CCRIF, 2010). A key constraint to the growth of ecosystem-based adaptation has been recognized as a lack of data on benefits and costs (Beck et al., 2022). Moreover, there is a necessity for a priority-based study to figure out where Green Infrastructure (GI) construction is most needed and most feasible (Lithgow et al., 2020). Economic analysis is considered one of the crucial components of that feasibility test. Scholars frequently link GI with the importance of ecological services and examine the social aspect of GI in terms of social value (Zhang and Ramírez, 2019), while the economic value of GI is also commonly studied in the Natural Capital Modeling framework. For example: (Sutton and Anderson, 2016) calculated the market worth of the land that Central Park occupies in New York City and suggested a "holistic evaluation" technique to measure the minimal value of ecological services provided by urban parks. Natural resource economics considers nature as capital and ecosystem services as the income or dividend associated with that asset (Hinterberger et al., 1997).

Objectives and Overview

Our first objective is to compare and contrast the neo-classical economics approach to assessing the provision of public goods and common-pool resources (Modern Welfare Economics) to recent innovations in ecological economics and other fields (mostly falling under the heading of Multi-Criteria Decision Analysis). In doing so, we strive to provide an interdisciplinary understanding of these tools. Secondly, we explore ways to integrate microeconomic theory, valuation results, and multi-criteria decision analysis approaches to improve efficiency and equity in assessing the merits of different infrastructure investments designed to reduce flood risk, control sedimentation, and better manage ecological service flows, with a particular emphasis on Green and Hybrid Infrastructure approaches. Lastly, we apply the results to one or several case studies.

CHAPTER 2

NATURAL CAPITAL AND GREEN INFRASTRUCTURE

Any long-lived, productive “good”, like a machine, automobile, kitchen appliance, or ecological system, can be considered a capital asset. In the modern economic context, capital assets are categorized into four types (Ekins et al., 2003): Manufactured capital, Human capital, Social and Organizational capital, and Natural capital. The idea of natural capital is centered on environmental assets that can provide ecosystem benefits to people directly or indirectly (Chenoweth et al., 2018). While green infrastructure is a concept that aims to better include the natural environment in modern planning and development, natural capital is a concept that strives to better integrate the natural environment into economic decision-making. So, the holistic concept of GI encompasses the symbiotic relationship between humans and the natural environment (Chenoweth et al., 2018). According to the EU strategy “GI is a strategically planned network of natural and semi-natural areas with other environmental features that are developed and maintained to provide a wide variety of ecosystem services” (Hermoso et al., 2020). It can also be defined as “A network of connected green spaces that preserves the values and functions of the natural environment and helps human populations.” GI is a new term for concepts that have been in practice for about 150 years. In 1903, landscape architect Frederick Law Olmsted pointed out that no park, no matter how big or how well built, could provide the benefits of nature to people. This initiated a green movement in infrastructure and park design (Benedict et al., 2002). Since then, the study of GI and ecological benefits has been widely researched in the literature (James et al., 2009). But there has been a lack of implementation of these research findings in regional development; urban and spatial planning policies (Kansanen, 2004, Banzhaf, 2010). This shortfall can partially be explained by the location-specificity of the effects of green space as well as the less evident and indirect advantages of green infrastructure in several socioeconomic domains (Schipperijn et al., 2010). Thus, there is a necessity of providing a clear, simple, and accurate technique to assess the value of GI investments in order to inform and include the general public and other stakeholders in evaluating the significance of these kinds of green investments (Vandermeulen et al., 2011). One of the fundamental ways to value GI is by determination of ecosystem services valuation (ESV) provided by that particular investment. Ecosystem Service Valuation(ESV) is an approach that describes the value of natural capital, which is basically an anthropogenic concept, but ecosystem services have both intrinsic as well as utilitarian value (Fishburn & Lavalle, 1999). A utilitarian framework defines valuation as the process of determining how well an item or activity contributes to the achievement of a specific objective, regardless of whether the person involved fully understands that contribution. In the context of neo-classical economics, a good is valued if it helps people achieve their goals of individual satisfaction, as measured by economic value (willingness to pay or willingness to accept) (Fishburn & Lavalle, 1999). According to (Costanza & Folke, 1997), applications of ESV should focus on three major goals: ecological sustainability, fair distribution of resources and property rights, and efficiency regarding resource allocation.

CHAPTER 3

WELFARE ECONOMICS

Foundations of Welfare Economics

The study of how the distribution of resources and goods impacts social welfare is known as welfare economics and is directly related to the study of income distribution and economic efficiency, as well as how these two elements impact the general welfare of people in the economy (Schmitz et al., 2004). There are two fundamental assumptions to the approach of the welfare economics (Just et al., 2005): a) Welfare level of any society should be solely determined by members of that society ("the fundamentals of ethical postulate or principle of individualism"); and b) Society is better off until and unless any individual is made better off without making another worse off (also known as the Pareto Principle, coined by Vilfredo Pareto in 1896). Welfare economics faces a challenge in measuring the level of satisfaction or welfare, also known as utility. In positive economics, preference can be measured ordinally as one option being preferred over another. However, in normative economics, it is important to determine how much one option is preferred over another to make informed choices regarding scarce resources. This means that welfare economics utilizes a cardinal system that requires the measurement of the magnitude of the preference (Just et al., 2005). For example, when proposing a policy, it's crucial to quantify the amount of additional utility provided by one alternative over another to make a favorable decision. But knowing the magnitude of utility is also not enough to identify social choices that maximize social welfare due to the difficulties of interpersonal comparisons (Arrow,1950). Sagoff

(1988) has a unique opinion regarding this topic, according to him, after fulfillment of basic needs, determining whether x is preferred over y is not a useful concept. He stated that adopting Willing to Pay (WTP) for a particular commodity is the better way to policy implications related to that commodity. Measurement of WTP when there is a shift from one alternative to another is considered as given by John R. Hicks also called the Hicks measure can be considered as an alternative to the measurement of preference relating to each alternative. This is also considered to be the basis of modern economics. Hicks in 1943 gave the concept of WTP which directly measures the change in utility (increase or decrease) as certain policy changes which may be positive or negative. And, such utilities are aggregated in order to calculate the unique total measurement. According to Hick's measure, only when the consumer surplus area closely resembles the real WTP metric does it have welfare implications. As per John R. Hicks, there are two measures of WTP; compensating variation which is the maximum money an individual is willing to pay, or the least amount of money an individual is willing to receive for welfare gain and loss respectively, and equivalent variation which is the total amount paid to an individual to maintain the same level of satisfaction with or without change. But as per Scitvosky 1941, WTP measures are inconsistent for policy analysis because this measure does not take into consideration possibility of preference change over time as well as policy reversal. Also, in the case of WTP for environmental valuation like for adaptation of GI, the response of the general public will be heavily dependent on their knowledge related to GI and its services as well as disservices and on their income level. WTP for any environment-related adaptation for rich people will mostly be higher for well-off segments of society (Hanley, 2001). There can be a conflict between experts and public priorities (Hanley, 2001). If the decision is made solely on the opinions of experts, then it is the case of Ecological dictatorship. Ecological dictatorship is a possible alternative that disregards the preferences of the general public and solely relies on the opinions of experts to make decisions. However, this approach may neglect cost considerations and lacks inclusivity and democracy (Hanley, 2001). Therefore, what is necessary is to balance the opinions of both public as well as experts which demands an integrated approach as well as taking account of income disparities. According to Hanley 2001, it can be done by giving different weights to different income groups.

Social Welfare Function and The Impossibility Theorem

Social Welfare Function was first recommended by Professor Bergson, followed by a further study by Professors Samuelson and Tintner. According to Bergson, social welfare economics should include measures of either an aggregate of welfare obtained by individuals or the quantity of goods or services utilized by each individual in society. This is rather a broad definition of welfare economics that comprises both external economies and diseconomies, and the welfare of one individual is considered potentially dependent on another. In its valor, this approach attempts to address deep questions of human welfare related to preference regarding efficiency, equity or both, since the social welfare function is dependent upon both one's welfare as well as on that individual assessment of the distribution of welfare among other members of the society.

Kenneth Arrow Concept(Arrow, 1950)

Professor Kenneth Arrow pointed out an important limitation of social welfare function based on his well-known "Arrow Impossibility Theorem" (Arrow, 1950). He has demonstrated that, in general, if a decision must be made between more than two options, it is impossible to build a social welfare function that would accurately reflect individual preferences and result in a social ordering of all available options that is both consistent and non-contradictory.

Arrow has given the following axioms to denote preference:

Axiom I: For all x and y, either any individual preferred x to y, y to x or different between them symbolized as x R y, y R x, and x I y respectively, R denotes "ordering relation" with knowledge of all pairs in the given set S.

Axiom II. For any x,y and z. If xRy, yRz then xRz.

Following are Arrow's possibility conditions:

Condition 1: For every pair of individual orderings that are permitted, R1, R, the social welfare function is defined. It should be stressed that condition I restrict the shape of the social welfare function because we demand that it be valid for a sufficiently large variety of sets of individual orderings.

Condition 2(Pareto Improvement): If an alternative social state x is chosen over another alternative y before the change in individual orderings and x rises or does not fall in that ordering of individuals without any other change in those orderings, then x is still preferred over y. It means that the change adopted for social welfare should have a positive impact, at minimal not negative.

Condition 3: Independence of irrelevant alternatives: It means that all social decision-making processes are of the voting kind. The choice between x and y is purely based on the preferences of the community members as between x and y if S is the set consisting of the two options x and y. In other words, we can determine the community's decision if we know which members prefer x to y, which are indifferent, and which prefer y to x. The complete social ordering and, thus, the social choice selected from any set of different options, are determined by the social decisions made in pairwise comparisons.

Condition 4: The condition of citizen sovereignty: – there should be no comparisons that are not permitted. Individuals of the community should have the freedom to choose any of the given alternatives as per their preference.

Condition 5: Non-dictatorship: – SWF shall not reflect the preferences of only one individual.

Arrow makes use of mathematical relations to prove if the social welfare function follows conditions 2-3 as well as axioms I and II, then either condition 4 or 5 is violated. These conditions serve to prevent individuals from comparing social utility to other individuals by either direct measurement or comparison to other social states**.** So, in order to find social welfare judgment values free from imposition, then some of the conditions should be adjusted or relaxed.

An important point given by Kenneth Arrow for the determination of social welfare in terms of multi-commodity is that without a standard of value to make the various commodities comparable, there is no clear-cut way to compare total production in any two social states. Typically, such a standard of value must be dependent on how income is distributed. In other words, total output has no significance regardless of distribution.

Amartya Sens' Concept (Bruni et al., 2008)

Since Arrow ruled out both interpersonal comparability and cardinality. Another feasible method to determine the social welfare function is voting which was determined as inconsistent by French Mathematicians around 200 years ago (Condorcet and Broda). Amartya Sen provided his view on various points of welfare economics ("The Economics of Happiness and Capability," 2008). Measuring welfare in terms of utility is called welfarism and summing individual utilities is called sum ranking. In the old approach, consideration was not given to other factors than utility like variables social situation, freedom, opportunities, etc. According to him, Interpersonal comparison is restrictive if individual well-being is attempted to be measured with a very narrow criterion. In the case of simple addition of utilities, there is no differentiation between two similar utility distributions. This simply lacks an assessment of situations that shaped individuals' perspectives. In 1930, Lionel Robbins stated that there is a lack of scientific basis for interpersonal comparison. Wide Acceptance of this concept by economists gave rise to "mutilated welfare economics" also called new welfare economics which evaluates individual utility avoiding interpersonal utility by relying on ***Pareto Criterion.*** "Pareto Optimal" or "Pareto Efficient" is a state beyond which no one can be made better off without making another worse off. It has the same limitation as that of utility distribution which does not take into account freedom, liberties, rights, and opportunities. It is considered a necessary but insufficient condition of social optimality which gives rise to the addition of other criteria. According to Sen, "New Welfare Economics" which started in the 20th century completely depending on Pareto Principle has a high possibility of reaching a dead end from the "Impossibility Theorem." So, he suggests that rather than modifying impossible axioms, there should be an attempt to make an interpersonal comparison of utility by adding inputs (information) to the analysis. If Arrow's axioms are stated again holding the feasibility of interpersonal comparability, all axioms will hold true which can also be shown by the application of stricter interpersonal comparison on John Rawls's "Difference Principle." He suggested that in place of denying interpersonal comparison, we should use different informational bases to demand various types of interpersonally comparable information.

CHAPTER 4

BENEFIT-COST ANALYSIS (BCA)

BCA is the widely used tool for policy and project analysis (Hanley, 2001) rooted in economics. It involves evaluating a project or alternative action by quantifying all positive(benefits) and negative factors(cost) in a common currency, such as dollars. This allows for the calculation of the ratio or difference between benefits and costs (net benefits), determining if the benefits outweigh the costs (Gramlich,1981). Only projects with positive net benefits (where benefits exceed costs) and a benefit/cost ratio above 1 are considered viable (Wedley et al., 2001). When selecting among multiple options, the project with the highest benefit/cost ratio would yield the greatest return on investment. BCA is based on the "compensation principle" of Hicks and Kaldor (Munda, 2006). According to this the concept of the social cost associated with a particular output can be defined as the total amount of money required to compensate all the individuals who experience a loss in their level of utility due to the production of that output, in order to restore their utility levels to what they were before (Munda, 1996). It means that any policy is considered as efficient based on overall net benefits without taking into consideration distributional equity. In this way, BCA results in Potential Pareto Improvement. BCA frequently uses subjective assessments of people's preferences for various products or services, such as willingness-to-pay (WTP) or willingness-to-accept (WTA), to estimate economic value. However, it might be difficult to calculate WTP or WTA precisely because doing so implies evaluating intangible advantages like social or environmental externalities, which might not have clear market pricing. The accuracy and dependability of BCA results may be impacted by disagreements or debates regarding the acceptable valuation methods or assumptions.

Weaknesses of BCA

According to Hicks-Kaldor compensation criterion & utilitarian philosophy (Hanley 2001, pg. 109); compensation for environmental damages may not occur, raising objections (protest bids in CV analysis). This is time consuming & expensive method. Discounting in BCA can provide unfavorable results to future generations and be unsatisfactory from an environmental perspective (Hanley, 2001). But the authors did not reject the use of discounting but rather suggested a more precise approach to adopting discounting. “According to the critics, BCA fails to capture social and ethical concerns such as cultural and moral values because they are not amenable to tradeoffs and monetary transactions” (Chan et al., 2012; Kenter et al. 2015). This method diminishes citizen values, including normative beliefs, principles, and collective meanings into consumer preferences (Sagoff, 1998; Spash, 2007; VatnVatn, 2009), and ignores ecological thresholds and distributional impacts (Wegner and Pascual, 2011; Farley, 2012; Kallis et al., 2013).” So, BCA needs to be modified to account for diverse beliefs about environmental changes, deal with scientific complexity in transparent ways, and offer more persuasive results by framing environmental decisions in sympathetic ways (Hanley 2001).CBA cannot take into consideration the cumulative and indirect effects of the study (Hanley, 2001). Cost-Benefit Analysis (BCA) has the challenge of accurately estimating costs and benefits, particularly in regions or sectors where there is limited availability of data(Airey & Taylor, 1999). For a variety of reasons, nature is essential to human existence and well-being; as a result, it is unrealistic to try to fit these values into a single economic indicator as done by Cost-benefit Ratio (Fishburn & Lavalle, 1999).

According to (Hanley, 2001), another tool known as Multi-Criteria Analysis (MCA) takes into consideration large numbers of attributes and is more suitable to ensure sustainability. Likewise, in contrast to Cost-Benefit Analysis, which uses a single common denominator such as a monetary value, the MCDA method allows for the consideration of decision problems' multidimensionality by using many criteria (Montis, 2000). But (Hanley, 2001) also noted that like CBA, has the potential to be influenced by institutional capture and can be technocentric and exclusionary. Additionally, the weights used in MCA are unlikely to accurately reflect consumer preferences. Therefore, decisions made with the help of MCDA may lack representativeness and democratic principles. (Arrow et al., 1996) contend that decision-makers should not be restricted from taking into account the costs and benefits in developing or modifying regulations; CBA should be mandatory for all "significant" regulatory decisions. They also suggest that although agencies should not be obligated to abide by the findings of a CBA, they should be prepared to justify why they did not follow the "recommendations" of a CBA evaluation. This interpretation directs toward the integration of CBA with other valuation tools. This paper will further explore different other methods as well as the scope of integration to make ESV more credible.

CHAPTER 5

ALTERNATIVE FORMULATIONS FOR ASSESSING PUBLIC INVESTMENTS

Multi-criteria Decision Analysis (MCDA)

Multi-Attribute Decision Making (MADM), now more commonly known as Multi-Criteria Decision Analysis (MCDA) was introduced by Churchman, Ackoff, and Arnof (1957). MCDA is a systematic approach to combining multiple decision/outcome attributes like benefits, cost, risks, distributional outcomes, and other stakeholder and beneficiaries' views to assist in collective decisions. MCDA is defined as an "umbrella terminology for a collection of formal techniques that strive to take explicit account of various factors in assisting individuals or groups in exploring important decisions" (Belton and Stewart, 2002). Environmental decisions are usually perceived as complex, encompassing several natural, physical, economic, social, political, as well as ethical aspects. This may be the reason that in the last two decades, the use of MCDA in papers related to environmental management has increased significantly (Huang et al., 2011). The focus of MCDA applications in environmental management and policy-making has switched to multistakeholder procedures to frame challenges and promote dialog on the relative merits of different courses of action (Marttunen and H¨ama¨la¨inen, 1995, Marttunen and Ha¨ma¨la¨inen, 2008, Keune and Dendoncker, 2013, Geneletti and Ferretti, 2015). Some claim advantages of MCDA in comparison to Cost-Benefit Analysis and classical EIA (Environmental Impact Assessment Method) due to its ability to integrate ecological, social, and economic values, as well as various stakeholder preferences among various social groups, spatial locations, and temporal dynamics (Bouma &

Beukering, 2015). MCDA can broaden the scope of the study and enable analysts to take into account various, simultaneous, and even conflicting factors. This attribute makes MCDA appropriate for addressing complex problems where not only efficiency but also concerns about fairness and equitable distribution must be taken into consideration (Montis, 2000). Including multiple stakeholders to weight or rank multiple criteria, however, does not ensure all these goals will be met. The criteria, weights, and processes used to determine the best options, as well as the type of outcomes obtained, are crucial components, and these are the tools for making decisions within the context of multicriteria methodologies (Montis, 2000). The selection of stakeholders should also be considered an equally crucial aspect of MCDA, as this aspect determines the quality of participation which contribute to the equity and distribution aspect of the decision-making.

The basic steps of the participatory MCDA process are (Saarikoski et al., 2016):

i. Identification of the problem: Defining the decision context, key stakeholders, their objectives and concerns, and the scope & scale.

ii. Structuring of the problem: Defining alternatives and criteria used for their evaluation.

iii. Assessing the effectiveness of alternatives with respect to criteria: This usually involves an impact matrix, which can make use of direct measures, like monetary units or hectares, or proxy measures that indirectly determine the effectiveness of alternatives (e.g., the number of trees as a measuring stick of air-quality).

iv. Attributing value to each criterion: Assess the performance of each criterion across each alternative by engaging stakeholders and decision-makers. This typically involves ranking alternatives in preference order.

v. Tradeoff analysis: Use a mathematical model to analyze tradeoffs and the overall performance of alternatives, either to suggest a solution to the decision-making problem, to explain multiple views, and/or to explore new solutions.

vi. Sensitivity Analysis: Assessing the robustness of the study by measuring the sensitivity of the outcomes to alterations in model parameters and assumptions.

All methods of MCDA have similar mathematical features: alternative values are assigned for a number of dimensions, then multiplied by weights, and eventually combined to generate a final score (Saarikoski et al., 2016). But the approaches can have vastly different mathematical properties, employing distinct techniques to assign and combine values that produce different total scores for each method. According to (Guitouni & Martel, 1998) important part of MCDA is its theoretical and technical aspects which can be categorized as:

(i) Input capabilities - The method's input capabilities are determined by the type of information it accepts, such as cardinal or ordinal measures, uncertain or certain outcomes, ambiguous or unambiguous likelihoods, etc. Using an MCDA method that is designed for one type of information to process another type of information can lead to errors. Different types of criteria may be used based on the information features and DM's preferences, but not all methods can handle them. If the DM wants to set thresholds or assign importance coefficients to criteria, a suitable MCDA method must be chosen. In situations where there is no compensation between criteria, a totally compensatory method cannot be used. "Compensation between criteria" refers to the process of balancing and ranking; a favorable performance in one criterion can offset or compensate for a weak performance in another criterion(Guitouni & Martel, 1998).

(ii) Preference elucidation and modeling - Identifying and modeling preferences is crucial in decision analysis. MCDA methods use different modes, such as tradeoffs, lotteries, direct rating, and pairwise comparisons, to articulate preferences, with each mode having its advantages and disadvantages. Pairwise comparisons are generally considered a good mode. Most well-known methods require a priori preference articulation, but different methods may require elucidation a priori, progressively, or a posteriori. Definitive conclusions on the best mode are still not well-studied.

(iii) Aggregation procedure- MCAP is a mathematical procedure that involves algorithmic skills. It can be categorized into a *single synthesizing criterion*, *outranking synthesizing*, or *interactive approach*, each addressing a specific decision problem. MCAP involves various mathematical techniques such as kernel searching (reducing the problem to its most critical components or dimensions), ranking, matrix calculus, and graph circuit reduction (identifying key circuits or paths in the graph and reducing redundant or less important information).

This study focuses on the AHP and MAUT methods of MCDA because these two are the most popular approaches(Melià, 2017; Huang et al., 2011)**.**

Analytical Hierarchy Process (AHP)

This employs the pairwise comparison approach to determine how much more important is one alternative than another (Saaty, 1994). It is simple, flexible, and can work with inconsistent data arising as a result of differences in personal preferences, biases, lack of clarity in criteria or alternatives, and subjective interpretations(Kwiesielewicz & van Uden, 2004) using matrix algebra (either eigenvalue-based or similar calculation) to generate weights, and overall scores (Ishizaka and Lusti, 2006). The most important use eigen value in AHP is to compute the consistency ratio.

Since AHP involve a subjective judgment and is susceptible to inconsistencies, a consistency check is one of the strong tools for this approach (Ariff et al., 2012). Almost half of 312 papers published in the environmental field in MCDA between 2000 to 2009 have made use of the AHP (Huang et al., 2011). Putting it more specifically, 80 percent of the paper is in spatial/GIS, 50 percent in Natural Resources, 50 percentage of in waste, and 19 percentage in water management use AHP. There is no unique theoretical foundation for the AHP, such as the neo-Paretian welfare theory. It tends to combine tangible and intangible aspects, meaning it can handle both qualitative and quantitative attributes (Ananda & Herath, 2003)**.**

According to (Saaty, 1989), there are three main principles of AHP:

a. Hierarchies construction: The simplest model of the hierarchy consists of three levels: the first one is a primary objective of decision making which is also called a goal, whereas the second and third are constituted criteria and alternatives, and these hierarchies are flexible to an extension to any further levels (Montis, 2000).

b. Priorities establishment: Pairwise comparisons, or comparing elements in pairs with regard to a specific criterion, are employed in the AHP technique to determine the relative importance of elements at the same hierarchical level. A matrix of pairwise comparisons is created by comparing all the items of the same hierarchical level in pairs with their equivalent elements in the next higher level. As given by (Saaty, 1988), a pairwise comparison is executed by assigning a value from 1 to 9 to different elements according to their relative importance of the criterion of a pair of elements at one level to that of another. As a result, an n-by-n matrix is formed for each criterion, and the "principal eigenvector" of that matrix is computed to obtain relative priorities. This eigenvector is normalized using (v, with $\Sigma v_i = 1$) to get local priorities. Now, the local priorities of each node are aggregated to get the global priorities (Montis, 2000).

c. Logical consistency (Montis, 2000): The "maximum or major eigenvalue" of each matrix of pairwise comparisons is computed in the AHP method to determine the level of inconsistency. It is required to reformulate the judgments using fresh pairwise comparisons if the level of consistency is too high. Expert Choice is a piece of software that carries out the procedure.

There is also a comparison of the effectiveness of AHP and ANP (Analytical Network Process). "Most complex real-world decision-making problems have numerous interdependent elements that can be captured and processed utilizing the feedback and interaction capabilities of an ANP model" (Saaty & Ozdemir, 2021; Tjader et al., 2014). But, AHP does not take into consideration the interdependence among elements for simplification, so ANP is taken as more appropriate for the economic valuation of ecosystem services than AHP (Guitouni & Martel, 1998) but this method is the process of pairwise comparison so is more complicated and tedious (Asadabadi et al., 2019). The concept of ANP is beyond the scope of this paper. Further studies on ANP and its comparison with AHP can be studied in (Jorge-García & Estruch-Guitart, 2022).

AHP requires the decision-maker to compare each alternative choice pairwise against every other alternative choice based on a set of criteria. As the number of alternatives increases, the number of pairwise comparisons that need to be made also increases exponentially, making the process time-consuming and complex (Ishizaka et al., 2012). Also, the cognitive burden would be problematic in this case. So, in such cases, AHP is not preferred.

Our focus is to explore the use of the MCDA method for the economic valuation of ecosystem services provided by Green Infrastructure (which are public goods). In AHP, the individual judgments are aggregated across stakeholders' groups. This aggregation violates the possibility theorem of Arrow (1950). The ordinal ranking of the AHP method is limited in that we cannot interpret how much one alternative is preferred over another. There is the generalization that the first two or three rankings of MCDA are roughly the same. This means that MCDA does not follow the basic criteria of welfare economics. In order to consider all three goals of the economic valuation of ecosystem services which includes efficiency, equity, and sustainability, there arises the need for inference of part of economics that analyzes proposed policies and assists society in making the correct decision, which is Welfare Economics according to (Just et al., 2005). So, MCDA should be studied and developed from a welfare economics perspective so that policy recommendations from the result will produce maximum social welfare.

AHP also imposes direct interpersonal comparisons across stakeholders. This aspect of collective choice created much concern during early explorations of welfare economics. According to Sen (1979), the primary difficulty associated with assessing social welfare is not the lack of a cardinal system but the complication regarding interpersonal comparison. Additionally, Sen (1979) stated that “interpersonal comparability without cardinality is a way out of this impossibility” (Just et al., 2005). This statement supports this approach of MCDA, which addresses interpersonal comparison ordinally but fails to address the requirement of welfare economics of cardinality. One of the major drawbacks of MCDA is that it can only rank alternative options and does not show whether they lead to welfare improvement, which also applies to AHP (Bouma & Beukering, 2015). While ordinal ranking makes AHP feasible to conduct an interpersonal comparison, in the absence of cardinal measurement, there are no criteria to measure whether or not the adoption of recommended alternatives by AHP has acceptable societal benefits. In such cases, CBA has an advantage over AHP, since BCA over 1 indicates positive welfare, and below 1 is considered to have a negative welfare (Bouma & Beukering, 2015b). Some professionals propose that AHP's future applications should incorporate a combined approach that integrates this method with other techniques (Uhde et al., 2015).

MAUT, or Multi-Attribute Utility Theory

Keeney and Raiffa formulated the multi-attribute utility theory in 1993 (Melià, 2017), based on the expected utility theory (EUT) of von Neumann and Morgenstern (1944). In this method, the axioms of Von Neumann and Morgenstern are followed to convert alternative evaluation scores to utility levels. The three primary axioms of EUT are weak order, continuity, and independence, and these form the foundation of Von Neumann and Morgenstern's expected utility theory(Dyer, 2005). The implementation of normative decision theories becomes more practical with the adoption of the MAUT process. These techniques employ similar utility maximization (optimization of expected utility) to arrive at a normative course of action, but the main difference lies in the acquisition of subjective utility through an elicitation process. Elicitation refers to the process of gathering information, typically through questioning or interviewing, in order to obtain subjective opinions, preferences, or values from an individual or group of individuals. The qualitative component of MAUT is critical because it verifies normative axioms and evaluates utility functions. Expected utility refers to the level of satisfaction obtained by Decision Makers from expected outcomes which are determined by various choices made by DM (Melià, 2017). This approach is particularly significant in situations where adequate historical data is lacking or when multiple and competing attributes need to be taken into account (Kailiponi, 2010). In accordance with decision theory axioms, the course of action with the highest expected utility would also be the most preferred alternative. So, this method is rational for decision-makers who are clear about their preference and trade-offs.

MAUT employs a singular criterion synthesis approach, specifically utilizing the value function theory, which relies on a real-valued function U defined on the feasible option set (Montis, 2000). The goal of the decision maker is to attain their objectives, with a finite, exhaustive, mutually exclusive, and predetermined set of options ($A = (A_1, ..., A_m)$) available for consideration. The options can be measured using a set of attributes or criteria ($X = (X_1, ..., X_n)$), and the predicted outcomes of each option are specified by their performances (x_{ij}: performance of option A_j on attribute X_i) (Montis, 2000). When there are no hierarchical structures or interactions between attributes, an alternative would be a utility $(U_j)=\sum^n{}_{i=1(}w_i u_i\,(x_{ij})$; w_i is the weight of criteria assigned by different methods like SMART, AHP or pairwise comparison; x_{ij} is the evaluation score of criteria i with respect to option j which range from 0(worst performance) to 1 (best performance) and u is the utility function based on the evaluation score (Akpan & Morimoto, 2022). The goal of a decision maker is to optimize the utility with respect to each option represented as max $U(X_i(a))$: a Œ A, for all X_i, i =1,..,n (Climaco, 2012). Numbers which can also be called weights will be assigned to each attribute of the given options to form a score profile, and a value function is derived from each attribute whose difference is useful for interpretation rather than absolute values (Beinat, 1997). These weights (w_i) imply trade-offs between attributes rather than importance and are normalized from 0 (worst) to 1(best) in the performance profile (Montis, 2000). The decision is made on the basis of these scores of attributes of different options hence, the complete and transitive axioms are the basis of MAUT(Montis, 2000). Then, utility from each option can be obtained by aggregation of utilities of each considered attribute in additive or multiplicative form (Montis, 2000).

Keeney and Raiffa (Keeney & Raiffa, 1993) present one of the seminal works of MAUT in the literature, which provides a good example of MAUT in practice. Their study involves a structured approach to decision-making that requires the decision-maker to first identify the relevant attributes or criteria that will be used to evaluate the alternatives. Once the relevant attributes have been identified, the next step is to specify the weights or importance of each attribute which be done using a variety of methods, such as asking experts or conducting surveys to determine how much each attribute contributes to the overall decision. Then, a utility function can be developed to describe the decision maker's preferences for different attribute values. The utility function assigns a numerical value to this combination of attribute values that reflect the decision maker's overall preference. This method has a flexible framework to incorporate uncertainty by using probability distributions to model uncertain attribute values. This allows decision-makers to make more informed decisions even when they are uncertain about the exact values of certain attributes. Keeney and Raiffa (1993) use a decision tree with square nodes, which indicates decisions that can be controlled by DM, and circle nodes, which means decisions that are uncertain for DM, with several probabilities giving different results. The probabilities are assigned with caution based on past studies/data, expert suggestions correcting for any kind of biases, DM value judgments, and control for any internal inconsistencies. For value function, DM should assign a cardinal utility value to the path for each result, which is subject to various economic as well as psychological perceptions of the cost and benefits of DM and other stakeholders. This value also shows the ordinal ranking of DM in such a way if path 1 is preferred over path 2 then, the result can be transformed as $\Sigma p_1 * u_1 > \Sigma p2 * u_2$ where u_1 and u_2 are utility assigned to 1 and 2 paths respectively.

But, like every other method, has some limitations such as the difficulty of specifying accurate weights and utility functions, and the potential for biases and errors in the decision-making process. The authors argue, however, that despite these challenges, MAUT remains a powerful and valuable tool for decision-makers facing complex, multi-dimensional decision problems. Multi-Attribute Value Theory (MAVT), closely related to MAUT, also relies on identifying a value function, but MAUT has an edge over MAVT as it accounts for the decision maker's risk preferences and uncertainties (Kangas et al., 2015). Nonetheless, due to the vast amount of necessary data, MAUT may not be applicable to all decision problems (Uhde et al., 2015). Detail study on the comparison of MAUT and MAVT can be found on (Dyer, 2005)

MAUT from Economic Perspectives:

A mathematical theory of decision-making in the face of uncertainty and conflict was developed by von Neumann and Morgenstern in their book "Theory of Games and Economic Behavior" which is the theoretical basis of MAUT. They created the idea of expected utility, which is a technique to measure the worth or satisfaction that a person obtains from a specific result or choice. A key idea in decision theory is the expected utility hypothesis, which proposes that people prefer the option with the highest expected utility. MAUT is based on this concept of utility allowing flexibility in integrating the value judgment of decision-makers. This method provides decision makers with a magnitude of the difference of utility among given alternatives. Assuming a single decision-maker who can articulate their preferences regarding risks and benefits and make clear trade-offs between specific levels of achievement across various dimensions, this method enables logical decision-making (Huang et al., 2011). But the real-life situation differs from such an assumption. There will typically be multiple stakeholders having different levels of knowledge, subjected to cognitive biases, which require synthesis and aggregation. But the problem arises regarding the underlying theory beneath the aggregation of utilities. There are some conditions that must be fulfilled for such aggregation which are independence of preference, utility (Climaco, 1997), and attributes (Montis, 2000). The MAUT method has core drawbacks from the perspective of economics at least with respect to the economic valuation of ecosystem services; since attributes of ecosystem services are highly dependent on ecosystem health, structure, and function, most services are an interrelated phenomenon and likely to be correlated across space and time (Bouma & Beukering, 2015b). Moreover, preference and utility independence conditions are highly unlikely when decision-makers are giving weights to the set of interdependent attributes of different alternatives, which means that pre-conditions for aggregation of utilities across attributes do not hold. According to Arrow (Arrow, 1950), there is no available rule to aggregate individual preferences to societal ranking directly. If the assumption of independence is not suitable for a particular situation, there may be options available to rearrange the attributes so that interdependencies can be avoided, or to convert the functional form into a more intricate multiplicative format (Kwak et al., 2001). Keeney (Keeney, 1996) outlines the kinds of inquiries that should be posed to evaluate whether MUAT assumptions are appropriate in a given situation, but it is very time-consuming to execute these procedures among respondents (Kwak et al., 2001). In the case of ESV, when the attributes are interdependent and the analyst allow for trade-offs among them, the intensity of work needed will be very cumbersome. According to (Keeney & Raiffa, 1993) as cited in (Melià, 2017), the weighted sum can be employed for aggregation of utility across attributes if one is willing to assume a constant rate of substitution, otherwise the multiplicative utility function is more suitable. So, rather than applying linear utility for simplicity, there is a need for a study in that we figure out the type of utility curve formed by several attributes of ecosystem services provided by Green Infrastructure. This is the core of the MAUT method and needs to be focused on critically. Such a study should be conducted at the preliminary step of the approach (Mardle & Pascoe, 1999). The marginal rate of substitution (MRS) refers to the rate at which a consumer is willing to exchange a certain amount of one good for another, without changing their level of satisfaction or utility. There is the least chance that all ecosystem services have a constant rate of substitution because some attributes like religious and cultural values cannot be substituted. MAUT is a more sophisticated technique than AHP and is usually used when the number of alternatives is large and risks are involved and need to be addressed (Dyer, 2005). So, it is also important to note the requirement for assessment of risk and quantity of alternatives for ecosystem services valuation so unnecessary complications can be avoided.

A study on Multiple-attribute evaluation of ecosystem management for the Missouri River system done by the US Army Corps of Engineers in 2003(Prato, 2003) made use of MAUT to rank five alternatives Missouri River system. The authors took into consideration 10 attributes which are flood control, hydropower, recreation, Missouri River navigation, water supply, fish and wildlife, interior drainage, groundwater, historic properties, and Mississippi River navigation which are highly interdependent. But they made use of additive utility which does not hold for interdependent attributes. It is stated that non-linear utility functions follow diminishing marginal utility whereas linear does not do so. The reason given by the author regarding the use of linear utility was some attributes were negative which makes its' square root unidentified. So, the criteria for choosing a utility function are not clear in the given study. This will question the empirical basis of the above-given aggregation rule of utility. If attributes for the economic valuation of ecosystem services are independent and we use non-linear utility then will these environmental attributes fulfill the law of diminishing marginal utility?

The key question to be asked in the case of our study of ESV provided by Green Infrastructure are:

What is the marginal rate of substitution of ecosystem services provided by Green Infrastructures?

What is the functional form of utility provided by such ecosystem service attributes provided by GI?

What are the risk and uncertainty involved with such a Decision-Making process and how they can be addressed using the probabilistic features of the MAUT approach?

What will the trade-off between such attributes will look like? The trade-off between different ecosystem services could be depicted by the Production Possibility Frontier(PPF) which shows all possible pairs of two goods feasible to be produced from available resources) (Bouma & Beukering, 2015). The same study shows PPF for bio-diversity and recreation of forests which seems to be variable from constant, no trade-off to diminishing rate.

"Do preferences, attributes, and utility achieved in the non-market valuation of Green infrastructures fulfill this pre-condition to assign linear aggregation of MAUT as a credible method for such valuation?" According to (Hayashi, 2000), the notion of preferential independence is not realistic. Also, the MAUT method allows full compensation of bad performance on an attribute with good performance of another (Montis, 2000) which arises a situation to search for other non-compensatory methods like ELECTRE(Hayashi, 2000).

After addressing these questions, we can proceed to the next steps of MAUT**.** According to (Climaco 1997), the determination of utility function is the most difficult part of MAUT but still, it is popular in the environmental management field (Reichert et al., 2015). According to (Paillex et al., 2017), the following may be the reason behind such increasing use: (a) Rational choice axioms are the basis of these methods, which can be helpful in justifying decisions to the public; (b) These methods focus explicitly on the goals that a management plan should achieve rather than the selection of specific management actions, (c) Additional management actions can be incorporated into the decision-making process without altering the ranking of previously considered alternatives (d) These methods can account for uncertainties, such as environmental assessment, predicting the consequences of management actions, and stakeholder preferences, but for consideration of uncertainties non-linear utility function must be used which is rarely used due to its complicated procedure so this concept is rarely applied practically for ESV (e) Risk attitudes of stakeholders can be taken into consideration through the use of utility functions and (f) These methods can address a variety of ecological, socio-economic, and cultural management goals but these flexibility is not widely explored for ESV.

Another important point to be noted here is the use of the concept of cardinality and interpersonal comparison together in the MAUT method. Arrow ruled out both "Interpersonal Comparability" and "Cardinal Measure" of utility which questions the underlying concept of MAUT. But the initial one seems to be more important than the latter. According to Sen "New Welfare Economics" which started in the 20th century completely depending on Pareto Principle has a high possibility of reaching a dead end from the "Impossibility Theorem", (Sen, The economics of happiness and capability. Capabilities and happiness, 27., 2008). So, he suggests that rather than modifying impossible axioms, there should be an attempt to make an interpersonal comparison of utility by adding inputs (information) to the analysis. If Arrow’s axioms are stated again holding the feasibility of interpersonal comparability, all axioms will hold true which can also be shown by the application of stricter interpersonal comparison on John Rawls's “Difference Principle.” Sen (2008) suggested that in place of denying interpersonal comparison, we should use different informational bases to demand various types of interpersonally comparable information. It provides a motivation for combining multiple types of information. His statement has strong relevance in the case of MAUT. If MAUT is designed and conducted by adding sufficient information then it is possible to do interpersonal comparability which tends to address major drawbacks related to this method. Now, the question is what are those relevant information sets which need to be further explored?

MAUT has an economically rooted theoretical basis that is not explored and applied to its full extent. The reason behind the wide use of linear functions is their simplicity but non-linear functions offer a more realistic description of human risk-taking behavior and can provide more accurate results in complex decision-making scenarios(Melià, 2017). If the above-mentioned questions could be addressed to develop a strong practically applicable theoretical base of MAUT with respect to ecosystem services valuation; MAUT can be developed as a useful tool for ESV provided by public goods like Green Infrastructures.

Other Approaches of MCDA

NAIADE (Novel Approach to Imprecise Assessment and Decision Environments)

This approach is developed by Munda in 1995. This is a method that involves discrete multiple criteria and is based on pairwise comparisons. The evaluation matrices used in this method can contain various types of measurements, including crisp, stochastic, or fuzzy measurements, that correspond to the performance of each option for each criterion which accounts for the different levels of uncertainty in assessing the criteria (Munda, 2012). In this method, quantitative criteria indifference, and preference threshold are defined using four binary relations: indifference, strict preference, big preference, and incomparability. The NAIADE tool also allows the applicant to choose the compensation level for certain parameters. NAIADE can explicitly account for incommensurability relationships between criteria (and related values) which will reduce the trade-offs between criteria. Furthermore, the NAIADE tool provides an explicit approach to conflict analysis between social players (organized interest groups as well as society actors), based on institutional analysis and sociological research methods. So, this approach is different from participatory MCDA processes and is termed Social Multi-Criteria Evaluation (SMCE) (Munda, 2004). Participatory MCDA processes refer to procedures that are carried out in close collaboration with stakeholders for the formulation, structuring, and weighing of problems as well as impact evaluation (Saarikoski et al., 2016). NAIADE is better suited to address value incommensurability. It also facilitates non-negotiable objectives such as the protection of ecosystem processes that is sustainable for the well-being of future generations, which sometimes contrasts with stakeholder short-term demands which is also a measure of sustainability. But it has received little attention in ES assessments. According to (Shmelev & Rodríguez-Labajos, 2009), NAIADE has three phases-pairwise comparison of alternatives; aggregation of all criteria, and evaluation of alternatives. The technique is founded on the concept of the fuzzy preference relation, which is an element of the N × N matrix R = (r_{ij}) when A is assumed to be a finite set of N alternatives. So, $r_{ij} = \mu R$ (ai, aj) where i, j =1,2 …. N, $0 \leq r_{ij} \leq 1$, The value of r_{ij} in the N × N matrix indicates the degree of preference of ai over a_j. A value of 1 denotes the maximum degree of preference, while a value between 0.5 and 1 indicates a definite preference for ai over aj, with higher values indicating a stronger intensity of preference. A value of 0.5 represents indifference between ai and aj. Pairwise comparison is done by finding the semantic distance between a pair of fuzzy sets with respect to six different fuzzy relations: "much greater than," "greater than," "approximately equal to," "exactly equal to," "less than," and "much less than" (Montis, 2000). Thus, obtained pairwise comparison of alternatives is aggregated across each criterion to get fuzzy preference relation which is further evaluated which alternatives are best and which ones are the worst on a scale of 1 to 0 respectively. The disadvantage of NAIADE is the inability to use weight explicitly (Munda et al., 2008).

Outranking model

It includes PROMETHEE, ELECTRE, and ORESTE (Organisation, Rangement Et Synthese de donn´ees relationnelles). These methods compare alternatives pairwise, first in terms of each criterion, and then the preference information is summarized across all criteria. These methods attempt to establish the weight of evidence in favor of one alternative over others. Unlike MAVT, rank-based techniques use an ordinal scale rather than a cardinal scale and ask participants to rank the criterion (what is the most important criterion for you, second most important, etc.) This strategy requires less cognitive work from the participants, but it compromises some information about the relative importance of the criteria. For Example, AURORA (de Keyser and Springael,2009) software that is supported by the OpenNESS project is based on rating alternatives on an ordinal scale.

Partial Order Ranking (POR) methods. These are vectorial techniques that acknowledge that multiple criteria can be contradictory. This method not only ranks alternatives but also detects conflicts in the criteria used to rank them. So, it allows perceived incomparable conditions with residual order for structuring, weighing, and impact assessment.

TOPSIS (Technique for Order Preference by Similarity, Hwang and Yoon, 1981): This method compares a set of alternatives by identifying weights for each dimension, normalizing scores in each dimension, and calculating a distance across the weighted dimensions between each alternative and the ideal alternative (best on each dimension) and the negative ideal alternative (worst), using one of several possible distance measures (e.g., Euclidean distance). Finally, the ratio of the distance (separation) from the negative ideal to the sum of the distances from the ideal and negative ideal alternatives is computed. Alternatives are compared using this ratio.

Advantages of MCDA

It is capable of organizing an evaluation of a complex topic along with cognitive and normative dimensions, which are both crucial in evaluating ecological services (Vatn, 2009) and allows for the comparison of ecological objectives with sociocultural and economic objectives within a defined and shared framework (Mendoza and Martins, 2006). It can aid in multi-stakeholder processes, transparency, and debate about subjective aspects of policy analysis such as the nature and scope of the decision problem, the selection and description of possibilities (alternatives), and the characterization and prioritization of assessment criteria (Stirling, 2006, Keune and Dendoncker, 2013). It is capable of dealing with incomplete and confusing information, frequently observed in environmental planning situations, with the ability to combine a set of quantitative and qualitative data (Locatelli et al., 2008). According to (Bouma & Beukering, 2015), MCA has a significant advantage over CBA in that it does not require the valuation of all impacts in monetary terms. This makes it possible to avoid costly and complex valuation studies and to include qualitative criteria like political sensitivity in decision-making. MCA can offer a framework for analysis, structure, and transparency that goes beyond what is possible with CBA and other valuation approaches based on neo-classical economics.

Limitation of MCDA

The various techniques only focus on improving the specific procedures used in algorithms and do not tackle the fundamental elements of the decision-making process and the Decision Making Situation (DMS) so there is a necessity for the study that dwells deeply on axiomatic principles of each MCDA methods to point out the strengths as well as weaknesses of each method (Prell et al., 2009). The author also mentions that each MCDA method has its own assumptions and hypotheses which form the basis for its theoretical and axiomatic development. These limitations must be acknowledged as they set the boundaries for the use of the method. Unfortunately, these limitations are often ignored by practitioners and analysts and suggest a detailed study of a selection of a method. I think before making any criteria for the selection of a suitable MCDA method, there is the necessity of a detailed study of their procedure; their weakness; strengths, and exploration of further improvements. The prioritization of alternatives and the selection of an aggregation rule require special consideration when using MCDA for ES assessments. It has limitations while dealing with various scales of Ecosystem services demand and supply. It requires a lucid definition of problems. But in the real-world scenario, there are numerous stakeholders with differing opinions and interests which compromise the scope of the problem in many conditions. This approach is not considered representative or democratic because a small group of stakeholders will determine the best alternatives. The only way to take public preference into consideration is via WTP data obtained by survey. In MCDA methods like Multi Value Attribute Theory, trade-offs between criteria of alternatives may not be accepted by people. For example, the tradeoff of spiritual or cultural aspect or aspect that is required for subsistence. MCDA can handle non-commensurability in a monetary sense but cannot deal with categorical non-commensurability (lexicographic preference). Lexicographic orderings are comparative preferences in which an agent prefers any amount of one good (X) over any amount of another (Y). This problem can be addressed by a method like NAIADE by setting a minimum threshold level for trade-offs. MCDA relies on the judgment of the decision-making team to define alternatives, criteria, and to some extent, input data. This subjectivity may be a concern.

CHAPTER 6

OPPORTUNITIES FOR INNOVATION AND INTEGRATION

The European Commission's fourth framework project (EUNET) created a technique for combining CBA and MCDA. The EUNET framework assigns scores to investment criteria, such as benefit-cost rates (B/C-rate), and so regards the rates as any other criterion in the MCDA. Which criteria to include in the framework is a question of judgment, based on factors such as the dependability of the data and the preferences expressed by decision-makers and/or stakeholders in the decision-making process (KARATZAS and O'SULLIVAN, 1999). It can be used as a base to integrate MCDA with an estimate of meta-analytic value transfer since CBA and BT both estimate the monetary value of Green Infrastructure. MCDA criteria can be added to the CBA if value functions for the MCDA criteria can be generated using a weighting process that specifies the significance of each criterion. These two can be combined via additive value function which is a theoretically feasible and commonly used method (Keeney et al., 1993). A study done by (Uhde et al., 2015) concluded that there is a need for continued research into the development of hybrid MCDA methods that can effectively integrate multiple ecosystem services in different management planning. The authors suggest that future research should focus on developing methods that can account for the dynamic nature of ecosystem services, the uncertainty associated with their assessment, and the social and cultural values associated with different services.

Cardinal measurement of Utility

Neuroscientific research suggests that economic decisions are influenced by neural activity related to the release of dopamine, a neurotransmitter associated with motivation and learning which can be measured and correlated to probability to predict preferred option between binary choice (Robson et al., 2022). Such dopamine indicates expected satisfaction of an individual so is considered to be useful in economic decision making. Robson et al., 2022 had given explicit real-time low-rationality adjustment mechanism of model to map neural system with economic decision making. Two publications published recently in the area of neuroeconomics examine how adaptive reward encoding affects risk attitudes(Robson et al., 2022). According to Khaw et al. (2020), logarithmic encoding of rewards results in risk attitudes that are similar to reversion to the mean. Frydman and Jin (2019), on the other hand, investigate how endogenous encoding of lottery payouts adjusts to the distribution of decision problems and influences choice. These results demonstrate the importance of adaptive reward encoding in influencing risk perceptions in economic decision-making. This concept can be further explored for valuation of ecosystem services in terms of cardinal utility.

Since, ecosystem service attributes for GI valuation are highly interdependent, a non-linear utility model is more suitable for such analysis. Moreover, impact of ecosystem services is localizing. Therefore, study on spatial distribution is required in case of GI and its' ecosystem service valuation(Meerow, 2019). So, MCDA can be integrated with tools like GIS to prioritize GI requirement.

Normalization process result in preference reversal in most of all traditional method of MCDA. The development of trustworthy decision-making techniques that are totally impervious to the Rank Reversal (RR) phenomena has been the focus of recent research efforts. The Characteristic

Objects Method (COMET), Stable Preference Ordering Towards Ideal Solution (SPOTIS), and Ranking of Alternatives through Functional mapping of criteria sub-intervals into a Single Interval (RAFSI) are a few significant approaches that have been created recently(Kizielewicz et al., 2021). COMET stands out among them for its great precision and lack of need for arbitrary weights. However, one drawback of COMET is that it is time-consuming due to the exponential relationship between the quantity of criteria and characteristic values and the number of required pair comparisons. So, there is scope of study for combination of other methods of MCDA with decision making technique to better address rank reversal.

An integrated approach of AHP and BCA

Since the MCDA method, MAUT fails on the economics groups of aggregation of individual preference to obtain societal preference according to Arrow impossibility theory. Whereas the AHP method is found to have an economic basis as it gives ordinal ranking and according to Sen, interpersonal comparability without cardinal ranking is way out of impossibility. According to some experts, future applications of AHP should be integrated with other approaches (Vaidya & Kumar, 2006). These authors claim that AHP lacks information regarding the cost; this information may be incorporated by integrating AHP with the benefit-cost ratio. This method is based on the (Wedley et al., 2001). The process of economic valuation of Green Infrastructure will consist of the following steps(Ariff et al., 2012):

a. Define Problem: In this case, the selection of the best alternative of GI to maximize social welfare is the main problem.

b. Hierarchy Development: For this problem, hierarchy is depicted graphically as follows:

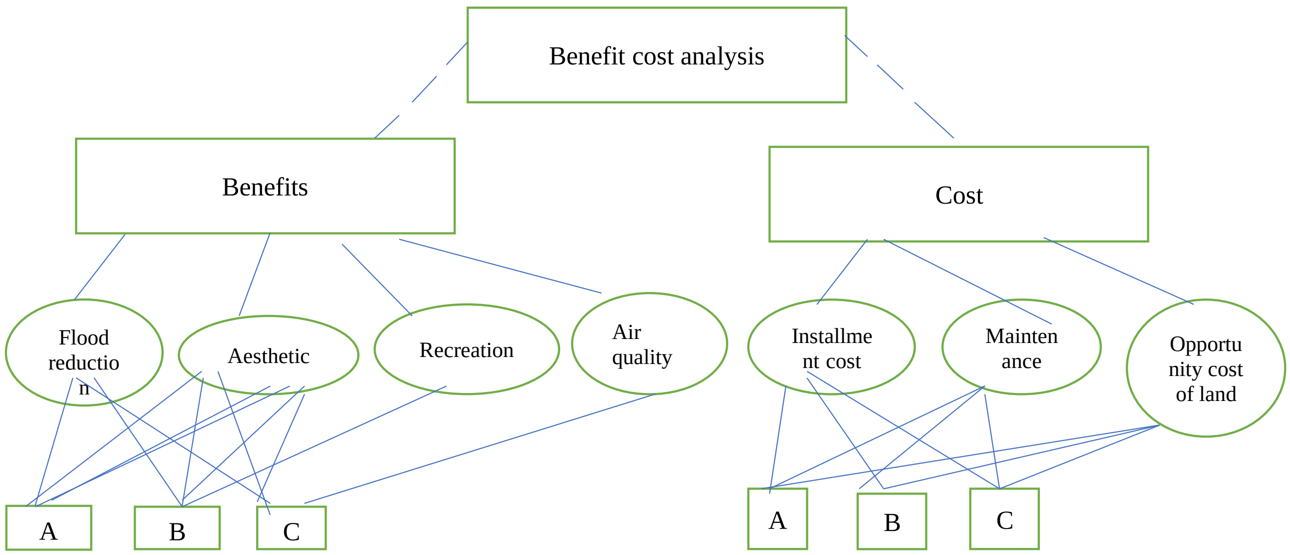

Fig 1. AHP for cost-benefit analysis of Green Infrastructure

Here, the goal is the assessment is Benefit/Cost analysis, the first hierarchy is Cost and benefits, second hierarchy is criteria that determine the cost and benefits which will be based on literature review and expert suggestion. The dotted line between cost and benefit of the second hierarchy indicates the partial relation between cost and benefit. It indicates that there should be a magnitude adjustment at the beginning to make costs and benefits commensurate. Attributes are assumed just for reference for the model framework denoted as $C_{i,}$ where i= 1 to n, C1, C2, C3, and $C4_{,}$ are four criteria. Thirds hierarchy is alternatives (A, B, C, and D) of the Green Infrastructure type denoted by j= 1 to n.

c. Construction of pairwise comparison matrices for criteria

First, weight is to be elicited to cost and benefit by asking the question, which one is more important between benefit and cost of GI and by how much? Suppose we got a weight of 2/3 on benefit and 1/3 on cost. At last, these weights are multiplied by original benefits and cost priorities. Then, a pairwise comparison of the criteria of benefits and cost separately. For benefit, a 4*4 (n*n) matrix is constructed with criteria as elements. Then, weight is assigned to each criterion with respect to other criteria by using Saatys' comparison scale as shown (Saaty,1986) in Table 2.

	C1	C2	C3	C4	Priority vector(PV)
C1	1				
C2		1			
C3			1		
C4				1	
Sum	T1	T2	T2	T4	

Table 1. Assigning criteria weights

The assigned scale on each column is summed. Each column is divided by its total score. Thus, the obtained value is aggregated across each row and averaged to get a priority vector.

Importance of one criterion over another	Definition
1	Equal preference
3	Moderate preference
5	Strong preference
7	Very strong preference
9	Extreme preference
2,4,6 and 8	Can be compared between above values

Table 2. Saaty's comparison scale (Saaty, 1977)

d. Consistency test

Firstly, the eigenvalue is obtained as shown in table 3.

	C1		C2		C3		C4		New vector	Consistency Index (CI)
C1	1	PV1	1/4	PV2	2	PV3	3	PV4		CI= $(\lambda_{max}-n)/(n-1)$ CR=CI/RI
C2			1							
C3					1					
C4							1			
Sum	T1		T2		T2		T4			

Table 3. Calculating Consistency Ratio

Here, New vector (NV) = 1* PV1+(1/4) *PV2+ 2* PV3+ 3*PV4. Then, the ratio of (NV/PV) is aggregated to each row to obtain the maximum eigenvalue (λ_{max}) followed by the calculation of CI. Finally, the Consistency Ratio is calculated as (CR)= CI/ (Random Index). A random index will be provided by a random index table based on matrix size.

When using comparison matrices, if there are more than three criteria, it can lead to inconsistencies because people struggle to maintain consistency when there are many components to consider as subjected to cognitive burden. To address this issue, each matrix is assigned a consistency ratio (CR). For matrices with a rank of n greater than 4, inconsistencies below 10% are considered acceptable, while for n equals 3, inconsistencies below 5% are acceptable, and for n equals 4, inconsistencies below 8% are acceptable. If the established CR is surpassed, experts need to redo the pairwise comparison matrix (Jorge-García & Estruch-Guitart, 2022). These Standards Are Arbitrary. Taking into account the consistency ratio tends to address Arrow's comment that when more than two individuals are involved in decision-making, inconsistency involved makes their aggregation obtain societal ranking unreliably. It is not possible to have consistency in various individuals' opinions, but allowing certain inconsistencies as a measure of result credibility is a good measure to address this universal existing situation.

e. Pairwise comparison of criteria with respect to each alternative

After obtaining criteria priority weights and passing the consistency test, there will of pairwise comparison of each criterion with respect to each alternative. It can be shown by a matrix as follow:

For alternatives A (assigned as j)					Weights
	C1j	C2j	C3j	C4j	
C1j					Aw1j
C2j					Aw2j
C3j					Aw3j
C4j					Aw4j
Sum					

Table 4. Assigning criteria weight with respect to alternative A

In this step, criteria are scored with respect to particular alternatives. All other steps resemble to that of step c. Cij indicates criteria weights for attribute i with respect to alternative A. Another same process as in step c is repeated to obtain the weight of each criterion for alternative A denoted as Aw_{ij}..Here, the sum of priorities obtained in each column is obtained and divided with each score of that column. This process is called Normalization. Further, the normalized weight of each cell of the row is aggregated to get the weight of each criterion across alternative A. Such matric will be reproduced for the other three alternatives with respective consistency tests to finally obtained the following matrix.

f. Obtaining final priority vector

	C_1	C_2	C_3	C_4	Overall Priority Vector
Weights of criterion	W_1	W_2	W_3	W_4	$(W_1 * Aw_{ij}) + (W_2 * Aw_{ij})$ $(W_3 * Aw_{ij}) + (W_4 * Aw_{ij})$

A	Aw_{1j}	Aw_{2j}	Aw_{3j}	Aw_{4j}	
B					
C					
D					

Table 5. Matrix to obtain total criteria weights across each alternative

Where, i=1 to n, the number assigned of the criteria

J= 1 to n, number assigned to alternatives,

Final Priority weight of A= $(W_1 * Aw_{ij})+ (W_2 * Aw_{ij}) (W_3 * Aw_{ij})+ (W_4 * Aw_{ij})$, aggregation of product of priority weight of each criterion and priority weight of each criteria with respect to alternatives.

g. All steps from c to f is repeated to obtain total cost priority vector.

h. Selection of best alternatives

Obtained benefit priorities will be divided by cost priorities to obtain B: C priorities. Finally, alternatives having the highest B: C values will be selected. The most important point to be noted for this integration is the ability to the usual interpretation of the result. B: C priorities greater than 1 means the benefit exceeds the cost and less than 1 implies that the cost exceeds the benefits. Also, it allows net benefits calculation by subtracting benefit priorities from cost priorities.

CHAPTER 7

FUTURE RESEARCH PROSPECT

A detailed in-depth study is required to assess the applicability of other Multiple Criteria Decision Analysis (MCDA) methods for the economic valuation of Ecosystem Services (ES) provided by Public Goods/Services such as Green Infrastructure. The valuation should take into consideration the underlying theory of welfare economics, ensuring that it encompasses all three goals of ES valuation: sustainability, efficiency, and equity. Distributional equity or equity in the distribution of ecosystem benefits is still a less explored aspect of ES valuation, and more studies are needed to address this goal. The ranking of options and the adoption of an aggregation rule require special consideration in the application of MCDA for ES assessments. Our study concluded that the interpersonal comparability and aggregation of individual preferences to social ranking adopted in MCDA methods such as the Analytic Hierarchy Process (AHP) and Multi-Attribute Utility Theory (MAUT) may violate basic principles of welfare economics. Following Sen's (2008) suggestion, adding additional information for analysis could address the issue of interpersonal comparability. Further studies that identify inputs that can address this problem would be highly valuable. Additionally, if such information could incorporate concerns of equity or unequal income distribution, it could lead to a paradigm-shifting research approach. A study on approaches to addressing ignorance, uncertainty, and ambiguity in various MCDA frameworks is necessary, as risk and uncertainty are often not adequately addressed in most economic valuation tools (Schaafsma and Brouwer, 2006). Bayesian Belief Networks (BN) provide an appropriate modeling technique for combining economic values and biophysical catchment processes, using probabilistic links to describe knowledge uncertainty, particularly regarding ecological changes (Kragt et al., 2011). Therefore, a study on how well Bayesian Belief Networks can address the issues of measuring uncertainty in MCDA is required.

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