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Solving the "Tragedy of the Commons" with local solutions

by

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Abstract

Pasture lands are one of the primary common-pool resources that create the environment for the livestock to grow, reproduce, and generate benefits from the various production outputs. However, what if no control will be imposed on how people use the common resource, like pasture lands? The tragedy of the commons will occur as an answer to this question, and in the case of pasture lands, the overuse of the resource will lead to a high stocking rate of pastures. This is very important, especially for Mongolia, where a big part of the economic share has to do with animal husbandry. So, the rural community is very vulnerable to the harsh environmental conditions (e.g., cold winter) since animal farming is the primary source of profit. Moreover, when the pasture degradation hits the land, amplifying harsh ecological conditions, people may suffer considerable financial losses due to a high livestock death toll. To address this problem, this research will explore local management solutions, for instance, the thesis's research will be conducted on a cost-benefit analysis of pastureland affected by a high stocking rate for two case scenarios. Mainly, Business as usual and a more sustainable scenario will be compared and analyzed for the region of Bayantsagaan, Mongolia. The economic feasibility of two management approaches will be taken to the main course, allowing us to show the long-term benefits of sustainable practices and how they affect investment. Moreover, an information technology solution will be represented as a tool for sustainable managerial practices. Following the idea of a sustainable pasture management scheme, I will additionally discuss possible practical uses of the app and its benefits.

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LIST OF ABBREVIATIONS

AFY	Average Forage Yield
BAU	Business-as-usual
BCA	Benefit-cost Analysis
CBA	Cost-benefit Analysis
CC	Carrying Capacity
CPR	Common-pool Resource
ELN	Exceeding-livestock Number
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
GPS	Global Positioning System
IMF	International Monetary Fund
IRR	Internal Rate of Return
IT	Information Technology
LGR	Livestock Grazing Rate
LN	Livestock Number
MNT	Mongolian Tugrik
NDVI	Normalized Difference Vegetation Index
NPV	Net Present Value
PCC	Pasture Carrying Capacity
PU	Percentage Use
PU	Pasture Unit
RSD	Relative Stocking Density
SR	Stocking Rate
STM	State and Transition Model
SU	Sheep Unit
UI	User Interface
USD	American Dollar
WHO	World Health Organization

1 Introduction

1.1 Background: Pasture lands as a Common Pool Resource and the Tragedy of the Commons

Pasture lands are one of the few examples of Common-Pool Resources (CPRs), which supply an essential forage for the livestock. Two main characteristics describe CPRs, which are the difficulty of exclusion and the subtractability of use (Ostrom, 1990). Subtractability of use means that each time a resource is under usage, less of it is available for other users (Ostrom, 2016). The challenge arises when the collective benefit decreases due to all herders' decision not to contribute to the joint effort, but to free ride on the efforts of others (Ostrom, 1990).

The expression “the tragedy of the commons” often means the environmental degradation of scarce resources when many individuals use them in common (Hardin, 1968; Ostrom, 1990). In the pasture that is open to all, it is expected that each herdsman will try to keep as many livestock as possible (Hardin, 1968). The core issue lies in the individual incentives of herders, where a pasture user will gain additional benefit from having one unit of livestock when the cost of the environmental degradation lies on the shoulders of the entire community. For example, in the pastures, the cost of degradation is overgrazing, and only a fraction of the degradation price will be distributed to each herder (Hardin, 1968). Following this logic, the only way for each rational pastoralist to increase the benefit will be to add another animal to the herd, and so on (Hardin, 1968). This will be the conclusion reached by the whole herder’s community (Hardin, 1968). Therein is the tragedy (Hardin, 1968).

On the other hand, Ostrom challenged Hardin’s idea that the helplessness of common-pool resource users is due to being trapped in a social dilemma (Ostrom, 2016). Moreover, she argues that the capacity of individuals to resolve tragic overuse varies (Ostrom, 1990). Providing empirical cases where users overcome the dilemma and craft the rules to govern their resources (Ostrom, 2016).

We can conclude that the “tragedy of the commons” hazard exists in the pasturelands due to the characteristics of a commons. Furthermore, Ostrom’s work drastically shifted the understanding of common-pool resource management by showing that collective action can change the dramatic outcome of the tragedy (Ostrom, 1990). Having said this, I will use this essential framework in my study for analyzing the challenges and solutions of pasture management, as demonstrated by the works of Hardin and Ostrom on the dilemma of common-pool resources.

1.2 Problem Statement: Overgrazing, Pasture degradation, and Economic Vulnerability in Mongolia

Studies confirmed that 70% of the widespread vegetation decline across the steppe is substantially caused by the increase in livestock numbers (Hilker et al., 2014). Another factor besides overgrazing that causes degradation is climate change, which is characterized by an increase in the average temperature across the country and harsh winters (Tuvshintogtokh & Ariungerel, 2013). It was found that these main factors of degradation lead to the land transformation from a typical steppe to a desert steppe and further to a desert, as well as the appearance of plants in the northern part of Mongolia that usually grow in deserts (Tuvshintogtokh & Ariungerel, 2013). That is why arid areas and high mountain steppes are especially vulnerable to grazing, which is specified by the decline of vegetation cover, species diversity, and above-ground biomass (Munkhzul et al., 2021). This vulnerability is caused by the high grazing rates, and the harsh climate creates a pressure that makes arid places potentially sensitive to biophysical changes (Munkhzul et al., 2021). Furthermore, one can find evidence of the ecological pressure from herders' observations. It was reported that due to rapid environmental shift, there was an overall decline in the richness of desirable plant species and an increase in the undesirable ones. This phenomenon is a valid indicator of land degradation (Bruegger et al., 2014).

A big part of the Mongolian economy is livestock production (Gao et al., 2015). This makes it vulnerable to climate change and degradation. For example, Dzuds (harsh winter conditions) in 1999-2002 and 2010 caused 35% and 22% reductions in livestock numbers nationwide (Gao et al., 2015). Basically, it was a considerable livestock death toll due to the animals' starvation (Gao et al., 2015). Therefore, it can be concluded that the main hindrance to stable livestock production is the decline of the pasture rangelands' health; in other words, pasture degradation is the leading cause (Densambuu et al., 2018). Sadly, privatization and the concurrent decline in state support have changed general herders' views, and now they cannot expect the government to help them restock in case of a bad winter or livestock-decimating diseases (Rossabi, 2021). Furthermore, the economic value of ecosystem services and goods derived from land has declined due to human factors and environmental change in general (Sutton et al., 2016). Land degradation can exacerbate the situation of the rural population, which is one of the most vulnerable parts of society to unemployment and poverty, because mostly these communities' survival depends on what is provided by the land (Quillérou et al., 2016).

1.3 Research Objectives and Research Questions

This thesis has two case scenarios: business as usual (BAU) and a sustainable scenario that incorporates livestock mobility to avoid overgrazing. I will conduct a cost-benefit analysis on both cases, calculating corresponding net present values (NPVs). In the first case, BAU, I will calculate the costs and benefits for livestock husbandry. The second case involves including the additional term for transportation costs for the initial year, to minimize the regions with high livestock grazing rates (LGR) (Nandintsetseg et al., 2018). I will simulate the mobility of the households from overgrazed pasture units to undergrazed ones in the study region. Moreover, comparing the resulting NPVs in both cases, my research objective is to show the benefits of the optimized stocking rates in pasture units for the livestock production and define the positive impact of a sustainable contemporary management approach, such as information technology (IT) solutions, for the livestock husbandry.

Research questions are as follows:

1) What is the situation with grazing pressure in the study region?
2) What is the NPV difference in the two case scenarios and their economic implications?
3) What socio-economic feasibility does a modern IT solution have in pasture management?

Addressing these questions and achieving the research objective will allow us to cover the most important milestone of this work. This will be an example of how sustainable practices may increase the long-term financial returns in livestock management, improve monitoring, and restore the condition of the pastures.

2 Pastoralism and Pasture Management in Mongolia

2.1 Historical Overview of Pasture Management

Historically, the Mongolian timespan can be divided into four main periods: feudal Mongolia, communist period, post-communist transition, and contemporary time. Let us begin with the first part of the timeline, being under the Manchu rule from 1691, pasture lands were controlled through administrative units known as a “khoshuu”; the privilege to govern over such units was primarily granted to hereditary nobility, and in some cases to Buddhist monasteries (Fernández-Giménez, 1999). The units were powerful enough to control access to pastures under their governance and command over the serfs who were living there (Fernández-Giménez, 1999). The colonial regulation of 1789 made it impossible to leave beyond the “natal khoshuu” or the “khoshuu” where the person was born, for the commoners and nobles, heavily restricting the mobility between “khoshuu” units (Fernández-Giménez, 1999). Although there was a dual management system that involved both formal and informal regulatory institutions, the discrimination among pastoralists was evident, where the ones who were the better-off or wealthier always got the better-quality pastures, leaving the poor ones far behind during drought (Fernández-Giménez, 1999).

The early communist period, which was followed by the revolution in 1921, was marked by the demolition of the feudal regime, where the feudal estates (fixed property and herds) were confiscated, destroying the Buddhist clergy, and the nobility lost all their feudal privileges (Worden & Savada, 1989). The first attempt at collectivization failed with the civil war in 1932, where the herders were unhappy with the new regulations, and essentially, the collectivization became gradual due to the losses in livestock and the widespread resistance (Linden, 2022). The process involved promoting voluntary cooperatives (khorshoo) and state farms, and while private livestock owners dominated in the region with a 98.3 percent share of total livestock, the state was able to increase its influence by increasing taxes for the people outside of “khorshoo” and supplying cooperatives with vital goods (Worden & Savada, 1989).

After the attempts of the state to increase its authority, using incentives and pressure, collectivization took another turn (Linden, 2022). The government accomplished its initial plan, where the number of cooperatives doubled from 139 to 354, and the collectivization of agriculture was finished by the 1960s (Worden &

Savada, 1989). This period is also known as a collectivization period. Herders working in the cooperatives became state workers with salaries and vacations included, where herders had specific expertise in tending a different type of communal livestock, though private herding was still permitted. While investment toward infrastructure, such as shelters, wells, hay stations, transportation, and veterinary service, was provided by the state, the administration of negdels had a rigid control over seasonal movements called “otor” and pasture allocation (Fernández-Giménez, 1999).

Mongolian Socialism officially came to an end in 1990 during the collapse of the Soviet Union, and it meant a change from the old governance to a democratic one. This transition was accompanied by the dissolution of the cooperatives and livestock privatization, though pastures were left as state property, and a management vacuum occurred (Fernández-Giménez, 1999; Linden, 2022). In this period, there was a sharp rise in livestock numbers, especially goats, due to the demand in the cashmere market (Himmelsbach, 2012). A lack of transportation led to the reduction of herder mobility, where poorer Mongolians were mainly affected, and issues like high rates of trespassing, out-of-season grazing, livestock concentration near roads, and towns poured oil into the fire, aggravating grazing rates (Fernández-Giménez, 1999). In order to regulate nomadic pastoralism, a law was enacted in 1994 and revised in 2002. The law introduced allocation rights for winter campsites usage and distributed management rights for the local sum and bag authorities, but due to the flawed implementation and lack of budget, it had little impact on pastoralism (Himmelsbach, 2012). By the 2000s, international donor agencies introduced community-based natural resource management, where 2000 herder groups (nöhörlöl) were created in 19 aimags (provincial level administrative unit), each such group went through training where people were taught about the negative consequences of spatial livestock concentration and overgrazing. To support this initiative, the pasture draft law was introduced to provide possession of winter/spring pastures, creating legal status for the herder groups (Himmelsbach, 2012). However, despite the efforts, there are some issues: contribution to the social segmentation that leads to the exclusion of some herders from the pasture, and a hard time with nationwide implementation of the system alongside the persistent problems like overgrazing and the impact of climate change (Tuvshintogtokh & Ariungerel, 2013).

2.2 Economic Importance of the Livestock Sector

Livestock pastoral production is considered to be one of the main pillars of the Mongolian economy, where rural livelihood depends on it. Semi-nomadic Herders graze their animals around pasture lands during spring, summer, and fall, returning to the protected camps in the winter season. The sheep and goats are popular livestock among pastoralists, followed by cattle, horses, yaks, and camels (Gao et al., 2015). Cold and arid environments are the traditional livelihoods of the Mongolian rural population, but it is endangered by climate hazards such as drought and dzuds, a Mongolian word that describes severe winter conditions (Nandintsetseg et al., 2018).

Despite the challenges related to the decline of rangeland productivity in livestock grazing by 20-30% due to climate hazards throughout Mongolia, pastoralism remains in its place as a fundamental part of the Mongolian economy and culture, where about 70% of the land is considered to be rangeland, employing up to 40% Mongolians from the total population and holding 20.6% of the country's gross national product (Bruegger et al., 2014). Most notably, although Mongolia relies on animals and animal products, and – to a lesser extent – tourism, mining provides 83.7 percent of the country's export, which makes it dependent on the non-renewable resource, and this notion is reflected in the country's environmental policies. To protect nature, especially pastures which are the central common resource that supports pastoralism development, special environmental organizations were created, and one of them is Oyu Tolgoi Watch. This organization collaborated with herders, instructing them on the international environmental standards and human rights issues (Rossabi, 2021).

About 4.4 trillion Mongolian tugrik (MNT) or 1.7 billion American dollars (USD) was produced by livestock husbandry in 2018 (Ulziibaatar & Matsui, 2021). Moreover, this sector employs 288,700 herders and contributes 642.9 million USD or 9.2% to export income (Ulziibaatar & Matsui, 2021). Two-thirds of households earn income from livestock or other agricultural activities, and 40% of rural income comes from these sectors (Haile et al., 2022). The agricultural sector had been a dominant part of the Mongolian economy, as evidenced by the rank that the sector held from the second to the third place in the industry ranking for the last two decades (Gombodorj & Pető, 2022). There is one crucial fact that needs to be understood: a big part of the Mongolian agriculture is the livestock industry, which accounts for 90 percent of the total share. Therefore, Animal husbandry is the social fabric of the nation, where it employs 1 out of 4 Mongolians. Nevertheless, this relationship between people and the industry creates a strong dependence of the entire rural population on the weather shocks, since weather conditions can dictate household income and influence pasture (Dept, 2019).

Mongolia is one of the few countries with a profound nomadic history that is mirrored in its pastoral culture, supported by the vast rangelands. The country is well known for its sustainable, rangeland-based goods that can be offered not only to Mongolian citizens but also to global consumers who value sustainable goods as a premium (Densambuu et al., 2018). The main issue of sustainable livestock production that has been present for many years is the decline of rangeland health, which is the set of environmental conditions that keeps the productivity and biodiversity of pasturelands (Densambuu et al., 2018).

2.3 Current Pasture Management Practices and Degradation Challenges

Mongolia is a country between China and Russia, located in Central Asia, with a total area of 1,566,600 square kilometers. The territory is composed of vast steppes, mountain ranges, and arid areas, including the Gobi Desert (Densambuu et al., 2018). Such geography creates a place for the nomadic lifestyle, where five commonly spread animal species are raised, also known as the "five animals" (tavan khoshuu mal), such as sheep, goats, cattle, horses, and camels. And about 70% of all the land is allocated for livestock grazing purposes. However, despite the vast land size, the population density is relatively low, about 3.3 million citizens. Combining low population density and large land size, primarily for pasture uses, creates an opportunity for extensive livestock grazing. Nevertheless, this causes many disadvantages to the grazing land; for example, according to the study, 57 percent of monitoring sites were considered to be altered because of degradation and climate change in Mongolia (Densambuu et al., 2018).

Additionally, according to recent studies, due to widespread vegetation decline across the steppe, about 70% of the land is considered to be degraded (Hilker et al., 2014). Climate change that resulted in harsh ecological conditions particularly contributed to the significant losses for herders, such as 5.9 million livestock deaths, which is about 9% of the total amount, affecting almost 90% of the country in 2023-2024. Moreover, this event, notably "dzud", comes with extreme temperatures dropping to minus 30°C or even lower with strong winds, heavy snow, and ice during winter (WHO, [World Health Organization], 2024). More than that, exacerbation by a hotter summer season destabilizes pasture lands' health and livestock survival, creating a threatening situation for sustainable herder practices (IMF [International Monetary Fund], 2019).

The pasture land covers about 96 percent of the agricultural land and bout 70 to 80 percent of the country's area (Bruegger et al., 2014; Haile et al., 2022). However, the traditional pastoral system suffered significant shifts due to the overuse and degradation of resources, explained by an increase in livestock numbers (Nakayama, 2025). This rapid increase has been traced since 1990, when the special announcement was made that "grasslands and pastures are owned by the people" and "national freedom" in choosing a place of residence, which became one of the main drivers of livestock increase in Mongolia (You et al., 2024). The total population of livestock increased over the past ten years by almost 2.6 times from 1990 to 2018, and from the mid-2010s to 2019, the number has doubled from 33.1 million to 71.8 million (Haile et al., 2022; Sanzheev et al., 2020). This is key evidence that the livestock sector primarily grew due to the increasing animal numbers (Haile et al., 2022). The livestock population structure changed substantially due to the privatization and development of the export cashmere wool market, shifting from subsistence to a market economy, where the share of the goat population nearly doubled from 19.8% in 1990 to 40.8% in 2018 (Michler et al., 2024; Sanzheev et al., 2020). A high demand for goat hair and cashmere products significantly reshaped the sector structure (Sanzheev et al., 2020).

Such structural changes in the proportions of different types of livestock have a tremendous environmental impact on the grassland (You et al., 2024). Where a surge in the stock of goats reached the same number as sheep (You et al., 2024). An increasing number of sheep and goats combined can pose a threat to the environmental carrying capacity since the grassland is eaten by these animals takes a longer time to recover, exacerbating the problem of degradation that leads to desertification (You et al., 2024). Carrying capacity is the maximum number of animals that can be supported by the pastureland without degradation (Wang et al., 2024). As a result of socio-economic changes, privatization led to the number of livestock exceeding the carrying capacity in many Mongolian rangelands, and herd sizes are further increasing (Sainnemekh, Barrio, et al., 2022; World Bank Group, 2024).

Traditionally, overgrazing and overloading of livestock are considered to be the primary drivers of rangeland degradation, while an increasing number of studies have challenged this view (Sainnemekh, Barrio, et al., 2022; You et al., 2024). Desertification is another driver of degradation, which is amplified by climate change (Nyamtseren et al., 2025). Due to factors like overgrazing, land-use, and climate change, the environmental and economic stability of Mongolia's vast grassland is facing challenges, resulting in reduced vegetation cover, soil erosion, and decreased fertility (Wang et al., 2024). Long-term viability of the pastoral economy is threatened by the rising livestock numbers that put pressure on fragile pasture lands (Michler et al., 2024). This pressure creates overgrazing, resulting in vegetation cover degradation that reduces the number of plant species (Sanzheev et al., 2020). So, on the one hand, temperature and precipitation changes, and on the other hand, anthropogenic factors could be considered jointly as the leading causes of land degradation due to increasing herd sizes, climate change, and a shift in herd structures (Sanzheev et al., 2020). Since the vegetation cover is affected by the different degradation rates, its classification is inherently linked to grazing pressure. Speaking of specifics, heavily grazed pastures considered to be degraded contain less grass and more unpalatable plants like Artemisia that are degradation indicators (Sainnemekh, Barrio, et al., 2022). In terms of numbers, due to overgrazing that resulted in pasture degradation, the fodder yield decreased by 30 percent from 284 kg/ha in 2011 to 198 kg/ha in 2020 (Haile et al., 2022). Furthermore, as a consequence of desertification, the following outcomes can be listed: pasture deficits; a reduction in plant species and pastureland quality; a reduction in water volumes for drinking, domestic, and livestock watering; an increase in mobility, etc (Sanzheev et al., 2020).

After the privatization of livestock, there were no effective changes in property rights with respect to grasslands, resulting in unplanned grassland use, which plays a role in exacerbating desertification (You et al., 2024). Negative changes occurred in the natural pasture ecosystem due to changes in herd sizes and livestock overstocking in a limited area near a water supply over a long period (Sanzheev et al., 2020). Bad livestock management resulted in inadequate winter herding practices and overgrazing, leading to degradation (Haile et al., 2022). Biodiversity conservation and wildlife guarding in protected areas are under pressure because these places are often considered as emergency pastures during droughts and harsh winter conditions, posing an additional threat to the sensitive ecosystem when resources are already scarce (Michler et al., 2024). The current high number of livestock poses a risk not only to pasture productivity and biodiversity but also to nomadic pastoralist communities that depend on these very rangelands (Michler et al., 2024). Furthermore, it creates vulnerabilities to extreme climate for herding communities (Michler et al., 2024).

In response, an impactful policy measure was implemented and included sustainable herding practices through rotational grazing systems, imposing restrictions on overgrazing in sensitive areas (Nyamtseren et al., 2025). And identifying regions that could benefit from the interventions, such as pasture rotation, adoption of sustainable grazing practices, or livestock regulation, is crucial for the long-term sustainability and the livelihood of herding communities they support (Wang et al., 2024).

3 Literature Review

3.1 Theories of Common-Pool Resource Management

"The tragedy of the commons" has become an equivalent expression for symbolizing a degradation (Ostrom, 1990). Due to the rational nature of herders, each pastoralist seeks to maximize their gain, keeping as many cattle as possible (Hardin, 1968). According to Hardin's model, which is usually formalized as a prisoner's dilemma, where each player tries to defect no matter what the other player chooses, with the best dominant strategy, and when they both choose the dominant strategy, they produce an equilibrium that is the third-best outcome (Ostrom, 1990). But this creates a paradox, where individually rational decisions lead to collectively irrational results, defying the belief that rationality can give birth to rational outcomes (Ostrom, 1990).

Common-pool resources (CPRs) are rival, non-exclusive, scarce goods due to slow replacement rates (Himmelsbach, 2012). The existence of a common-pool resource is defined by the presence of natural resources and human facilities, where excluding users is complex and highly expensive, and consumption by one reduces benefits for others (Fernandez-Gimenez, 2000; Ostrom, 2016).

Hardin's call for the privatization or public regulation of common-pool resources to fully internalize the resource cost carried by the users has shaped the natural resource management policies, especially in developing countries (Himmelsbach, 2012). In general, there are two schools of thought on which system is more suitable for managing the commons to avoid tragedy: the first recommends that the central government should control most common resources, and the other claims that the only viable option is to establish a common-property system of private property rights (Ostrom, 1990). However, both privatization and centralization advocates agreed on the tenet that institutional change should come externally and be imposed individually (Ostrom, 1990).

The observation suggests that neither the state nor the market is uniformly effective in sustaining the long-term use of the natural resource system by users (Ostrom, 1990). Based on the evidence, it is undeniable that due to problems like corruption and inefficiency, central governance frequently exacerbates resource depletion and deterioration (Ostrom, 2016). The consequence of nationalizing the ownership of forests in third-world countries was the creation of open-access resources, where limited access to common resources had already existed. This action was justified by the idea that villagers cannot manage the common-pool resource (Ostrom, 1990). Multiple studies confirmed that a community-based management system is capable of overcoming social dilemmas to craft rules and govern resources (Ostrom, 2016). Ostrom’s work has shifted the understanding of common-pool resource management, defining a new alternative as a community-based approach that does not necessarily lead to the tragedy of the commons (Himmelsbach, 2012).

Common property theorists have suggested that shared beliefs and preferences, meaning beliefs which stipulate that users will be harmed if a mutual agreement on resource use is not reached, are one of the primary criteria that determine the successful implementation of the development of common property resource management institutions (Fernandez-Gimenez, 2000). The likelihood of successful establishment of institutions to manage common resources ruled by communities is higher when factors such as a low discount rate, homogeneous interest, low cost of communication, and low cost of reaching enforceable agreements are present (Ostrom, 2016). From the Ostrom perspective, collective action difficulties can be overcome if the users and the resource system are clearly defined, non-group members are excluded from resource allocation, and the shared rules on appropriation norms are followed with checked compliance (Himmelsbach, 2012).

Natural resource management is conceptualized as a governance that goes beyond governmental ruling, where the different forms of vertical and horizontal cooperation between the state and stakeholders are possible (Himmelsbach, 2012). In other words, this is called “co-management”; this type of natural resource management is not just a one-time institutional structure, but rather a process (Himmelsbach, 2012). The inclusion of shareholders will facilitate better information sharing, which is suitable for common-pool resource governance, and allow for creating better appropriation rules to comply with local norms linked to environmental protection (Himmelsbach, 2012).

3.2 Rangeland Ecology: Carrying Capacity, Grazing Rates, and Degradation Indicators

Pasture degradation poses a risk to the natural ecosystem functioning, but its definition is still an arguable question (Sainnemekh, Barrio, et al., 2022). The controversy exists because there is no standard definition of rangeland degradation, although it is frequently assessed as a change in vegetation cover. Moreover, only a few studies have determined different levels of degradation (Sainnemekh, Barrio, et al., 2022). Nevertheless, the bad rangeland health is the primary hindrance to sustainable livestock husbandry (Densambuu et al., 2018). One obvious symptom of rangeland health decline is a shift toward more grazing-tolerant plants and a reduction in valuable forage species (Densambuu et al., 2018).

Pasture carrying capacity (PCC) or carrying capacity (CC) is one of the important indicators when it comes to pasture health assessment; it is defined as the maximum number of livestock the land can bear without risking density-related mortality of husbandry animals and environmental degradation (Nandintsetseg et al., 2018; Wang et al., 2024). Between 2000 and 2019, the average annual capacity in Mongolia was 0.93 sheep units (SU) per hectare. However, due to the livestock masses moving from southern to northern Mongolia, carrying capacity in northern Mongolia has reached its maximum of 2.8 sheep units per hectare, while a decline in CC has appeared in southern regions, reaching as low as 0.3 sheep units per hectare (Wang et al., 2024). Estimation of average forage yield (AFY) is one of the important steps to address pasture carrying capacity, being represented as an edible part of the total biomass, it is affected by multiple variables like weather conditions, soil attributes, plant species composition, and management methodologies (Wang et al., 2024). Pasture carrying capacity can be determined by dividing the edible share of biomass by the product of the grazing period and the livestock's daily intake (Nandintsetseg et al., 2018). Similarly, other studies show the akin calculation of carrying capacity, where to get the CC, one divides the total forage by the forage consumption requirements (Wang et al., 2024).

The relation between carrying capacity and the grazing rate is fundamental because the ratio of the actual livestock number against the pasture carrying capacity (PCC) is used to determine the livestock grazing rate (LGR) (Nandintsetseg et al., 2018). Respectively in other studies, there is a stocking rate (SR) that represents livestock units per unit area (e.g., livestock units/ha), and the ratio between the stocking rate (SR) and the carrying capacity (CC) determines the degree of the grazing pressure called relative stocking density (RSD) (Wang et al., 2024). In general, the indicator of grazing pressure is also defined as a percent use (PU), representing the ratio between forage demand and forage supply (Gao et al., 2015). To shed light on the livestock unit, which is an important variable in calculating grazing pressure indicators, I shall present conversion rates of sheep units (SU): one horse = 7 SU, one camel = 5 SU, one cattle = 6 SU, one sheep = 1 SU, and one goat = 0.9 SU (Nandintsetseg et al., 2018). The difference between the actual number of livestock and the pasture carrying capacity (PCC) results in what is called "overgrazing", when the requirements of livestock are not met with the capacity of the land, it leads to degradation of vegetation cover, erosion, and compaction of soil (Nandintsetseg et al., 2018). There is a certain threshold of grazing pressure rate; a value close to one suggests sustainable use of the grassland, and vice versa, values above one suggest overgrazing, leading to grassland degradation (Wang et al., 2024).

Leading indicators of degradation identified by the herders are decreasing livestock production, increasing bare ground, the presence of less desirable or non-nutritious plant species, and declining species richness (Bruegger et al., 2014). Based on 2016 monitoring data taken from sites in Mongolia, 13.5% of the land was slightly degraded, 21.1% moderately degraded, 12.8% heavily degraded, and 10.3% thoroughly degraded. (Densambuu et al., 2018). In most cases, grazing and climate (temperature and precipitation) are frequently indicated as the primary drivers of overgrazing (Sainnemekh, Barrio, et al., 2022). Precipitation changes can explain about 30% of rangeland degradation in whole Mongolia, but in areas with denser vegetation cover, this number can get up to 50% (Hilker et al., 2014). Nevertheless, according to the results, the primary contribution to degradation is made by the overgrazing, and it is partially responsible for desertification (Hilker et al., 2014). In combination with climate hazard and overgrazing, high livestock mortality appeared in areas characterized by moderately to heavily overgrazed pastures, suggesting that harsh winter conditions like dzud can exacerbate herders' situation (Nandintsetseg et al., 2018).

3.3 Sustainable Pasture Management Strategies in Mongolia

The management of natural resources is under constant threat due to soil erosion and pastureland degradation in Mongolia (Sainnemekh, Densambuu, et al., 2022). Since the demand for accessible and productive land is increasing, new ways of understanding the pastureland ecosystem to preserve rangeland health are needed (Sainnemekh, Densambuu, et al., 2022; Sutton et al., 2016). In response, after joining the Partnership for Action on Green Economy in 2013, Mongolia created the Green Development Policy (GDeP), where its primary goals were protecting the sustainability of ecosystem services, enhancing the performance of natural resources consumption, and ensuring sustainable economic growth (Haile et al., 2022).

Some of the strategies for pastoral management involve local communities' participation and utilize their traditional herding practices. To fill the managerial void, the last decade has brought a lot of international donor projects to Mongolia, where herder groups engaged in management capacity building (Himmelsbach, 2012). Other initiatives aimed at addressing the vulnerability of rural households, developing and enhancing local property institutions and supervision mechanisms, such as "rule of the steppe" with the combination of nomadic herders' wisdom and insights from the work of Nobel Prize winner Elinor Ostrom (United Nations, 2011). A recent social science study showed that groups often evolve in resource appropriation and conservation rules, limiting excessive exploitation (Kennedy, 2003). They revised Hardin's "hard choice", where coercive consensus that limits excessive utilization of resources, or repressive governance to manage the utilization, takes place (Kennedy, 2003). Furthermore, some researchers argue that mobile pastoralism, which is a vital aspect of animal herding, is, in fact, environmentally friendly since it allows the biomass to recover and can be considered a more sustainable herding strategy (Gonchigsumlaa & Damdindorj, 2021). From the herder's perspective, specifically pastoralists from mountainous and forest steppe regions have indicated that factors contributing to rangeland health are keeping the livestock in pasture carrying capacity, letting the pastures regrow and recover with resting and rotation, and decent periodical rainfalls (Jamsranjav et al., 2019). Interestingly, herders from the steppe have indicated similar factors as: regular rainfall, not exceeding the carrying capacity of pastures, and frequent herd movement (Jamsranjav et al., 2019). Either way, it was found that mobility is also beneficial for herders in terms of profit (Gonchigsumlaa & Damdindorj, 2021). Another potential herding approach that addresses degradation is to promote participatory monitoring where the community is involved in rangeland management, blending herders' and scientists' knowledge (Jamsranjav et al., 2019). It involves various stakeholders in terms of different interests and different levels of conducting and designing the monitoring of pastures (Jamsranjav et al., 2019).

Besides the community-based approach for pastoral management, there are more structured management systems. Since the primary driver of rangeland ecosystem degradation is growing herds, more rigorous approaches for herd management are required to reduce grazing pressure (World Bank Group, 2024). Notably, livestock number control is the precondition for effective pastureland management (Dept, 2019). Moreover, key strategic insights from the paper are as follows: precise calibration of stocking rates to prevent overgrazing, a flexible management system that can adapt to changing environmental conditions, integration of nomadic knowledge, continuous monitoring, and a multi-disciplinary approach to enhance the grazing system (Wang et al., 2024). Another possible strategy to address environmental degradation is to create a legal environment for safeguarding pasture usage and development (Haile et al., 2022). A promising ecosystem management approach called the application of State and Transition Models (STMs), which helps to understand mechanisms behind degradation and can suggest suitable actions for preserving the health or restoring degraded pasturelands (Sainnemekh, Densambuu, et al., 2022). The research shows that STMs are practical tools for analyzing rangeland health monitoring data and providing a scientific basis for planning and implementing rangeland management (Sainnemekh, Densambuu, et al., 2022).

The state intervention in terms of a better resource management approach may also be remarkable in addressing problems of desertification, pastoral land degradation, decreasing fodder availability, water resource depletion, and environmental pollution (Haile et al., 2022). This action will require a reorientation of subsidies for better herders' incentives, like the adoption of sustainable practices, including strengthening herd health management, limited and controlled grazing, livestock waste management, and tree-based fodder production (Haile et al., 2022).

However, there are challenges in implementing any management strategy. It should be noted that common resources may fail the implementation stage of management practices due to high transaction costs and political and economic interventions on a large scale (Kennedy, 2003). When implementing the management strategy, there is a trade-off between system flexibility for the local peculiarities and the transaction cost of establishing such a system, depending on the scale (Kennedy, 2003; Wang et al., 2024). As Kennedy (2003) stated, it is our turn to answer the question: whether science can prevail over economic, political, and social hindrances, the same question that was posed decades ago by Hardin. Thus, better managerial frameworks are required to: quantify the scale of the problem, calculate the cost of business-as-usual (BAU), and evaluate the cost and benefits of restoration (Sutton et al., 2016).

4 Methodology

This chapter will address the framework for environmental degradation assessment. For this purpose, a particular study region will be chosen, and environmental indicators like pasture carrying capacity and livestock grazing rate will be incorporated into a cost-benefit analysis.

During my study as an exchange student at Humboldt University of Berlin, I established successful cooperation with the "MORE STEP" project. It is a collaborative and interdisciplinary research project of Mongolian and German partners funded by the German Ministry of Research, focusing on the tipping points of the Mongolian steppe. The primary goals of the projects are to understand how climate change in the future and in the present time affects or may affect vital aspects of pasture lands, such as fodder availability, mobility, and diversity of wildlife and livestock (*MORE STEP - Home*, n.d.). In my research, I have acquired access to the empirical data, such as remote sensing biomass data and information on herders and their livestock, in my study area.

In this research, I will follow the environmental degradation assessment framework for pasture degradation assessment and employ cost-benefit analysis (CBA) (Sutton et al., 2016). The methodology will consist of four main parts: (1) I will quantify livestock grazing rate (LGR) and pasture carrying capacity (PCC) for each pasture unit, (2) I will calculate NPV (net present value) using cost-benefit analysis for the business as usual scenario, (3) also I will calculate NPV for the case when grazing pressure is evenly distributed across pastures let us call it "sustainable management (relocation) scenario", (4) in the last part I will compare the results of different scenarios accounting for the costs and benefits incurred in each case to conduct a CBA (Sutton et al., 2016). The framework will help us to better understand the outcome of complex management approaches and provide sophisticated results utilizing the corresponding data.

Pasture carrying capacity and livestock grazing rate will be utilized in the CBA, and the importance of CBA and its application in the scenarios will be discussed.

Furthermore, I will explore the information technology (IT) solutions and the role of contemporary management systems in shared resource governance.

4.1 Case Study Selection: Bayantsagaan, Mongolia

The Bayantsagaan region was chosen as a study area where, in total, 258 households are situated (calculated from the dataset), with 229 pasture units and a cumulative area of 6474 km², while being the third-largest steppe in the province. Several key characteristics, data availability, and relevance to the research question were the reasons for picking this place as a case study region. Here I have the justification criteria listed:

1) Geographically, this region represents the most widespread type of land, located in the central steppe of Mongolia, where 70% of the country's territory consists of the pastures, and using the region as a case will allow us to examine challenges for similar rangelands (Baival & Fernández-Giménez, 2012; Bruegger et al., 2014).
2) Due to climate change and degradation, pastoralists are under threat from harsh climate vulnerabilities, leading to a high death toll among livestock (Gao et al., 2015). Moreover, a big part of the Mongolian agriculture is livestock production and employs up to 40% or 1 out of 4 of the population. Analysis of various management scenarios addressing stocking rates is highly relevant (Bruegger et al., 2014; Dept, 2019).
3) Bayantsagaan is primarily dominated by the goats and sheep, exhibiting pastoral system characteristics, which is an important part of the culture since ancient times (Baivaland & Fernández-Giménez, 2012; Bruegger et al., 2014).
4) Mobility is the key aspect of pasture management strategy and a significant part of pastoralism. Furthermore, it is very relevant to examine relocation strategies, since prior studies showed interest in the mobility patterns and economics in the Bayantsagaan region (Gonchigsumlaa & Damdindorj, 2021; Jargalsaikhan et al., 2015).
5) The Last but not least important factor that contributed to the decision to choose the region as a case study was the availability of the data collected by the "MORE STEP" research project.

Therefore, choosing the Bayantsagaan region is not arbitrary but based on the relevance of the degradation issue in Mongolia, data availability, and the importance of rangelands for a significant part of the Mongolian economy: livestock production.

Figure 1. Bayantsagaan
Source: “MORE STEPS”

4.2 Incorporating Pasture Carrying Capacity and Livestock Grazing Rate

The pasture carrying capacity (PCC) and livestock grazing rate (LGR) are important parts of the rangeland degradation assessment. There is a high demand for pasture health monitoring due to a decline in vegetation cover and a rise in overall degradation in Mongolia, and these indicators can spot abnormalities in pasture usage, like overgrazing (Hilker et al., 2014; Nandintsetseg et al., 2018).

Let us first tackle pasture carrying capacity. To be precise, this indicator defines the maximum number of cattle that can be supported by the pasture without overgrazing threat and density-dependent livestock mortality (Nandintsetseg et al., 2018; Wang et al., 2024). The concept is accepted worldwide and is known for the range management assessment of natural resource use (Nandintsetseg et al., 2018). Both the pasture carrying capacity and the livestock grazing rate formulas are taken from (Nandintsetseg et al., 2018).

The formula used for pasture carrying capacity (PCC) (Nandintsetseg et al., 2018):

$$PCC = \frac{Y_1 S}{Y_2 D} \quad 4.1$$

Where:

1) PCC – Pasture carrying capacity (SU). To convert sheep units (SU), the study uses: one camel = 5 SU, one goat = 0.9 SU, one sheep = 1 SU, one camel = 5 SU, one horse = 7 SU, one cattle = 6 SU.
2) Y_1 – Summer forage production (kg/ha), in other words, is an edible share of biomass.
3) Y_2 – Livestock daily intake (kg/day), the value varying between 2.5 and 3% depending on body weight, in the literature, is defined as $Y_2 = 1.4\frac{kg}{day}$ (Nandintsetseg et al., 2018).
4) D – Grazing time (90.5 days determined from the "MORE STEP" data for the summer season).

The most important part of the environmental assessment is to figure out the stocking rates of pastures, and the livestock grazing rate is the best indicator for it. It is defined by the relation of the actual livestock number to the ecological pasture carrying capacity (4.1), based on the forage availability, which shows the relative grazing pressure on a pasture.

The formula for LGR is:

$$LGR = \left(\frac{N}{PCC}\right) * 100\% \quad 4.2$$

Where:

1) LGR – A pasture's grazing rate (%).
2) N – Total livestock population at the pasture unit in sheep units (SU).

3) PCC – Pasture carrying capacity of the pasture unit in sheep units (SU).

In order to interpret the livestock grazing rate, I can use the following interpretation, since this value indicates the degree of grazing pressure (Nandintsetseg et al., 2018):

1) Over-sufficient pasture: $LGR \leq 50$ (pasture reserve).
2) Sufficient pasture: $LGR = 50.1\ to\ 100$.
3) Overgrazed: $LGR = 100.1\ to\ 300$.
4) Moderately overgrazed: $LGR = 300.1\ to\ 500$.
5) Heavily overgrazed: $LGR \geq 500.1$.

Akin indicators are shown in different studies that have similar implications; for example, studies show that stocking rates above one indicate overgrazing, which leads to permanent vegetation cover deterioration, soil erosion, and decreased fertility (Wang et al., 2024). It is a valuable tool to mitigate the outcomes of pasture degradation via monitoring for the herders and managers (Wang et al., 2024).

In Mongolia, it was found that herders who kept their livestock below the pasture carrying capacity in the 2009/2010 "dzud" incident did not experience a significant number of livestock deaths compared to herders who did not follow this recommendation, which can be additional evidence that highlights the importance of the livestock grazing rate indicator (Nandintsetseg et al., 2018).

4.3 Cost-Benefit Analysis Framework

Benefit-cost analysis (BCA) and cost-benefit analysis (CBA) are referred to as similar terms, and are mainly an accounting framework that provides a consistent procedure to assess the financial consequences of decisions (Dreze & Stern, 1987; Zerbe & Scott, 2015). Other sources refer to CBA as an economic estimation of projects that aim to improve the delivery of environmental services or actions that might affect the environment, and also measuring a project's societal value that makes costs and benefits comparable in monetary terms by quantifying the societal effect (Atkinson & Mourato, 2008; Koopmans & Mouter, 2020). Others state that the purpose of CBA is to increase public welfare, not profit (Zerbe & Scott, 2015). In these terms, concerning the thesis's objectives and research questions, I am trying to measure the economic effect of the overgrazing on the costs and benefits of herders and the study region of Bayantsagaan by utilizing cost-benefit analysis. Specifically, I compare the cost-benefits in two different scenarios (i.e., business-as-usual scenario, and scenario with higher herders' mobility).

The basic steps in cost-benefit analysis, according to the study, are as follows: (Zerbe & Scott, 2015):

1) Definition of the scope and cost-benefit analysis assumptions.
2) Determining the outcomes and cost-benefit evaluations for each alternative.
3) A discount rate selection (interest rate) and the present value calculations of costs and benefits.
4) Measure selection for the alternatives' comparison and necessary calculation execution.
5) Risk and uncertainty discussion.

The first step of the scope and assumptions definition requires the designation of the perspective in which the analysis is being conducted, and the identification of the costs and benefits of actors with economic standing, clearly stating the problem (Zerbe & Scott, 2015). After identifying the perspective, problem definition, costs, and benefits, the next step is to determine the period of the analysis (Zerbe & Scott, 2015). The specification of the baseline is the last step after the scope setting. The baseline should account for the state where the case calculation without the presence of the project, problem, or factor is assessed, serving as a tool for comparison of costs and benefits against the case where this presence exists (Zerbe & Scott, 2015).

The next step is identifying and quantifying the costs and benefits (Zerbe & Scott, 2015). To do so, I need to determine the policies and the policies' outcomes; in my case, the policies are different scenario settings. The costs and benefits must be held in monetary units; if not, conversion to that unit is required (Zerbe & Scott, 2015). The reason is simple: I need to ensure comparability between alternative cases. The flow of cost-benefits needs to be defined for the analysis period for each alternative scenario. But when the market relation is present between goods and services, it is comparatively easier to employ them in CBA (Zerbe & Scott, 2015). Otherwise, if the benefits and costs are non-market related, I need to convert them to monetary units whenever possible (Zerbe & Scott, 2015). However, the valuation of the non-market goods can be complicated, and the prices of such goods with non-market behaviour are called “shadow prices” (Zerbe & Scott, 2015).

Cost-benefit analysis evaluates a project's monetary flows that occur at the outset and in the future (Zerbe & Scott, 2015). For example, a project with a high initial cost may turn out to be very profitable, and vice versa. There is also another factor that needs to be accounted for, and that is the time value of money, e.g., $100 today is not the same as $100 one year from now, and thus the cash flow each year needs to be discounted to the respective present value (Zerbe & Scott, 2015).

The present value is the future discounted amount of cash flow that an investor would get if money were invested today (Zerbe & Scott, 2015):

$$PV = \sum_{t=0}^{N} \frac{F_t}{(1+r)^t} \tag{4.3}$$

Where:

1) F_t – Net cash flow at time t.
2) r – Discount rate.
3) N – The number of future years is included in the analysis.

According to Zerbe and Scott (2015), all the monetary amounts must be comparable with each other, all in a constant monetary unit, or all in a nominal one. Constant or real monetary unit takes inflation into account. However, it is recommended to use real monetary value rather than nominal because of the inflation strategy used to get values (Zerbe & Scott, 2015). For example, 10% of the nominal rate is adjusted to the expected inflation rate, or in simple terms, it is the lender’s guess about future inflation. If the real inflation rate ends up being high or low from the expected number, it may affect the gain value, making it volatile (Zerbe & Scott, 2015). On the other hand, real value is calculated without expected inflation adjusted to the discount rate, making it better in terms of transparency and stability, but worse for the real-world scenario without the inflation factor (Zerbe & Scott, 2015). So, the conclusion is to use a monetary unit with the nominal discount rate, where the expected inflation rate is employed as an adjustment. Talking about the discount rate, it has a formidable effect on the evaluation of projects, which can determine their worth, so choosing the discount rate is an essential step in the analysis (Zerbe & Scott, 2015).

The time horizon and the discount were chosen according to the papers' recommendation for developing countries, where a 10 percent discount rate and 25 years as an analysis period were selected (Clark, 1996; Nkonya et al., 2011). To summarize all the cash flows that are discounted, bringing them into comparison, I can utilize the net present value metric (NPV) (Zerbe & Scott, 2015). The NPV is the present value of benefits minus the present value of costs. An investment is said to pass the cost-benefit analysis check, making it financially desirable if the NPV value is greater than zero (Zerbe & Scott, 2015).

Let us define my NPV formula with the designated parameters, like the discount rate and the time horizon (10% and 25 years, respectively):

$$NPV = \sum_{t=0}^{25} \frac{Benefit_t - Cost_t}{(1+0.1)^t} \tag{4.4}$$

Where:

1) $Benefit_t$ – Present value of benefits at period t.
2) $Cost_t$ – Present value of costs at period t.
3) r – Discount rate (10%).
4) N – Time horizon of the analysis (25 years).

Since the decision to use nominal evaluation with the expected inflation has been made, I will adjust new terms to calculate benefits and costs:

$$Benefit_t = Benefit_{t-1} * (1 + average\ food\ inflation\ rate) \tag{4.5}$$

$$Cost_t = Cost_{t-1} * (1 + average\ general\ inflation\ rate) \tag{4.6}$$

Where:

1) $average\ food\ inflation\ rate$ – 9.53% (FAOSTAT)
2) $average\ general\ inflation\ rate$ – 8.39% (World Bank)

According to the study, farm input prices have exhibited a dynamic different from general inflation, but some inputs, like hay costs, have shown the same or lower level of price change with respect to the overall inflation rate (Langemeier, 2023). From this, one can conclude that different inputs have different dynamics, sometimes being overrated compared to the general inflation rate. Thus, using various inflation rates to adjust for cost or benefit calculation is justified. Such an adjustment will allow us to avoid missing the fundamental relation between the distinct supply and demand of inputs (Langemeier, 2023).

Besides NPV, there are metrics like benefit-cost ratio (B/C) and internal rate of return (IRR) that can be used as a judgmental point to determine whether the project or case is good or bad in terms of investment and efficiency (Zerbe & Scott, 2015). The benefit-cost ratio is determined by the relation of two monetary values, as its name suggests. Generally, this metric has to be more than one for the scenario to be accepted financially (Zerbe & Scott, 2015). Furthermore, the internal rate of return represents the efficiency of the project; it should be greater than the opportunity cost for acceptance. In technical terms, the internal rate of return is the discount rate at which NPV equals zero (Zerbe & Scott, 2015). So, using these metrics can provide us with some insights and give us more space for the comparison of alternative scenarios (Zerbe & Scott, 2015).

Let us define the benefit-cost ratio and the internal rate of return mathematically:

$$Benefit\ Cost\ Ratio = \frac{\sum_{t=0}^{N} \frac{Benefit_t}{(1+r)^t}}{\sum_{t=0}^{N} \frac{Cost_t}{(1+r)^t}} \tag{4.7}$$

$$NPV = \sum_{t=0}^{N} \frac{Benefit_t - Cost_t}{(1+IRR)^t} = 0 \tag{4.8}$$

Where:

1) $Benefit_t$ – Present value of benefits at period t.
2) $Cost_t$ – Present value of costs at period t.
3) r – Discount rate (10%).
4) N – Time horizon of the analysis (25 years).

5) IRR – internal rate of return (it is a discount rate where NPV is equal to zero)

When a cost-benefit analysis is conducted for future cash flow calculations, consideration of risk and uncertainty is important because these factors are inherently present in the analysis (Zerbe & Scott, 2015). The definition of risk usually means an uncertain outcome with a probabilistic distribution, and uncertainty is an outcome to which one cannot assign a quantitative description (Zerbe & Scott, 2015).

To deal with risk and uncertainty, the Monte Carlo analysis can be utilized, where CBA is simulated a considerable number of times (usually 10000), and all the uncertain parameters vary in each iteration (Zerbe & Scott, 2015). The resulting distribution of outcomes for different parameters can be used to demonstrate the potential impact of uncertainty and risk on the analysis (Zerbe & Scott, 2015). Similarly, sensitivity analysis can be employed in the same way, but with one distinction, where instead of several uncertain parameters, this approach usually isolates only one uncertain parameter and manipulates the value (Zerbe & Scott, 2015). Thus, using these approaches can ensure accounting for uncertainty and the risk in my analysis of costs and benefits.

4.4 Scenario Development

I will utilize the cost-benefit analysis over two scenarios according to the environmental degradation assessment framework (Sutton et al., 2016). The first case is called “business as usual,” where NPV will be calculated using the original data. In the second scenario, I will calculate NPV using the data after sustainable relocation. The baseline for the comparison will be the business-as-usual scenario, and I will try to assess the effect of sustainable management on the NPV of all households in Bayantsagaan. I have already determined my main NPV formula with the corresponding discount rate and time horizon of analysis, so in the following chapter, I will primarily discuss the cost and benefits calculation for the scenarios and underlying math formulas with algorithms. The CBA assumption of using a single monetary unit will be followed; in my case, it is the Mongolian Tugrik (MNT), where one tugrik is equal to 0.0004 American dollars (USD) (according to the 2020 exchange rate). Moreover, the costs and benefits will be calculated with respect to each pasture unit and summed up to the total NPV of the Bayantsagaan region.

4.4.1 Scenario 1: Business as Usual (BAU)

Calculation of benefits and costs for the BAU scenarios is straightforward because the evaluation is based on the unchanged original dataset. Let us first define the benefit, which is a product of several variables; here, I shall pay attention to the sale percentage, which is a ratio between the total number of livestock sold and the total livestock. This ratio and the average livestock price are determined from the data collected by the "MORE STEP" research project. I also consider the number of livestock per household and the average market price per livestock. Taking a product of these variables will give us a benefit that each household gets each period, in other words, it is the average yearly price of the share of livestock sold:

$$Benefit_t = LN * \ Sale\ Percentage * Price_{livestock} \quad (4.9)$$

Where:

1) LN – The number of livestock per household is present in the dataset
2) $Sale\ Percentage$ – 11,35600481% ("MORE STEP")
3) $Price_{livestock}$ – 82 969 (MNT/head) ("MORE STEP")

Cost evaluation involves employing the livestock grazing rate (LGR) and pasture carrying capacity (PCC). LGR shows the grazing degree, which can be converted into a percentage by multiplying by 100. When the LGR is 0.9, it means that the pasture unit is under 90% utilization; in other words, the actual livestock number in the pasture unit is equal to the carrying capacity or maximum number of livestock that rangeland can endure without being overgrazed and degraded (Nandintsetseg et al., 2018; Wang et al., 2024). So, I will use this threshold to determine pastures under the high stocking rate. Since I have all the relevant data like LGR, PCC, biomass, area, household information, livestock amount, polygon points (a list that contains pairs of latitude and longitude that can be used for displaying maps) and name for each pasture unit collected by "MORE STEP" research group, I can use this information to classify pasture according to their LGR, distinguishing them by the threshold (LGR=0.9), into overgrazed and undergrazed. After finding pasture units with LGR bigger than 0.9, where 10% of the pasture will be preserved for restoration purposes, the cost of fodder in the overgrazed pastures will be calculated. Knowing the exact condition of the place, I can get the pasture carrying capacity and subtract it from the current number of livestock, getting the exact number of cattle that exceeds carrying capacity (Nandintsetseg et al., 2018). In other words, it is the amount of livestock for which the pasture fodder is insufficient. Later, the product of the excessive number of livestock, daily forage intake per sheep unit, grazing period, and average hay price can give us an average cost per pasture unit that needs to be covered to keep the excessive cattle. Additionally, all the livestock numbers or livestock-related variables (LGR, PCC) are evaluated in sheep units (SU) in the dataset (by “MORE STEP”) for the consistency of calculation (Nandintsetseg et al., 2018).

Let us define the cost of the business-as-usual scenario:

$$Cost_t = hay\ price_{kg} * Daily\ intake_{per\ livestock\ unit} * GP * ELN \qquad 4.10$$

$$ELN = Current\ Livestock\ Number - PCC \qquad 4.11$$

Where:

1) ELN – The number of livestock that exceed carrying capacity per household, which is present in the dataset.
2) $hay\ price_{kg}$ (MNT/kg) – 512 MNT/kg (“MORE STEP”).
3) $Daily\ intake_{per\ livestock\ unit}$ – 1.4 kg/day/livestock unit (Nandintsetseg et al., 2018).
4) GP – Grazing period (90.5 days according to “MORE STEPS”).
5) PCC – Pasture carrying capacity of a pasture unit.
6) $Current\ Livestock\ Number$ – The current livestock number is in a pasture unit.

4.4.2 Scenario 2: Sustainable Management

The second scenario involves more preparatory steps before actual calculations of costs and benefits. As its name suggests, I first need to perform sustainable management actions. What can be understood by sustainable actions is steps to minimize total grazing pressure in the study region. In order to achieve this, I can use pasture carrying capacity (PCC) and livestock grazing rate (LGR) to classify pastures into two categories of overgrazing, one of which is undergrazed pastures (where LGR<= 0.9) and the other is overgrazed ones with LGR > 0.9 (Nandintsetseg et al., 2018; Wang et al., 2024). Using these indicators provided for each pasture unit in the dataset (by “MORE STEP”), I can move to the next steps since I have all the relevant data for each pasture unit, like PCC, LGR, livestock amount, household-related data, pasture unit area, polygon units with the pairs of latitude and longitude to draw the pasture unit’s border on the map, name of the place, and pasture unit biomass. Having prepared everything, I can simulate relocation, where, depending on the pasture unit LGR indicator (e.g., if LGR > 0.9), I will relocate the household with the relevant amount of livestock from one pasture to another with a lower LGR. For this, I will use geospatial data provided in the dataset, like longitude and latitude, moving from the initial household location to a final destination with a certain degree of approximation. The approximation is done by using non-exact coordinates of the final destination, and placing new households around the center of the pasture unit.

To calculate the distance between two points, that is, the pairs of latitudes and longitudes, I use the Haversine formula (Kifana & Abdurohman, 2012). Going back to the formula definition, the Haversine is a mathematical equation to calculate the great circle distance between two pairs of latitude and longitude on the surface of a spherical object, such as the Earth (Kifana & Abdurohman, 2012).

Let:

1) ϕ_1, ϕ_2 – The latitudes of point 1 and point 2.
2) λ_1, λ_2 – The longitudes of point 1 and point 2.
3) $\Delta\phi = \phi_2 - \phi_1$ – The difference between latitudes.
4) $\Delta\lambda = \lambda_2 - \lambda_1$ – The difference between longitudes.
5) R – Earth’s mean radius (e.g., 6378 km)

Following the steps, I can calculate the great-circle distance:

$$a = \sin^2\left(\frac{\Delta\phi}{2}\right) + \ cos(\phi_1) * cost(\phi_2) * \sin^2\left(\frac{\Delta\phi}{2}\right) \tag{4.12}$$

$$c = 2 * atan2\left(\sqrt{a}, \sqrt{1-a}\right) \ or \ c = 2 * \mathrm{asin}\ (\sqrt{a}) \tag{4.13}$$

$$d = R * c \tag{4.14}$$

So, 4.14 gives us the great-circle distance in km units. I will count each household relocation distance like that, which will be used for cost calculation in later stages. However, now, after clarifying the algorithm and relevant formulas, I can proceed with relocation simulation, so each household in the pasture unit with high stocking rates (where LGR > 0.9) will be placed in the nearest pasture unit with low grazing pressure, and doing so, I can ensure evenly distributed grazing rate across whole Bayantsagaan. In other words, low grazing pressure will imply less degradation factor on pastures, better access to fodder, and lower high-density related livestock death, also cutting expenses for the forage that herders need to buy due to overgrazing (Gao et al., 2015; Hilker et al., 2014; Tuvshintogtokh & Ariungerel, 2013). It should be noted that the simulation of household mobility will be written in the Python programming language. Nevertheless, due to relocation, I will need to add new terms for the cost related to mobility. However, before I proceed with cost calculations, it needs to be noted that benefit calculations will stay similar to formula 4.9 from the business-as-usual scenario. Only cost calculations will be different.

In order to evaluate the distance-related cost, first let us define transportation cost per km in MNT (Mongolian Tugrik) according to the paper (Gonchigsumlaa & Damdindorj, 2021):

$$Cost_{transport,km} = \frac{fuel\ consumption_{100km}}{100km} * fuel\ cost_{1\ liter} * MD \tag{4.15}$$

Where:

1) $Cost_{transport,km}$ – Cost of transportation per km.
2) $fuel\ consumption_{100km}$ – Fuel consumption per 100 km in liters.
3) $fuel\ cost_{1\ liter}$ – 1 liter of fuel costs per 100km.
4) MD – Mobility distance of households in km.

The study of Gonchigsumlaa & Damdindorj (2021) provides relevant data to calculate the numerical value of transportation cost per 1 km. Let us start with the average fuel price in 2019, which is 2.423.4 MNT or 0.97 USD across four provinces, including Tuv, Khentii, Sukhbaatar, and Dornod, per 100 km. The most commonly used trucks are “Bongo” and “Porter,” with an average fuel consumption of 14.2 litres per 100 km. So, having all the required information, I can now proceed with the assessment:

$$Cost_{transport,km} = \frac{14.2\,\frac{litres}{100\ km} * 2423.4\,\frac{MNT}{100\ km} * 1km}{100km} = 344.1228 \qquad 4.15\ a$$

The transportation cost per one km equals 344.12 MNT or 0.14 USD according to 2019-2020 data in Mongolia.

Now that I know the average cost of transportation, I can continue with the cost calculation. As mentioned before, the benefit formula for this scenario will be the same as the BAU case’s benefit calculation, 4.9. My expense calculation for this case will consist of two stages for the initial period, with new terms, and for the period starting from the 1st to the 25th iteration. The reason why I have two stages is straightforward: I will include transportation costs only for the initial year, because relocation is only a one-time operation in my scenario, and later I will not use these new terms in the formula, meaning that the second stage will utilize cost formula for the BAU scenario 4.10.

Let us define cost calculation for the scenario of sustainable relocation:

$$Cost_0 = hay\ price_{kg} * Daily\ intake_{per\ livestock\ unit} * GP * ELN + \\ + Cost_{transport,km} * distance_{km} \qquad 4.16$$

$$Cost_{t\in 1..25} = hay\ price_{kg} * Daily\ intake_{per\ livestock\ unit} * GP * ELN \qquad 4.17$$

Where:

1) $Cost_{transport,km}$ – Cost of transportation per km.
2) $distance_{km}$ – The distance during relocation.

All other variables are the same from the 4.10 cost calculation. In the first stage, I will use the distance to calculate transportation cost, which I will determine from the Haversine formula while relocating households from one pasture to another.

So far, I have defined the costs and benefits calculation for two scenarios: BAU and sustainable relocation. I also discussed the underlying algorithms for determining pasture categories, math formulas, and the overall simulation procedure that will be written in the Python programming language. In the next chapter, I will discuss a contemporary management solution that involves different management strategies.

4.5 Information Technology Solution for Pasture Management

In this last topic of the chapter, I will discuss the contemporary management solution for sustainable pasture management to address the tragedy of the commons. Pastures are one of the representatives of a common-pool resource (CPR) that have two main characteristics: non-exclusivity and rivalry (Ostrom, 1990). Meaning, it is expensive to exclude actors from using and rivalry because if someone benefits from using it, fewer resources will be left for others. The nature of the tragedy of the commons can be explained by these characteristics and the herders' strategies. For example, each herder is locked in the system where they pursue the benefit of adding another livestock to their herds (Hardin, 1968; Ostrom, 2016). Moreover, when every herder follows this strategy, it leads to the tragedy of the commons, where resources are limited (Hardin, 1968; Ostrom, 1990, 2016). According to Ostrom (1990), monitoring and communication are the key principles of community-based governance for sustainable common-pool resource management. For instance, the people who have been selected to monitor the resource condition should be accountable to the common users, and they can be common resource users as well. Furthermore, talking about management approaches, many studies have confirmed the effectiveness of community-based governance of commons against central governance and private property (Ostrom, 1990, 2016). Where a central management system or private property system is claimed to be effective in managing the commons, but in reality, each of them has failed to prove this claim, except the community-based system (Ostrom, 1990).

I am presenting an IT solution implemented using the Dart programming language, grounded on the community-based principles. The developed application for managing the pastures contributes to more sustainable pasture management. Specifically, this application improves monitoring and communication among pasture users and managers in the Bayantsagaan community, but can also be scaled for other regions.

Let us discuss an IT solution in more detail. It is an application that can be installed on any mobile device, such as a phone. The primary purpose of the app will be the management of pastures, and it will have the following features:

1) GPS tracking and user location – In order to utilize the GPS unit in the device, the app will require a user to give consent to allow the app to utilize the phone's GPS information. By doing so, the app will access GPS, which enables GPS tracking and user location.
2) Pasture unit capacity monitoring – One of the app's main features is the interactive map that shows the real-time livestock grazing rate (LGR) indicator for each pasture unit in Bayantsagaan. It is a real-time map because if the cattle amount of the user changes, it will be reflected in the residual livestock grazing rate, lowering or raising the current LGR level. Moreover, depending on the LGR level, each pasture unit will have a different color, in other words, a color-coded indication of the pasture condition. This feature will allow real-time pasture capacity monitoring since each user can access this map. The data from the "MORE STEPS" research project will be utilized for this purpose.
3) User roles (Common Users and Managers) – During the signup process, the user can select two roles; the app's UI and functionality will vary depending on the user's role. Managers will have additional features to coordinate and manage common users, ensuring proper timing between them.
4) Cattle amount management – As it was said earlier, the manager user role can grant you some additional features, for example, during the signup process, together with other information, the user will need to indicate the current cattle number, and if you are a manager, you can change other users' livestock number directly or through the request that common user send to manager, so the one can approve or disapprove the request to change this number.
5) Communication (Chats) – Another important feature is the ability to chat between users, but only the managers can create those chats to restrict unnecessary overload due to high traffic. For this app, there will be a dedicated page that will contain all the relevant chats assigned to this particular user. Inside the chat, the modern UI with a fast response speed will accommodate effective communication.

6) Feedback Mechanism – If the user taps a little longer on any pasture unit, a new page will open that shows all the relevant information about that place, such as biomass, livestock amount, area, and name. At the bottom of that page, the user will see a special field for writing feedback about the place with a rating button from 0 to 4 stars (sustainability points). If the feedback is sent, it will appear on the feedback page with other feedback sent by users.

It is not just a simple app but a tool that will reduce information uncertainty concerning pasture conditions and enable communication channels between herders and managers to establish sustainable practices.

5 Results

In this chapter, I will discuss the results of the cost-benefit analysis of two pasture management scenarios incorporating pasture carrying capacity and livestock grazing rate in terms of net present value (NPV). I will conduct a comparative analysis to see the main differences between the scenarios and try to justify these differences in sensitivity and Monte-Carlo analyses. Lastly, the proposed IT solution will be presented as a contemporary approach to pasture management.

5.1 Pasture Carrying Capacity and Livestock Grazing Rate

Pasture carrying capacity (PCC) and livestock grazing rate (LGR) are an important part of my cost-benefit analysis. I am using them to incorporate into the environmental degradation assessment framework to identify the grazing pressure on the pastures (Sutton et al., 2016). The threshold for such classification is equal to LGR=0.9; in other words, the pasture units with LGR higher than 0.9 are considered to be overgrazed in the Mongolian context (Nandintsetseg et al., 2018; Wang et al., 2024).

In the data provided by the “MORE STEPS” research project, where the livestock unit amount, area (ha), biomass (kg/ha), along with other constants, were employed to calculate LGR and PCC for each pasture unit according to the 4.1 and 4.2 formulas. So, I developed the following distribution plots of LGR and PCC (Figure 2).

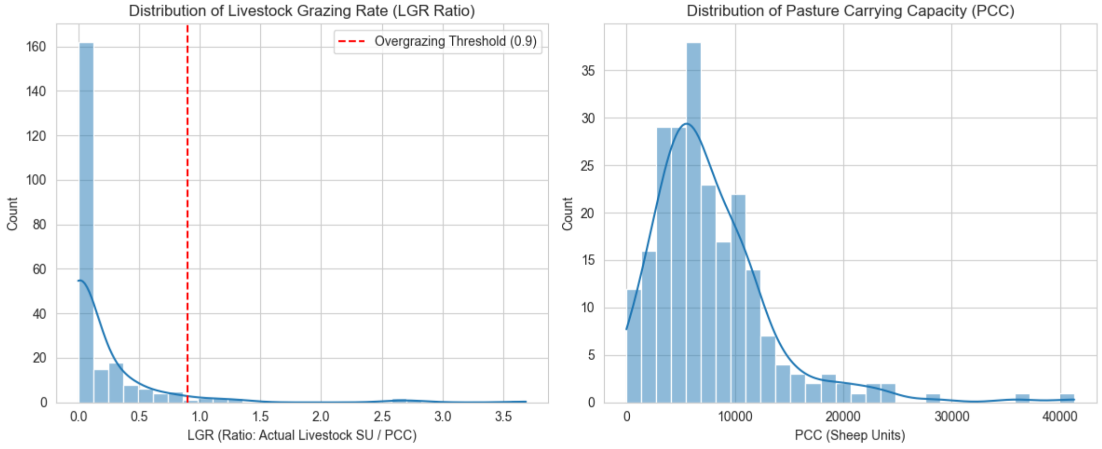

Figure 2. Distributional plots of pasture carrying capacity and livestock grazing rate.
Source: Author.

There are outliers in the LGR distribution plot that go beyond the threshold, indicating the pastures with overgrazing. On the other hand, I can also see that the pasture carrying capacity median is located at around 10,000 livestock units. That number corresponds to the most common pasture carrying capacity in the study region.

If one looks at the pasture map (Figure 3) constructed by utilizing calculated LGR and PCC with the polygon points provided for each pasture unit, specific patterns of overgrazing are evident. It can be concluded that pasture units with high LGR are spread across the region, although there are only a few of them.

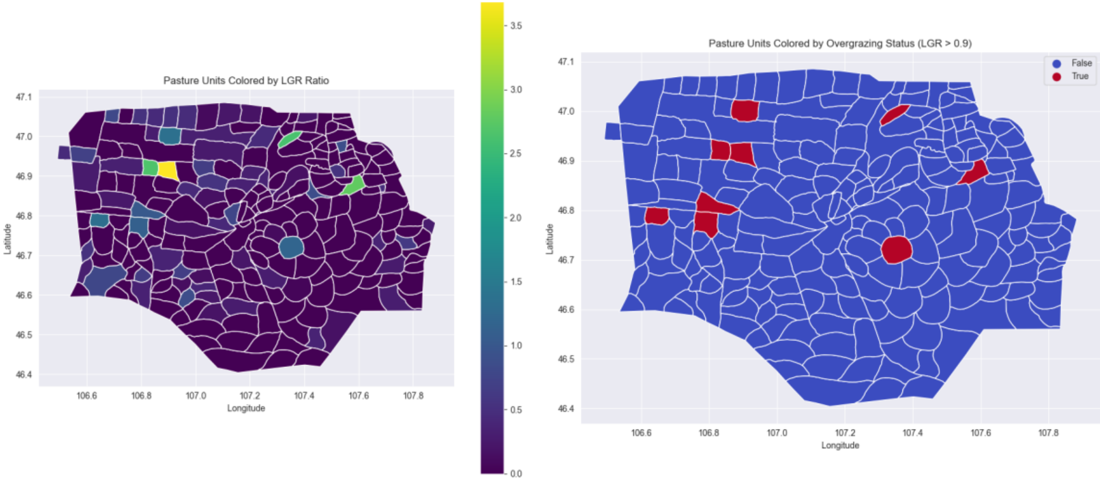

Figure 3. On the right, coloured pasture units by LGR indicator;
On the left, coloured pasture units are above and below the threshold.
Source: Author

I will discuss more about the LGR differences and patterns in the comparative analysis section, where the similar study region maps will be compared for two scenarios (business as usual and sustainable management).

5.2 Cost-Benefit Analysis

Cost-Benefit Analysis is a complex process that comprises several steps. Starting from the problem definition and ending with the sensitivity and Monte-Carlo analysis (Zerbe & Scott, 2015). The primary purpose of CBA in this thesis is to show the effect of sustainable practices on monetary cash flow (i.e., costs and benefits of the herders) (Zerbe & Scott, 2015).

5.2.1 Cost-Benefit Analysis: Business as Usual Scenario

I have included the benefits, such as the shares sold animals from the total number of livestock, where the average livestock price and the share percentage were determined from the household survey data provided by the “MORE STEPS” research project. Since I have an exact number of livestock for each pasture unit, I can calculate the benefits for the Bayantsagaan region according to the 4.9 formula. Furthermore, the cost of maintaining excessive livestock that exceeds the carrying capacity (4.10 and 4.11) was included in the net present value calculation.

After considering all the relevant variables and the calculation, I got the following results for the cost-benefit analysis of the business-as-usual scenario (BAU):

1) Average net present value per household (BAU): 120,343,593 MNT or 48,137 USD.
2) Total net present value in Bayantsagaan (BAU): 30,687,616,243 MNT or 12,275,046 USD.

The calculation indicates over 12 million in wealth evaluation with a 25-year analysis period, with a 0.1 or 10 percent discount rate. Since the inflation factor was utilized for the cash flow in each period, where I assigned different inflation factors to account for the fundamental difference in supply and demand of goods and services, I used a nominal calculation with expected inflation rates (Langemeier, 2023; Zerbe & Scott, 2015).

5.2.2 Cost-Benefit Analysis: Sustainable Management Scenario

As explained in the Methodology section, the sustainable management scenario includes higher mobility of livestock that avoids overgrazing and allows pasture to regenerate. First, I needed to conduct the relocation of the household if the livestock grazing rate in their region exceeds 0.9 (Nandintsetseg et al., 2018). Moreover, using the Haversine formula 4.12, 4.13, and 4.14, I calculated the distance between two mobility destinations or the great circle distance. Then I assessed the total distance that each household needs to cover, employing this number in a transportation cost calculation 4.15. However, I utilized this cost only for the initial period, 4.16, as mobility is a one-time operation according to the scenario. Following periods after the first one employ the exact cost 4.17 or 4.10 and benefit 4.9 calculations from the business-as-usual case.

Running the relocation simulation and calculating new terms in the cost evaluation gave us the following results:

1) Average net present value per household (Sust): 122,586,735 MNT or 49,034 USD.
2) Total net present value in Bayantsagaan (Sust): 31,259,617,407 MNT or 12,503,846 USD.

During the mobility simulation, the following changes have occurred:

1) Total relocated households: 34.
2) Total distance covered: 222.56 km.
3) Average distance per relocated household: 6.55 km.

With the same discount rate (0.1 or 10 percent) and the analysis period of 25 years from the business-as-usual scenario, I got a total of 12,503,846 USD (American dollars) for the Bayantsagaan region. After running the mobility simulation script that was written in Python, 34 households were moved, covering 222.56 km in total. Furthermore, the slight difference can be spotted in the total net present value and average NPV per household for the two cases. In the following comparative analysis subsection, I will discuss this difference in detail.

5.2.3 Comparative Analysis

If the net present value in the two cases is compared, the sustainable management scenario's outcome is higher than the result of the business-as-usual case. Figure 4 presents the difference in the total NPV comparison plot at 228,800 USD.

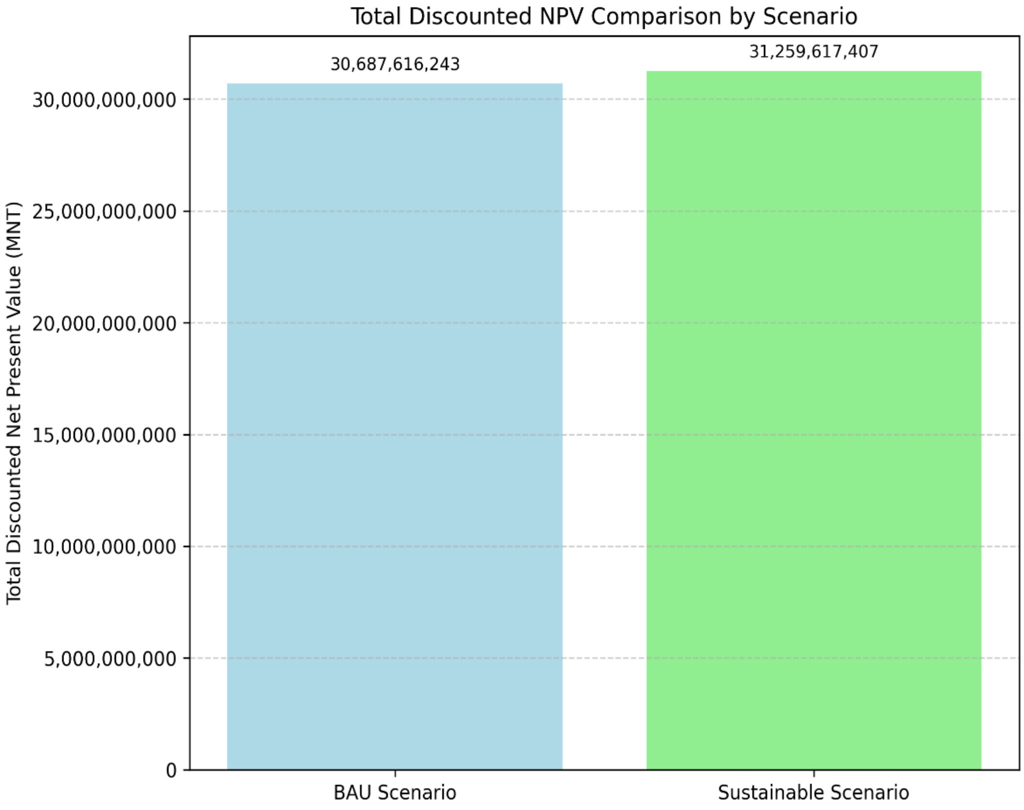

Figure 4. Total discounted NPV comparison of the two scenarios.
Source: Author

Moreover, Figure 5 depicts the change in average NPV for each period. We see the divergence between the two scenarios. Over the years, this difference has become tangible.

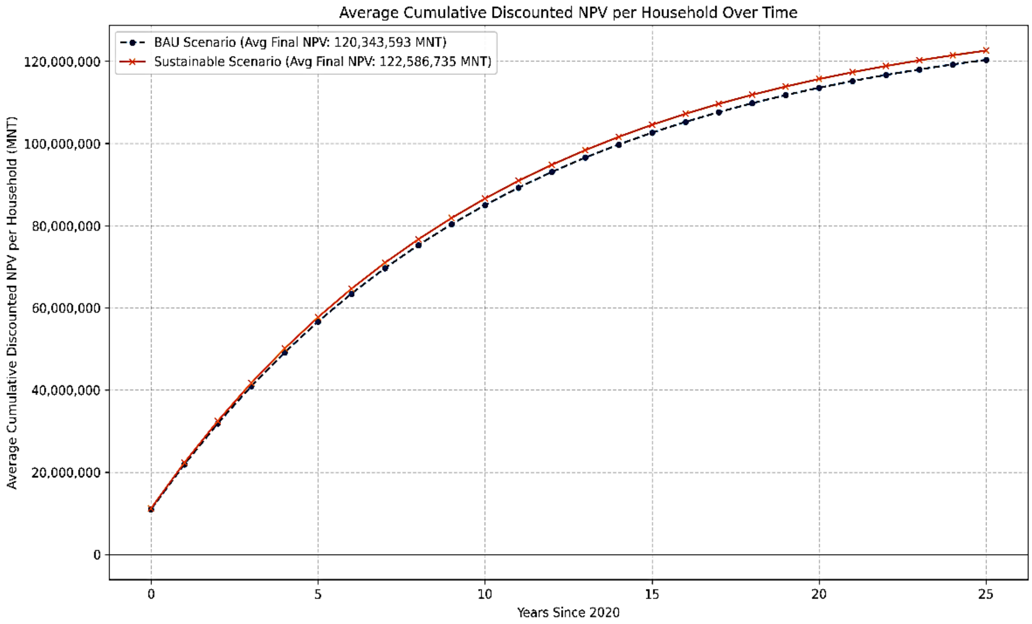

Figure 5. Average discounted NPV per household over time.
Source: Author.

There is obvious evidence that, in the case of sustainable management, average NPV gains increase compared to the BAU scenario. This cumulative increase in average NPV results in a difference of 228,800 USD in total NPV.

Let us analyze further to understand why, in the first place, the total NPV in the sustainable case is higher. First, I accounted for the hay cost in both scenarios, and in addition to the sustainable management case, I also included the transportation cost. Someone may argue that logically, the case with two types of cost should be less in terms of total NPV, but my calculations show counterintuitive results. Let us look at Figure 6, which represents the map of Bayantsagaan before the relocation, where the livestock grazing rate (LGR) indicator is color-coded depending on the grazing pressure.

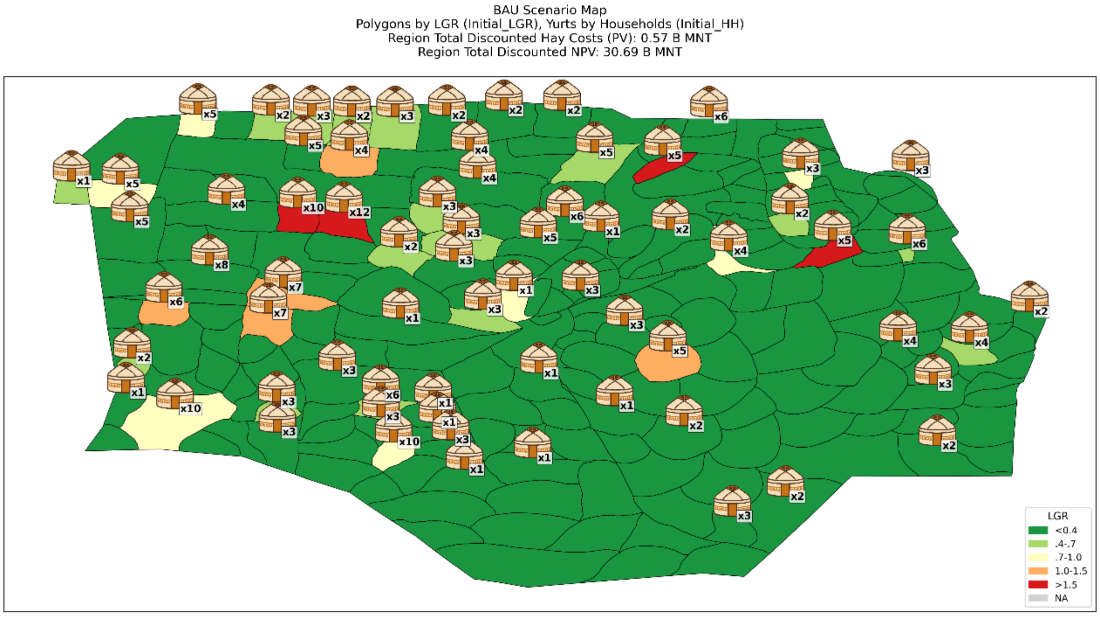

Figure 6. The map of the Bayantsagaan region before the relocation with the LGR indicator.
Source: Author.

This map represents Bayantsagaan with the LGR indicator and the households, which are depicted as yurts. The labels beneath each household show its exact number. In Figure 6, there are overgrazed pasture units where the LGR indicator is bigger than 0.9, which is a sign of a high level of grazing pressure (Nandintsetseg et al., 2018; Wang et al., 2024). Moreover, recalling the cost calculation (4.10 and 4.11), it can be concluded that the pasture units with high LGR also have a high fodder cost, which implies a larger number of livestock that needs to be maintained. Looking at Figure 6 again, one can find that the hay cost is about 570,000,000 MNT or roughly 228,000 USD, which is close to the difference in the total NPV comparing the two scenarios.

Let us look at the Bayantsagaan map, but after the relocation, where the grazing pressure is evenly distributed across the region (Figure 7).

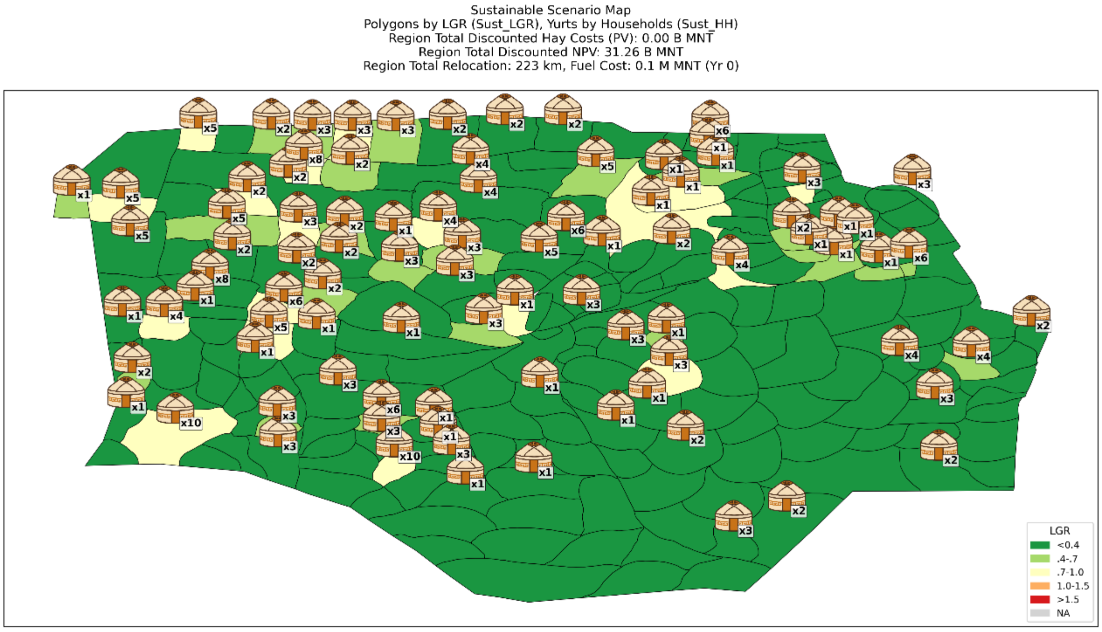

Figure 7. The map of the Bayantsagaan region after the relocation with the LGR indicator. Source: Author.

After the relocation, the overall number of highly overgrazed pastures was minimized, and thus the hay cost consequently dropped to zero. Let us look at the distributional plot to confirm that there are indeed fewer pasture units with more than 0.9 livestock grazing rate (0.9 is my threshold to determine whether pasture is overgrazed or undergrazed).

Figure 8 confirms my argument, where the pasture units that exceeded the threshold of 0.9 LGR (in Figure 8, it is indicated as a yellow dashed line) diminished in numbers after the relocation. Furthermore, comparing Figure 6 and Figure 7, the difference in total NPV in both scenarios came from the effect of relocation. In the next part, I will conduct sensitivity and the Monte-Carlo analyses to see whether my conclusion regarding the NPV difference is plausible.

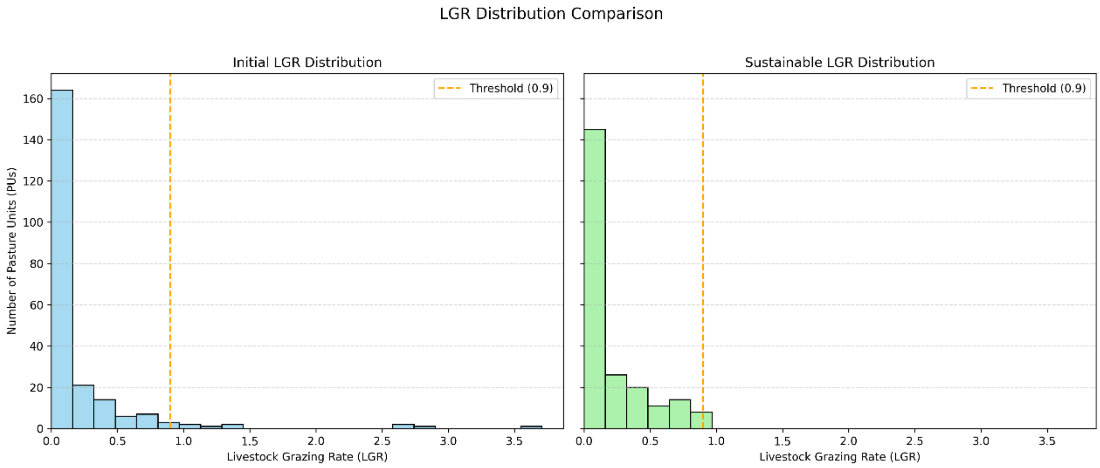

Figure 8. Initial and sustainable LGR distribution.
Source: Author.

5.3 Sensitivity and Monte-Carlo Analyses

To understand how my NPV models will behave under uncertainty and risk, I conducted sensitivity and Monte-Carlo analysis (Zerbe & Scott, 2015). It is necessary to check it because this process allows us to defend my claim regarding NPV results. Specifically, I claimed that there is an effect of relocation on NPV. Thus, the claim by conducting the analysis and testing it on uncertainty and risk can be accepted or rejected.

First, I started with a sensitivity analysis, which is the most straightforward and simplest way to conduct the test. The analysis consists of several steps, where one or two of the most important components of the NPV model were isolated, and by varying them, I checked how the total NPV changes as the values vary (Zerbe & Scott, 2015). It was decided to take the discount rate and the LGR threshold by which I classify whether a pasture unit is overgrazed or not (Nandintsetseg et al., 2018; Wang et al., 2024; Zerbe & Scott, 2015).

Let us start by comparing the total NPV change as I vary the discount rate for two scenarios (Figure 9). From Figure 9, it is clear that the difference in total NPV is maintained despite changing the discount rate for the scenarios with and without relocation. Interestingly, as the discount rate increases, the total NPV decreases, keeping a downward trend.

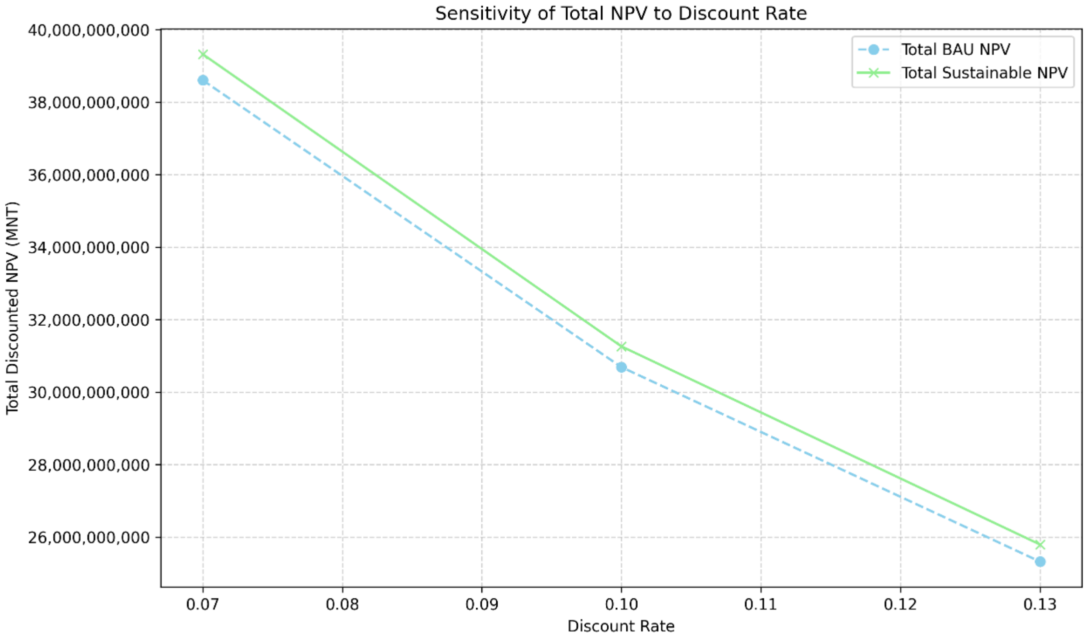

Figure 9. Total NPV comparison of the two cases, varying discount rate.
Source: Author

Now it is time to see the effect of varying the LGR threshold against the total NPV (Figure 10 and Figure 11). A similar situation can be observed in Figures 10 and 11, but with an upward trend. The similarities with Figure 9 are in the difference between the maximum and minimum values of the two cases. If one pays attention to the lowest and the highest points in Figures 10 and 11, in the case of sustainable relocation, these points are located higher compared to the BAU case. From this, it can be concluded that even a varying LGR threshold can still maintain the difference in total NPV due to the relocation effect.

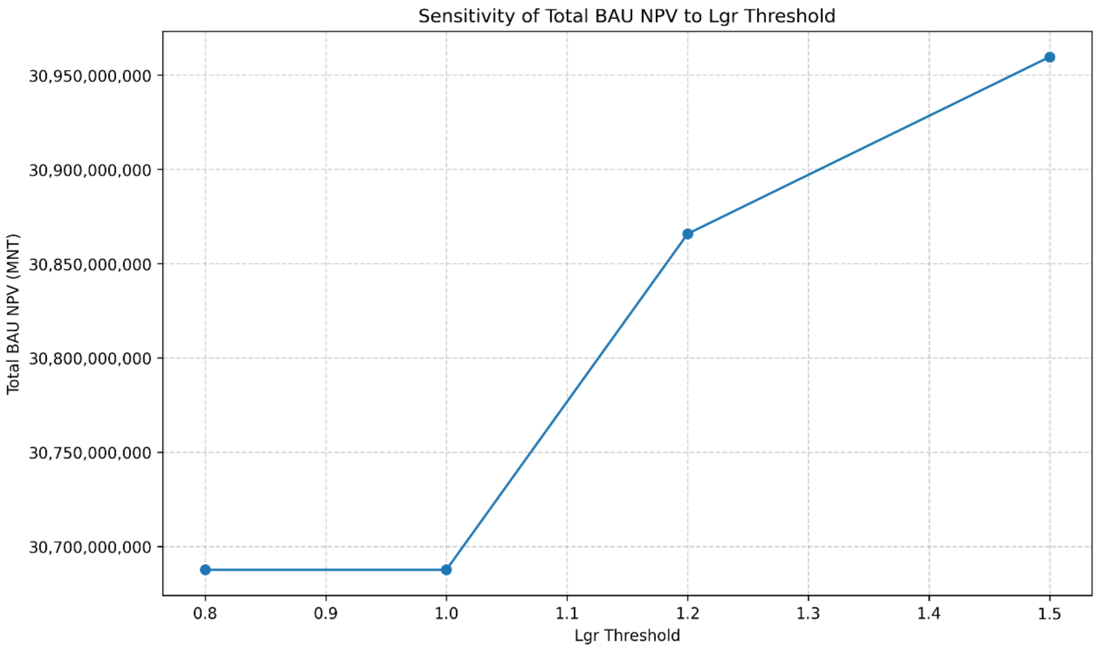

Figure 10. Total NPV against LGR threshold for the business-as-usual scenario.
Source: Author

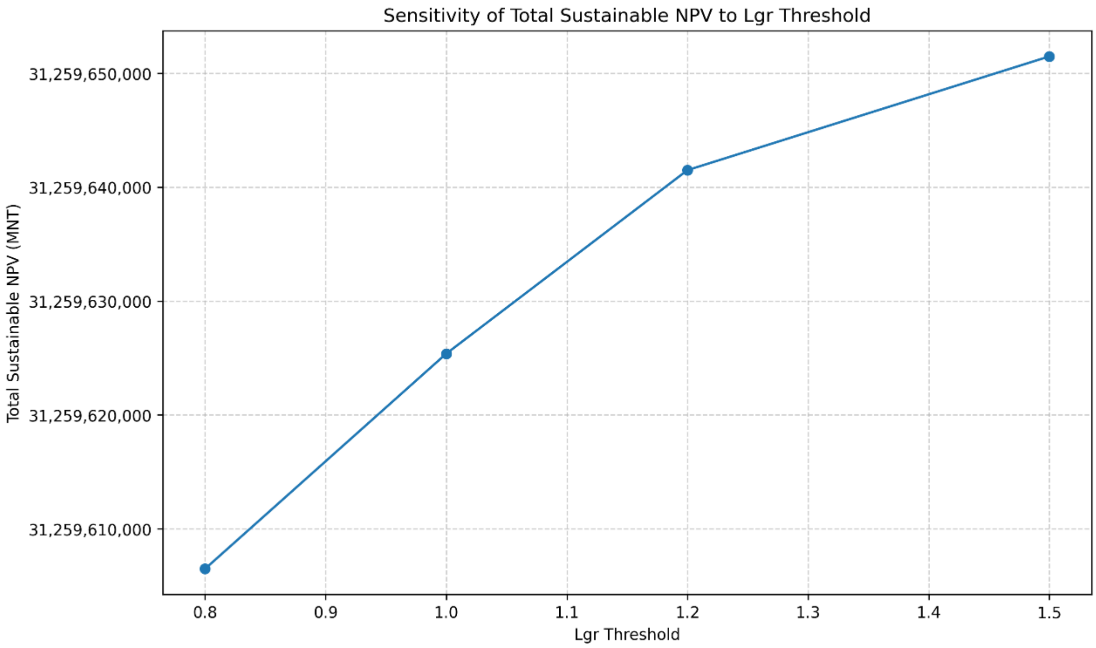

Figure 11. Total NPV against LGR threshold for the sustainable relocation scenario.
Source: Author

The last but not least important step will be conducting the Monte-Carlo stochastic simulation, where the main difference from the sensitivity analysis is that every possible component of the NPV model is varied, and the total iterations are usually repeated 1000 times (Zerbe & Scott, 2015). In this setting, I selected all variables such as the discount rate, food inflation rate, general inflation rate, livestock sale percentage, average price per livestock, average hay price per kg, LGR threshold, etc. (For more information about the parameters to vary, one can check formulas from

4.4 to 4.11). The result of the simulation can be represented as a probability distribution of NPV with varying parameters.

Monte-Carlo simulation, in my case, involves the identification of stochastic dominance (Levy, 2016; Zerbe & Scott, 2015). It is the process where one compares different distributions of results and determines the scenario with the better expected outcome (i.e., bigger mean value) (Levy, 2016). In other words, I am trying to find such a distribution under a particular scenario where the mean value is the biggest among other distributions (Levy, 2016). If I find one, it means the expected outcome under this scenario is much better than others, or first-order stochastic dominance (Levy, 2016).

As I observed the distributions in Figures 12 and 13, it is evident that the mean value under the sustainable scenario (31.8 billion MNT) is bigger than the BAU scenario's expected value (31.2 billion MNT). This finding solidifies my claim that the relocation has an increasing effect on the NPV. The effect can be observed as a difference between the total NPVs of the two scenarios. The result means that even when varying all the possible parameters of the NPV model, this difference will be maintained, justifying my claim. The subsequent discussion will consider a contemporary IT solution for pasture management.

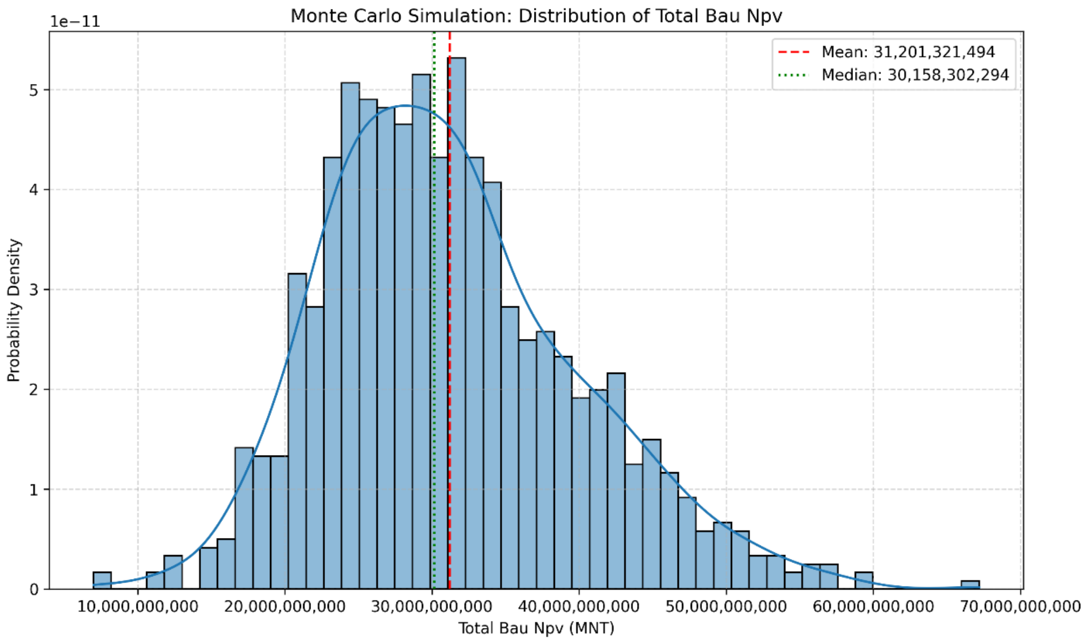

Figure 12. The probability distribution of NPV under the varying variables for the BAU scenario. Source: Author

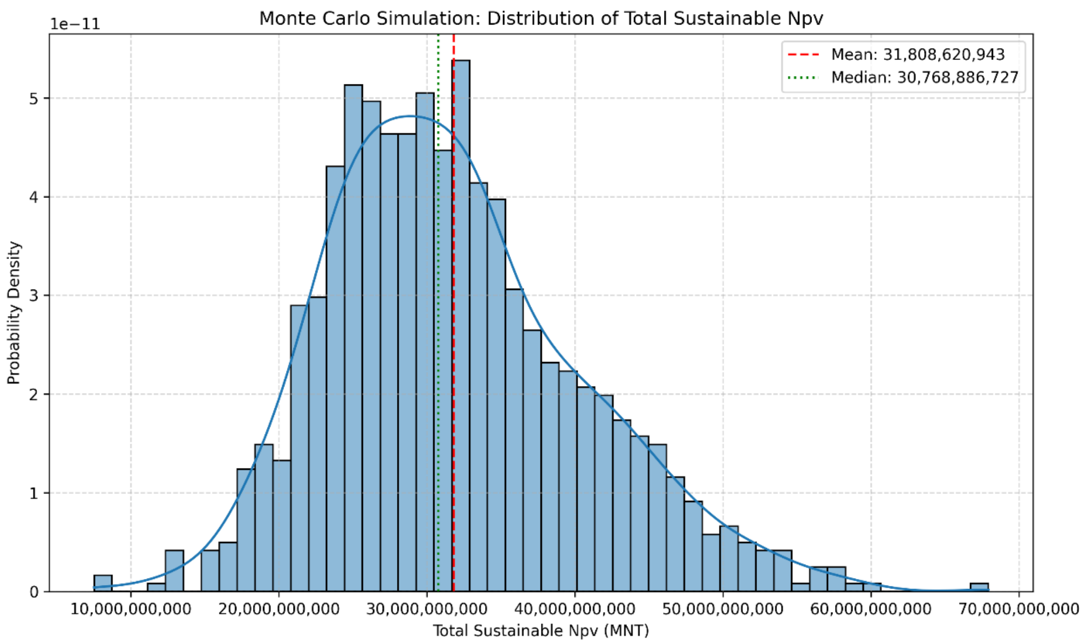

Figure 13. The probability distribution of NPV under the varying variables for the sustainable scenario.
Source: Author

5.4 Proposed IT Solution Implementation

This subsection is dedicated to the IT solution and its implementation. The first thing that the user will see is the consent for allowing the app to access the GPS. It is a crucial step because the whole application operates using GPS navigation (Figure 14).

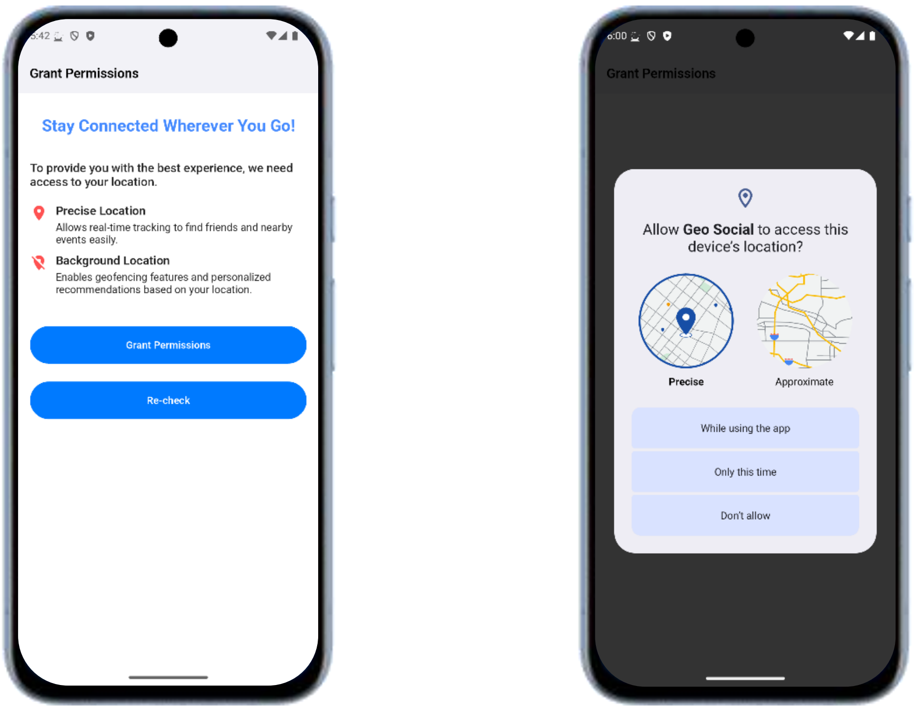

Figure 14. Permission page for the GPS access
Source: Author

After giving consent, the next step is to create a new user account or log in with an already created one. If a new account is required, the user must fill in the corresponding fields, such as the name, e-mail address, livestock amount, role, and password on the signup page (Figure 15). Otherwise, to use an old account, the sign-in page should be employed, and the corresponding fields, like email and password, should be filled (Figure 15). Choosing the role in the sign-up page implies a two-role system, one for managers and another for pasture users (i.e., herders).

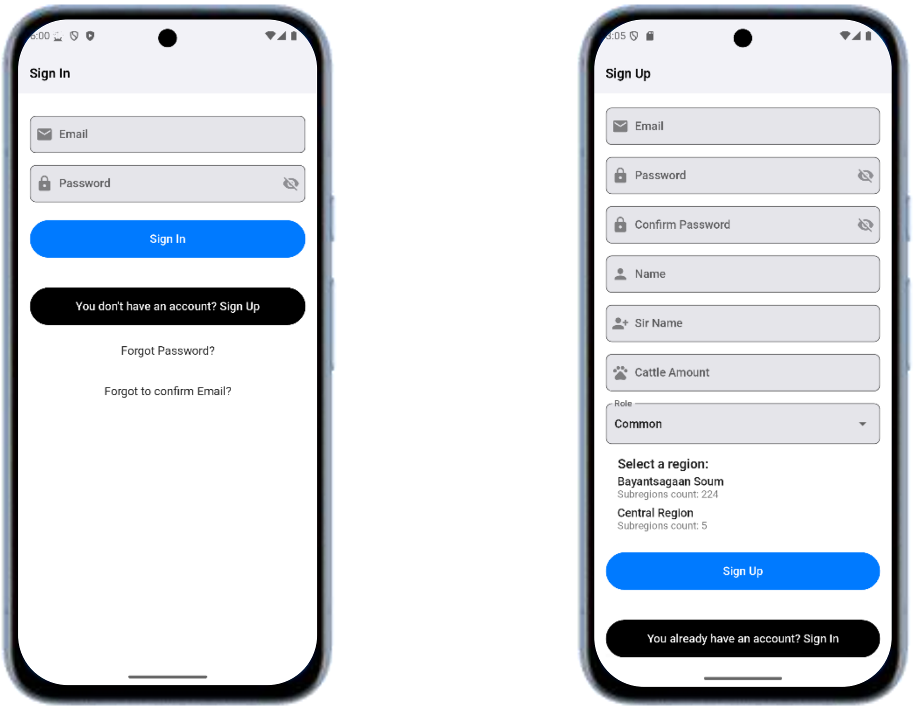

Figure 15. Login and Signup pages.
Source: Author

Successfully authorizing with the account opens a new page. This main page is the interactive map with the color-coded LGR (livestock grazing rate) indicator, where the map changes are shown in real-time. Such a feature allows for monitoring the current grazing pressure in the Bayantsagaan community and getting relevant information about the other herders in the pastures. It is a very important tool, especially for managers, who can observe all the pastoralists on the map without going after them in person. Using the GPS constantly shows even the slightest displacement of the herder on the map. The user tracking feature, two-role system, and interactive real-time map simultaneously address key management features such as monitoring and communication among pasture users and managers (Ostrom, 1990). The real-time map incorporates changes in livestock numbers, PCC, and LGR indicators. If LGR reaches a certain threshold, there are different colours for the pastures, signifying the residual carrying capacity. For example, a green pasture unit means high residual carrying capacity; a black one means no capacity left, yellow means medium, and red means low capacity (Figure 16).

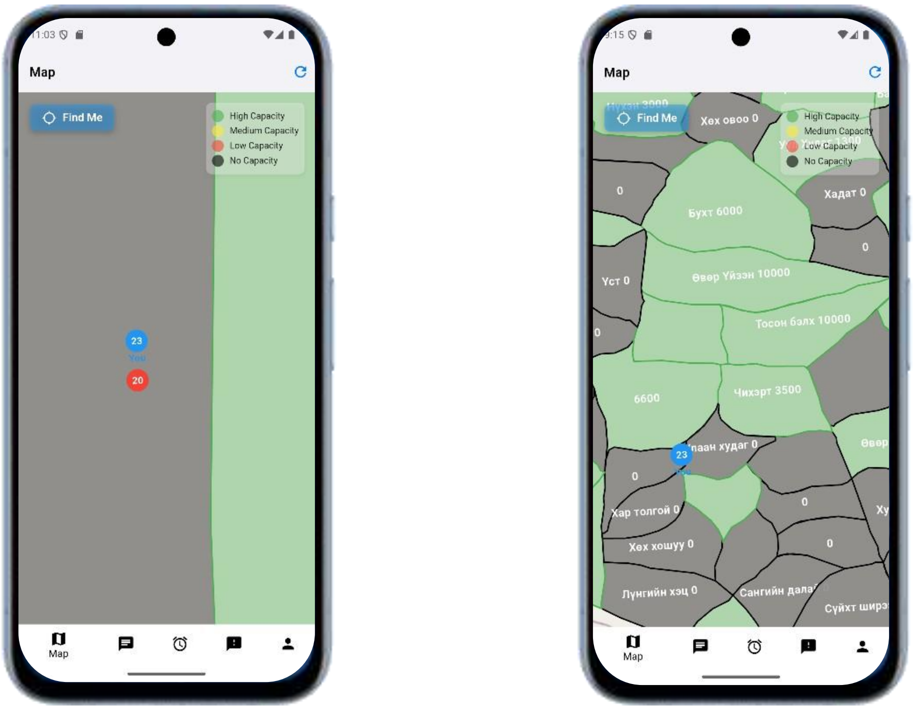

Figure 16. The map page with the LGR indicator and the displayed users.
Source: Author

The pasture maps (Figure 16) provide an overview of pasture use information (i.e., pasture carrying capacity, which is linked to the local conditions like pasture biomass, area size, and current livestock number). There is a special feature that allows you to see specific information about the pasture unit. If one taps long enough, a new window appears that contains information like biomass, initial and free carrying capacity, and user amount (Figure 17). Moreover, users can send feedback and ratings about the pasture unit at the bottom of the page. After writing and sending the feedback, managers can read it on the feedback page.

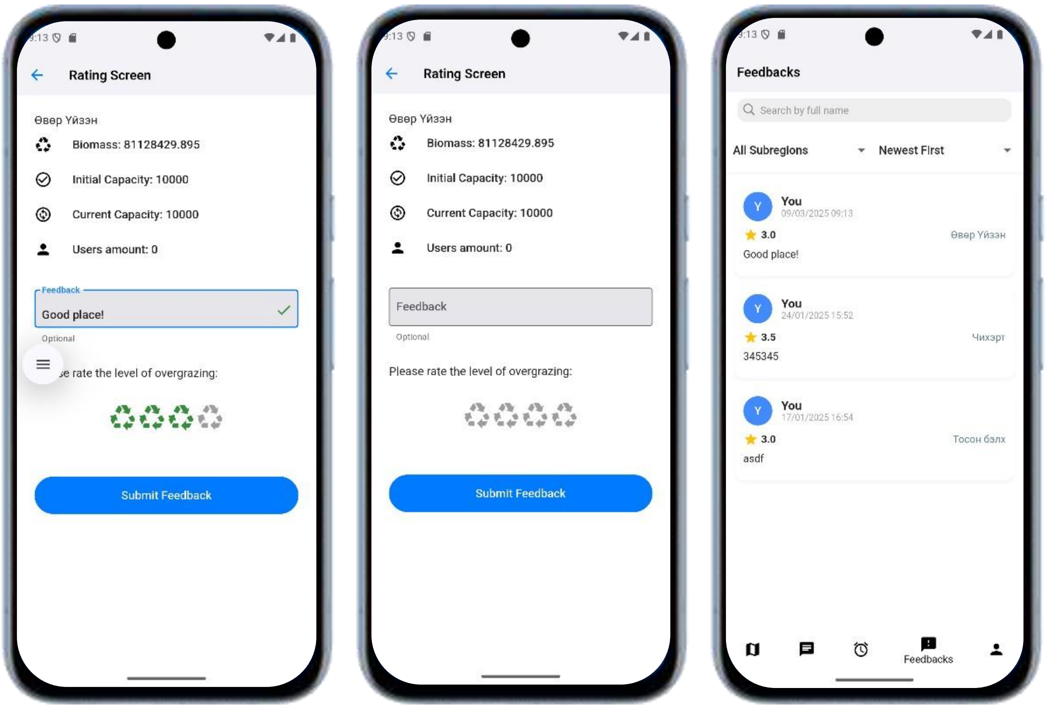

Figure 17. The rating page with the pasture unit information and the feedback page. Source: Author

There is a built-in system of communication, which is a chat (Figure 18). The first important fact is that only managers can start conversations by tapping on the active users and in their profiles and pushing the start conversation button. This mechanism is made to avoid excessive overloading of the servers and create an environment where the managers coordinate pastures using the chat feature, thus incentivizing the users to talk first with the managers. Another purpose of the feature is to create a channel through which managers can contact the herders who overgraze pastures.

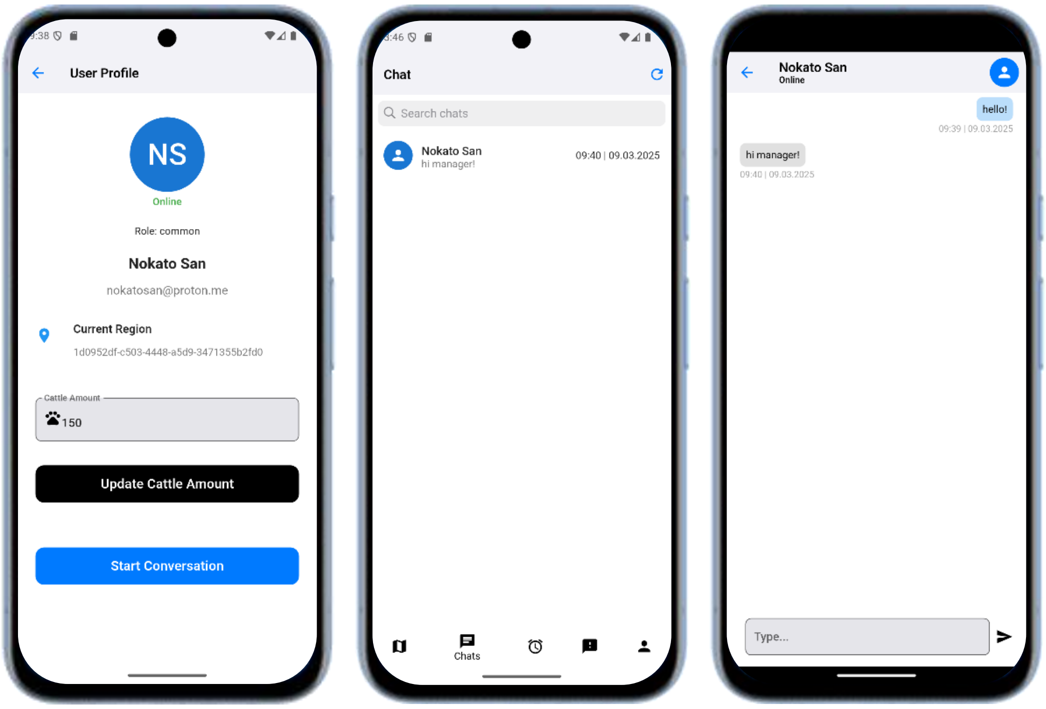

Figure 18. User profile and chat pages.
Source: Author.

The feature to accept or reject the user's request to change the cattle number was implemented (Figure 19), where the acceptance or rejection can be done solely by managers, who are selected by the users and are accountable for the place they are assigned to.

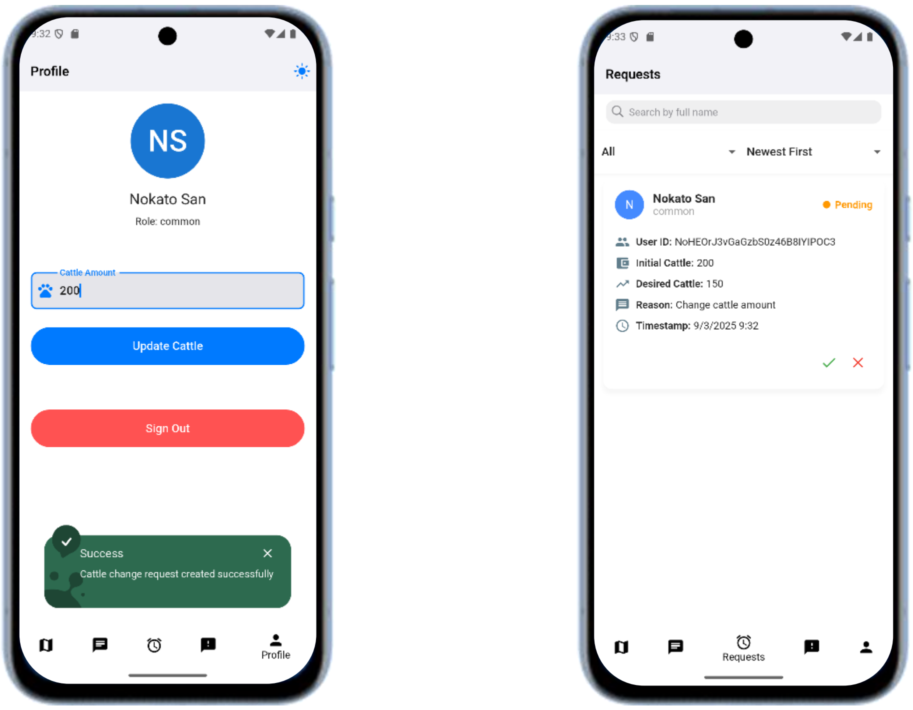

Figure 19. On the left is the user sending a request; on the right is the manager receiving it.
Source: Author

The application is a modern solution that was developed to improve the monitoring and communication of pasture use and contribute to more sustainable pasture management grounded in community-based practices. This IT solution was successfully tested by using the empirical-pasture use data from the Bayantsagaan community in Mongolia. It is expected that allowing herders to see the real-time condition of the pasture will reduce uncertainty about the rangeland state and incentivize cooperation and coordination among the herders, fostering sustainable practices.

6 Discussion

The research findings demonstrate that pasture units with high LGR are spread across the region, although there are only nine pasture units with such an indication. The low LGR implies less grazing pressure, and on the contrary, high LGR usually means that the current livestock number is far beyond the pasture's carrying capacity (Nandintsetseg et al., 2018; Wang et al., 2024). Thus, overgrazing occurs as a result, leading to vegetation cover deterioration, soil erosion, and decreased fertility (Wang et al., 2024).

This finding contradicts the literature that argues 70% of the Mongolian land has been degraded environmentally, and the primary driver of environmental decline is overgrazing, resulting in a shift of plant species, decomposition, and decreased biomass (Hilker et al., 2014; Tuvshintogtokh & Ariungerel, 2013). In the study community, I did not observe the overgrazing problem. The conclusion is made due to a few overgrazed pasture units, where the number is 9 out of 229, or less than 70% of the total pasture unit share.

Another important result of my study regarding the cost-benefit analysis (CBA) is the NPVs calculated for business-as-usual and sustainable scenarios. The sustainable scenario includes the relocation of livestock from the overgrazed areas. The primary goal of the relocation was to decrease the overall amount of pasture units by livestock mobility where a pasture LGR was greater than the threshold (LGR=0.9). The difference between these two scenarios was 228,800 USD (for 25 years). It was also confirmed that this difference is valid even under uncertainty and risk. In order to do it, sensitivity analysis and Monte-Carlo analysis were conducted, where the different NPV parameters, such as discount rate, LGR threshold, etc, were varied.

My research confirms the findings from other studies. For instance, Gonchigsumlaa and Damdindorj (2021) emphasize the overall positive impact of mobility on the herders' benefits per sheep unit. Utilizing both frequency and distance-based models for quantifying costs and benefits, it was found that the profits per additional sheep unit were 1.63 and 1.13 USD, respectively. This aligns with the findings from my study about the positive impact of mobility on the herders' profit. Precisely speaking, the NPV gap between the two scenarios in my study is due to the effect of sustainable relocation (i.e., mobility). Moreover, findings from another study are also confirmed by my research, where they employed a similar methodology to my work and conducted calculations in the study regions in Kyrgyzstan (Ridder et al., 2017). The authors utilized the CBA analysis with two case scenarios (i.e., business-as-usual and sustainable), showing varying NPV differences between them (Ridder et al., 2017). For example, the NPV gap between the scenarios ranged from 260,958 USD to 1,048,831 USD in the study communities (i.e., Kekilik and Katmy, respectively) (Ridder et al., 2017). Furthermore, my study results are comparable with the research findings of Ridder et al. (2017) because the authors selected a period for CBA analysis (25 years) and a discount rate (0.1 or 10%) similar to my research's NPV parameters, respectively (Ridder et al., 2017). In addition, findings from Ridder et al. (2017) confirm the central notion of NPV difference between scenarios when the improved carrying capacity is in place; it also shows that different regions have different potential or capacity for improvements in terms of NPV outcome. This explains roughly a four times gap in NPV differences for Kekilik and Katmy study regions, where the Kekiliks' difference (260,958 USD) is close to the number from the thesis's result (228,800 USD). This is an important fact because it shows the similarities between the CBA findings in my study region and those in Kekilik. Thus, the potential improvement between these study regions in terms of carrying capacity and NPV is similar.

The IT solution addressed the problems of coordination and cooperation by implementing the features that ensure compliance with the sustainable practices for managing the commons. So far, all the features of the application have focused on the community-based approach, considering principles such as communication and monitoring. By doing so, I ensured effective pasture management mechanisms in the IT solution. It is expected that this allows for low communication costs, which increases the chance of establishing a successful ruling system of the commons (Ostrom, 2016).

The community-based approach was implemented in terms of features to enhance communication, cooperation, and coordination between managers and users. In other words, the features where the community plays a crucial role in governing the commons have been prioritized in the application. Thus, one can expect a positive effect of the IT solution on pasture use management.

6.1 Limitations of the Study

As for the limitations of the cost-benefit analysis (CBA), there is a need to emphasize several points. So far, I have used the CBA framework to address the socio-economic effects of overgrazing for herders and the Bayantsagaan region. However, due to the simplicity of the NPV models, which included the cost of transportation and fodder, as well as the benefit of selling a particular share of the livestock, such a simple approach may not fully represent the totality of the cost-benefit relations. It would be recommended to include such benefits as the benefit from selling the dairy products, the animal skin, and the saved fodder, as well as the costs, such as the cost of the medical treatment for livestock, the cost of fences, labor cost, and the cost due to livestock death (Gonchigsumlaa & Damdindorj, 2021). However, due to the unavailability of the data, I did not include them in my study.

Moreover, in the Monte-Carlo simulation, I had 1000 iterations, but increasing it to twice as many or even more may present wider variability and better validity of the results against uncertainty and risk (Zerbe & Scott, 2015). Going back to the NPV model, I conducted the analysis only for the nominal discount rate, but additional calculations with the real discount rate would contribute to the clarity and stability of the picture, although the calculations with a nominal discount rate are suitable for real-world scenarios with an inflation factor adjusted (Zerbe & Scott, 2015).

Let us now discuss the limitations regarding the IT solution for contemporary pasture management. The first important fact is that the app has not yet been tested in the real world, and without the relevant feedback, it can only be theorized about the cons and pros of the solution. Moreover, there is a demand not only for the theoretical assessment of the app in terms of an institutional economics setting but also for regression analysis of the economic impact of the IT solution on pastoralism. Thus, demanding the economic assessment would require relevant data about the application usage collected in the field from user feedback and other analytical sources. Addressing the economic implications of the app would open a new dimension for research and discussion regarding the impact of contemporary management solutions on herding.

7 Conclusion

In my thesis, I have attempted to address the tragedy of the commons with local solutions such as cost-benefit analysis, incorporating LGR and PCC indicators, and an IT solution for sustainable pasture management. So far, I have discussed the interpretation of the thesis's results and the corresponding limitations. Let us now consider addressing the research questions that were posed in the beginning.

To answer all the research questions, I introduced a new approach for assessing the socio-economic impact of overgrazing, like mobility simulation using the available geo-spatial data about the pastures via the Python programming language, incorporating LGR and PCC indicators. Moreover, the simulation was integrated into the assessment of the cost-benefit analysis to get the numerical results for the two scenarios, checking the validity of the outcomes under uncertainty and risk via Monte-Carlo and sensitivity analyses. Not to forget about the IT solution, which was a developed app to showcase the applicability of the sustainable management approaches addressing the issues of overgrazing, lack of coordination, and communication.

Answering the first research question, which seeks to clarify the situation with the environmental degradation indicators in the study region, I have employed the formula of LGR (4.2) and PCC (4.1) using data provided by "MORE STEPS". It was found that 9 out of 229 pastures are overgrazed, meaning the environmental condition is not as bad as it may be in terms of degradation. Moreover, I found the economic impact of overgrazing on the herder's benefits. This effect is tangible and can be observed when cases with and without the presence of overgrazing are compared. I also determined that the claim that overgrazing has a negative economic impact on livestock production is justifiable.

The second research question inquires about the NPV difference between scenarios and their economic implications. So, I can firmly state that there is an NPV gap between business-as-usual and sustainable relocation scenarios. This effect is due to the mobility that evenly distributes the livestock grazing rate (LGR) across pasture units. During the mobility simulation, the fodder cost was minimized in the study region, but the cost of transportation was added as a new term. So, sustainable mobility has a positive long-term effect on the economic aspect of pastoralism, and also minimizes the LGR, giving pastures a chance to preserve and regenerate residual palatable biomass.

The last question looks for the socio-economic feasibility of the IT solution in pasture management. However, the answer to this question is not definite but can be answered in the context of institutional economics. The different studies have proven the effectiveness of community-based management systems for common resources. And I used the principles of a community-based approach (i.e., communication and monitoring) as a basis for determining the features and addressing key aspects of successful management, such as the low cost of communication. Thus, it is expected that the IT solution for the contemporary management of pastures can impact herding positively, minimizing the uncertainty about the rangeland condition and the cost of communication.

For future research, it is recommended to assess the socio-economic effects of high stocking rates not only through cost-benefit analysis but also by using other research methods to widen the field for interpretation (e.g., field experiments, case studies). Another potential research topic includes testing the IT solution in the field with pasture users and expanding it to other communities. Moreover, the socio-economic and environmental impact of the application needs to be scientifically assessed.

8 References

Atkinson, G., & Mourato, S. (2008). Environmental Cost-Benefit Analysis. *Annual Review of Environment and Resources*, *33*(Volume 33, 2008), 317–344. https://doi.org/10.1146/annurev.environ.33.020107.112927

Baivaland, B., & Fernández-Giménez, M. E. (2012). Meaningful Learning for Resilience-Building Among Mongolian Pastoralists. *Nomadic Peoples*, *16*(2), 53–77. http://dx.doi.org/10.3167/np.2012.160205

Bruegger, R. A., Jigjsuren, O., & Fernández-Giménez, M. E. (2014). Herder Observations of Rangeland Change in Mongolia: Indicators, Causes, and Application to Community-Based Management. *Rangeland Ecology & Management*, *67*(2), 119–131. https://doi.org/10.2111/REM-D-13-00124.1

Clark, R. (1996). *Methodologies for the economic analysis of soil erosion and conservation* (No. GEC 96-13). Centre for Social and Economic Research on the Global Environment. https://obnb.uk/p8369801-methodologies-for-the-economic-analysis-of-soil-erosion-and-conservation

Densambuu, B., Sumjidmaa, S., Bestelmeyer, B., & Ulambayar, B. (2018). *National Report on the Rangeland Health of Mongolia—Second Assessment | Land Portal*. https://landportal.org/library/resources/national-report-rangeland-health-mongolia-second-assessment

Dept, I. M. F. A. and P. (2019). Front Matter. *IMF Staff Country Reports*, *2019*(298). https://doi.org/10.5089/9781513514208.002

Dreze, J., & Stern, N. (1987). The theory of cost-benefit analysis. In *Handbook of Public Economics* (Vol. 2, pp. 909–989). Elsevier. https://EconPapers.repec.org/RePEc:eee:pubchp:2-14

Fernández-Giménez, M. E. (1999). Sustaining the Steppes: A Geographical History of Pastoral Land Use in Mongolia. *Geographical Review*, *89*(3), 315–342. https://doi.org/10.2307/216154

Fernandez-Gimenez, M. E. (2000). The Role of Mongolian Nomadic Pastoralists' Ecological Knowledge in Rangeland Management. *Ecological Applications*, *10*(5), 1318–1326. https://doi.org/10.2307/2641287

Gao, W., Angerer, J., Fernandez-Gimenez, M., Reid, R., Batkhishig, B., Fassnacht, S., & Wilson, D. (2015). Is overgrazing a pervasive problem across Mongolia? An examination of livestock forage demand and forage availability from 2000 to 2014. *Proceedings of Building Resilience of Mongolian Rangelands. A Trans-Disciplinary Research Conference*, 35–41.

Gombodorj, G., & Pető, K. (2022). IMPACT OF THE MINING AND AGRICULTURE SECTOR ON THE MONGOLIAN ECONOMY. *Oradea Journal of Business and Economics*, *7*, 74–85. https://doi.org/10.47535/1991ojbe139

Gonchigsumlaa, G., & Damdindorj, S. (2021). Private cost-benefit analysis of herder household mobility in Mongolia. *Mongolian Journal of Agricultural Sciences*, *34*, 65–79. https://doi.org/10.5564/mjas.v34i3.1921

Haile, M. G., Machiraju, S., & Gill, J. (2022). *Green Transformation of the Mongolian Agri-Food System*. World Bank. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099530006012264185/p17426201d1e7c09f0bf560a80824f5422a

Hardin, G. (1968). The Tragedy of the Commons. *Science*, *162*(3859), 1243–1248. https://doi.org/10.1126/science.162.3859.1243

Hilker, T., Natsagdorj, E., Waring, R. H., Lyapustin, A., & Wang, Y. (2014). Satellite observed widespread decline in Mongolian grasslands largely due to overgrazing. *Global Change Biology*, *20*(2), 418–428. https://doi.org/10.1111/gcb.12365

Himmelsbach, R. (2012). *Collaborative Pasture Management: A Solution for Grassland Degradation in Mongolia?* Brill. https://doi.org/10.1163/9789004231474_010

IMF. (2019). *Greening Growth in Mongolia*. IMF. https://www.imf.org/en/News/Articles/2019/12/09/na121019-greening-growth-in-mongolia

Jamsranjav, C., Fernández-Giménez, M. E., Reid, R. S., & Adya, B. (2019). Opportunities to integrate herders' indicators into formal rangeland monitoring: An example from Mongolia. *Ecological Applications*, *29*(5), e01899. https://doi.org/10.1002/eap.1899

Jargalsaikhan, A., Batjav, B., Baival, B., Ulambayar, T., Lhagvasuren, T., Tsogtbaatar, S., & Nutag Action and Research Institute, P. (2015). *Contemporary mobility of herders in central Mongolia*. Colorado State University. Libraries. http://hdl.handle.net/10217/181716

Kennedy, D. (2003). Sustainability and the Commons. *Science*, *302*(5652), 1861–1861. https://doi.org/10.1126/science.302.5652.1861

Kifana, B. D., & Abdurohman, M. (2012). (PDF) Great Circle Distance Methode for Improving Operational Control System Based on GPS Tracking System. *ResearchGate*. https://www.researchgate.net/publication/267844420_Great_Circle_Distance_Methode_for_Improving_Operational_Control_System_Based_on_GPS_Tracking_System

Koopmans, C., & Mouter, N. (2020). Chapter One—Cost-benefit analysis. In N. Mouter (Ed.), *Advances in Transport Policy and Planning* (Vol. 6, pp. 1–42). Academic Press. https://doi.org/10.1016/bs.atpp.2020.07.005

Langemeier, M. (2023, November 10). Trends in General Inflation and Farm Input Prices. *Center for Commercial Agriculture*. https://ag.purdue.edu/commercialag/home/resource/2023/10/trends-in-general-inflation-and-farm-input-prices-202310/

Levy, H. (2016). Stochastic Dominance and Risk Measures. In H. Levy (Ed.), *Stochastic Dominance: Investment Decision Making under Uncertainty* (pp. 227–238). Springer International Publishing. https://doi.org/10.1007/978-3-319-21708-6_8

Linden, K. E. (2022). Milk is Gold: An Environmental and Animal History of Livestock Herding in Socialist Mongolia. *Dissertation*. https://www.academia.edu/91290598/Milk_is_Gold_An_Environmental_and_Animal_History_of_Livestock_Herding_in_Socialist_Mongolia

Michler, L., Kaczensky, P., Batsukh, D., & Treydte, A. C. (2024). *What will the future bring? – Socio-economic challenges to herder households in the Dzungarian Gobi, Mongolia*. https://doi.org/10.21203/rs.3.rs-4743895/v1

MORE STEP - Home. (n.d.). Retrieved May 1, 2025, from https://www.morestep.org/

Munkhzul, O., Oyundelger, K., Narantuya, N., Tuvshintogtokh, I., Oyuntsetseg, B., Wesche, K., & Jäschke, Y. (2021). Grazing Effects on Mongolian Steppe Vegetation—A Systematic Review of Local Literature. *Frontiers in Ecology and Evolution*, *9*. https://doi.org/10.3389/fevo.2021.703220

Nakayama, T. (2025). Grazing impacts on Mongolian grasslands assessed by an eco-hydrology model. *Environmental Science and Pollution Research*, 1–12. https://doi.org/10.1007/s11356-025-36083-2

Nandintsetseg, B., Shinoda, M., & Erdenetsetseg, B. (2018). Contributions of multiple climate hazards and overgrazing to the 2009/2010 winter disaster in Mongolia. *Natural Hazards*, *92*(1), 109–126. https://doi.org/10.1007/s11069-017-2954-8

Nkonya, E., Gerber, N., Baumgartner, P., von Braun, J., De Pinto, A., Graw, V., Kato, E., Kloos, J., & Walter, T. (2011). *The Economics of Desertification, Land Degradation, and Drought Toward an Integrated Global Assessment* (SSRN Scholarly Paper No. 1890668). Social Science Research Network. https://doi.org/10.2139/ssrn.1890668

Nyamtseren, M., Pham, T. D., Vu, T. T. P., Navaandorj, I., & Shoyama, K. (2025). Mapping Vegetation Changes in Mongolian Grasslands (1990–2024) Using Landsat Data and Advanced Machine Learning Algorithm. *Remote Sensing*, *17*(3), Article 3. https://doi.org/10.3390/rs17030400

Ostrom, E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press. https://doi.org/10.1017/CBO9780511807763

Ostrom, E. (2016). Tragedy of the Commons. In *The New Palgrave Dictionary of Economics* (pp. 1–5). Palgrave Macmillan UK. https://doi.org/10.1057/978-1-349-95121-5_2047-1

Quillérou, E., Guchgeldiyev, O., Ettling, S., Etter, H. C., & Stewart, N. (2016). *Economics of Land Degradation (ELD) Initiative: Broadening options for improved economic sustainability in Central Asia. Synthesis report* [Research Report]. Economics of Land Degradation (ELD) Initiative. https://hal.science/hal-01954788

Rossabi, M. (2021). *Mongolia's Environmental Crises: An Introduction*. Association for Asian Studies. https://www.asianstudies.org/publications/eaa/archives/mongolias-environmental-crises-an-introduction/

Sainnemekh, S., Barrio, I. C., Densambuu, B., Bestelmeyer, B., & Aradóttir, Á. L. (2022). Rangeland degradation in Mongolia: A systematic review of the evidence. *Journal of Arid Environments*, *196*, 104654. https://doi.org/10.1016/j.jaridenv.2021.104654

Sainnemekh, S., Densambuu, B., Bestelmeyer, B., Barrio, I., & Aradóttir, A. (2022). Rangeland Degradation in Mongolia – Using State and Transition Models to Help Understand Rangeland Dynamics. *IGC Proceedings (1989-2023)*. https://uknowledge.uky.edu/igc/24/1-2/42

Sanzheev, E. D., Mikheeva, A. S., Osodoev, P. V., Batomunkuev, V. S., & Tulokhonov, A. K. (2020). Theoretical Approaches and Practical Assessment of Socio-Economic Effects of Desertification in Mongolia. *International Journal of Environmental Research and Public Health*, *17*(11), 4068. https://doi.org/10.3390/ijerph17114068

Sutton, P. C., Anderson, S. J., Costanza, R., & Kubiszewski, I. (2016). The ecological economics of land degradation: Impacts on ecosystem service values. *Ecological Economics*, *129*, 182–192. https://doi.org/10.1016/j.ecolecon.2016.06.016

Tuvshintogtokh, I., & Ariungerel, D. (2013). Degradation of Mongolian Grassland Vegetation Under Overgrazing by Livestock and Its Recovery by Protection from Livestock Grazing. In N. Yamamura, N. Fujita, & A. Maekawa (Eds.), *The Mongolian Ecosystem Network: Environmental Issues Under Climate and Social Changes* (pp. 115–130). Springer Japan. https://doi.org/10.1007/978-4-431-54052-6_10

Ulziibaatar, M., & Matsui, K. (2021). Herders' Perceptions about Rangeland Degradation and Herd Management: A Case among Traditional and Non-Traditional Herders in Khentii Province of Mongolia. *Sustainability*, *13*(14), Article 14. https://doi.org/10.3390/su13147896

United Nations. (2011). From Vulnerability to Sustainability. In *Human Development Reports*. United Nations. https://hdr.undp.org/content/vulnerability-sustainability

Wang, Q., Okadera, T., Nakayama, T., Batkhishig, O., & Bayarsaikhan, U. (2024). Estimation of the Carrying Capacity and Relative Stocking Density of Mongolian grasslands under various adaptation scenarios. *Science of The Total Environment*, *913*, 169772. https://doi.org/10.1016/j.scitotenv.2023.169772

WHO. (2024, April 4). *Dzud emergency in Mongolia moves to risk of floods and environmental contamination*. https://www.who.int/mongolia/news/detail/04-04-2024-dzud-emergency-in-mongolia-moves-to-risk-of-floods-and-environmental-contamination

Worden, R., & Savada, A. (1989). *Mongolia: A country study*. https://unesdoc.unesco.org/ark:/48223/pf0000094752

World Bank Group. (2024). *Mongolia Country Climate and Development Report*. World Bank Group. https://openknowledge.worldbank.org/entities/publication/ac9550ec-3142-482e-97fb-c01bfb40ff30

You, Y., Zhou, N., & Wang, Y. (2024). Policies and Regulations for Desertification Prevention and Control in Mongolia. *Land*, *13*(4), Article 4. https://doi.org/10.3390/land13040559

Zerbe, R. O., & Scott, T. (2015). *A Primer for Understanding Benefit-Cost Analysis*.

Ridder, R., Isakov, A., & Kasymov, U. (2017). Transformation in Pasture Use in Kyrgyzstan. What are the Costs of Pasture Degradation? In K. Hagedorn & K. Khasanov (Eds.), Sustainable Land and Water Management in Central Asia: Institutions and Practices (pp. 1–31). Leibniz Institute of Agricultural Development in Transition Economies (IAMO).