CAPACITY BUILDING PROGRAMME ON THE ECONOMICS OF CLIMATE CHANGE ADAPTATION

Report on the Impacts of Climate Change on Nomadic Livestock Husbandry in Mongolia

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FOREWORD

Climate change, including climate variability, is having detrimental effects on human well-being across the developing world. Increasing temperatures, changing rainfall patterns, rising sea levels and increasing frequency and intensity of extreme weather events are adversely affecting ecosystem functioning, water resources, food security, infrastructure and human health. Moreover, these climate change effects are predicted to become increasingly severe. Conscious of the need to counter climate change impacts, which are already being felt in the region, as well as to prepare for more severe impacts in the future, countries are eager to understand how national budgets can be applied to address the challenges of climate change in the most cost effective manner.

The Capacity Building Programme on the Economics of Climate Change (ECCA) was a three-year programme, comprised of a series of technical training sessions interspersed with mentor-assisted, in-country applied work to enable trainees from ten countries in Asia to master key economic concepts and tools for adaptation planning and decision-making. Launched in October 2012, ECCA addressed a consensus reached during a regional stakeholder consultation that a more comprehensive approach to mainstreaming climate change risks into planning processes was needed to ensure economically efficient climate change strategies at the sectoral, sub-national and national levels. The innovative programme aimed to identify gaps in capacity development needs in an area that is critical for helping countries formulate national adaptation plans and access climate finance.

The programme targeted mid- and senior-level public sector officials from planning, finance, environment and other key ministries responsible for formulating, implementing and monitoring climate change programmes. They were grouped into multi-disciplinary country teams. The country teams participated in four regional workshops, which provided training on theory and the practical application of cost-benefit analysis, and introduced participants to forecasting, modeling and sectoral analysis, focusing on country-specific institutional development plans, within the context of ongoing and new initiatives. Each regional training was interspersed with fieldwork application, guided by economists who served as mentors to the country teams. Together, these two principal programme components provided building blocks to guide participants through the theory, principles and application techniques of economic analysis.

Country teams have now begun reporting the results of their training and in-country application. This report was prepared for the consideration of decision-makers in Mongolia by the Mongolia country team together with their economics mentor and ECCA expert staff. With this training and hands-on experience, it is expected that the members of the country teams will play pivotal roles in mainstreaming climate considerations into future development planning, ultimately seeking to institutionalize these important analytical skills.

The training activities, together with the country reports and the regional report, which compiles the individual country reports to take a view of regional considerations in the agriculture sector, has contributed to a key area of technical assistance required by countries, as per the United Nations

Framework on the Convention of Climate Change's (UNFCCC) guidelines for countries on the National Adaptation Plan (NAP) process – a process established under the Cancun Adaptation Framework (CAF) to help countries identify their medium- and long-term adaptation needs

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ACKNOWLEDGEMENTS

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The core team in Mongolia was led by Jinxia Wang as the country mentor and includes Tsendsuren Batsuuri and B. Erdenetsetseg.

Our thanks extend to the UNDP Country Team of Mongolia for their involvement, and for providing insight into their country portfolio and to Dounjung Roongruang for graphic design.

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EXECUTIVE SUMMARY

The Capacity Building Programme on the Economics of Climate Change Adaptation was supported by the Sustainable Development Cluster of the United Nations Development Programme (UNDP), in collaboration with the Adapt Asia-Pacific Programme of the United States Agency for International Development (USAID). The programme focused on strengthening the capacity of technical officers in the Ministries of Planning and Finance, as well as key line ministries (Agriculture, Water, Public Works and Environment) to understand the economics of adaptation as it relates to medium- and long-term national, sub-national and sectoral development plans. The programme also strengthened local capacities for evaluating different adaptation investment options, namely training on cost-benefit analysis and investment appraisal.

This report was prepared by the team of technical officers from Mongolia and UNDP. It focuses on an assessment of the impacts of climate change on, and potential adaptation options for Mongolia's agricultural sector. It is the product of more than two years of UNDP-led assistance to enhance the skills of technical officers and convening policy dialogues on climate change impacts in Mongolia. Training was provided under the programme to enhance the skills of technical officers at the national and sub-national level in order to estimate the economic costs and benefits of climate change impacts, as well as appropriate adaptation options.

Understanding the economic costs and benefits of climate change at the micro and sectoral levels requires detailed information of households within the sector. These data capture the contribution to productivity and the potential vulnerabilities these households face. Until this work started, there had been numerous ad hoc reports aimed at understanding the impact of climate change, but detailed data required for structured economic evaluation and understanding of the impact and optimal adaptation strategy were lacking. The results of this report and the policy response proposed are based on detailed primary and secondary information collected for the purpose of understanding the impacts of climate change and adaptation options from the bottom up.

Mongolia is a landlocked country, positioned in East and Central Asia, and bordered by China and Russian Federation. The agricultural sector plays a strategic role in the overall economy of the country, and almost the entire sector is focused on livestock. The livestock sector has increased in size over time, and today, around 30 per cent of the total population are herders.[1] As a recent development, the number of animals, specifically goats, in Mongolia, has increased dramatically as the price of cashmere has risen and restrictions on livestock herds have been lifted.

Household data collected through surveys financed by the United Nations Development Programme (UNDP) and the United State Agency for International Development (USAID) covered six agro-ecological zones: alpine, mountain taiga, forest steppe, steppe, desert steppe and desert in 20 provinces and 96 *soums*[2]. The analysis in this study focuses on the decisions that farmers make when choosing the number and type of livestock (such as cattle, horse, sheep or goat) to rear. This decision is influenced, implicitly and explicitly, by a variety of factors including knowledge and expectations

1 World Bank. Mongolia: Index Based Livestock Insurance Project, www.worldbank.org/en/news/feature/2009/09/23/index-based-livestock-insurance-project

2 Mongolia has 21 provinces, which have been divided into 329 districts or *soums*. A *soum,* sum or arrow is a district or a second-level administrative subdivision of Mongolia.

about climate. It stands to reason that a change in climate, all else being constant, would therefore affect the farmer's choice. It is important for policymakers to understand how farmers select livestock and how it is likely to change as climate changes over time, so that they can introduce appropriate policy responses to minimize adverse impacts on the population that rely on livestock for their well-being.

In order for Mongolia to increase the resilience of its livestock sector, including revenues for herders, numerous developmental and environmental challenges will need to be addressed. This study aimed to assess the vulnerabilities of the livestock sector to climate change and the impact of various climate change scenarios on the incomes of herders. Once this is understood, further analysis will be possible to understand herders' choices about the composition of their livestock species, which will change as climate changes. Based on preliminary analysis, the report presents a set of policy recommendations that the Government may wish to consider to address the challenges that herders are likely to face as a result of climate change. More generally, this report and the training that underpinned its preparation represent a template that the Government of Mongolia may wish to consider employing in the future as it prepares and refines climate policies and strategies for its main development sectors.

The report is structured in the following manner. The first three chapters (Background: Scope of the Research Undertaken in Mongolia, Physical and Socio-Economic Characteristics of Mongolia and Climatic Conditions in Mongolia) provide a brief description of Mongolia, presenting the geography of the country and the agro-ecological zones with a focus on potential vulnerabilities and gains as a result of climate change. These chapters also summarize the role of agriculture in the country and include a brief situation analysis. Chapter 'The role of agriculture and the situation analysis of the sector' provides summary statistics and information on the data that were collected specifically for the study on the vulnerability of livestock to climate change in Mongolia. In chapter 'Empirical Results', the econometric model used to evaluate the impact of climate change on agriculture is presented, including initial results that are likely to influence adaptation among livestock herders. Finally, the last chapter presents policy recommendations and conclusions.

Photo credit: UNDP

ACRONYMS

BNU	Beijing Normal University
BNU-ESM	Beijing Normal University Earth System Model
CMCC	Centro Euro-Mediterraneo per I Cambiamenti Climatici
CMIP5	Coupled Model Intercomparison Project
EIC	Environmental Information Center
FAO	Food and Agriculture Organization of the United Nations
FMD	Foot-and-Mouth Disease
GCM	General Circulation Models
GDP	gross domestic product
HadCM3	Hadley Centre Coupled Model Version 3
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
NACM	National Communication of Mongolia
NAP	National Adaptation Plan
NSO	National Statistical Office of Mongolia
OLS	Ordinary Least Square
SDG	Sustainable Development Goal
UNDP	United Nations Development Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
WTO	World Trade Organization

BACKGROUND: SCOPE OF THE RESEARCH UNDERTAKEN IN MONGOLIA

One of the key concerns about climate change in Mongolia is its impact on the agriculture sector. Concerns are high because a large fraction of the population, especially the rural and most vulnerable, are strongly dependent on the sector. In 1994, the Government of Mongolia initiated the National Poverty Alleviation Programme to alleviate poverty and achieve the Millennium Development Goals (MDGs) by halving the number of poor.[3] Extreme poverty is currently measured as people living on US$1.25 a day. With the MDGs transitioning to the Sustainable Development Goals (SDGs), the Government's efforts in reducing poverty (SDG1) are directed at eradicating extreme poverty by 2030.[4] Efforts to achieve food security (SDG2) include setting targets to end hunger and advance sustainable agriculture; to proliferate agriculture productivity; and to double the return of small-scale food producers, with particular attention given to women and indigenous people. The Government of Mongolia's action on climate change (SDG13) aims to strengthen resilience and adaptive capacity to climate-related hazards, as well as to implement early warning systems and mechanisms for capacity building applicable to climate change-related management and planning.

The agricultural sector accommodates up to 35 per cent of its work force (World Bank, 2012). However, evidence-based research on the impacts of agriculture in Mongolia is in a state of infancy. Studies are limited in their scope and our analysis aims to fill current literature gaps. A study by World Bank (2007) points out that 80 per cent of the agricultural sector in Mongolia relies on herding. A vulnerability assessment report shows that climate change impact on Mongolia's agriculture, forestry and natural resources sector will be considerably negative as a result of climate change (Smith et al., 1996). Due to a rise in temperature and reduced rainfall, the amount of arid and semi-arid areas will likely increase. This report suggests that high temperatures might result in a change of the composition of species in drought-tolerant crops and in investments in irrigation systems. Due to data limitations, however, the Smith report does not include any economic analysis.

The lack of economic analyses is a constraint to policymakers in formulating effective policy responses to support ongoing autonomous adaptation efforts and to facilitate planned adaptation. Without a detailed understanding of the impacts of climate change on the agricultural sector across households and across different regions in Mongolia, policymakers will be hard-pressed to identify and introduce targeted policy responses. After all, adaptation is a highly localized action where context matters.

This report provides evidence-based policy insights that are targeted towards supporting policymakers involved in the National Adaptation Plan (NAP) process to better understand the impact of climate change on the agricultural sector. It provides insights into the choices that farmers and livestock herders, the mainstay of the agriculture sector, are likely to make as the climate changes. It also provides an example of a methodology that Mongolia's policymakers can employ when preparing or refining their NAP. The policy insights are the product of analysis conducted by

3 Mongolia: Poverty in a Transition Economy, http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTPOVERTY/EXTPA/0,,contentMDK:20204904~menuPK:443280~pagePK:148956~piPK:216618~theSitePK:430367,00.html
4 SDG Goal #1, http://www.un-mongolia.mn/new/?page_id=1557.

technical officers from the Ministry of Environment and Green Development and the Institute of Meteorology, Hydrology and Environment in Mongolia, and peer-reviewed by economists within the UNDP and United States Agency for International Development's (USAID) Capacity Building Programme on the Economics of Adaptation and within Yale University.

THEORY

The study adopts two techniques: the Ricardian method to assess the magnitude of climate change damages; and cross-sectional adaptation studies, to understand how the livestock sector must adapt. The Ricardian method, first introduced by Mendelsohn, Nordhaus and Shaw (1994), has a rich history of application to study climate change impacts on households in Africa (Kurukulasuriya et al., 2006), Latin America (Seo and Mendelsohn, 2008), India (Dina et al., 1998)) and China (Wang et al., 2009) and across many other locations. Currently, there is no other study that applies the Ricardian method to examine the impacts of climate change in Mongolia;this study aims to fill this literature gap.

The essence of the Ricardian approach in the context of this study is that it compares how well herders cope in one climate versus a different climate. Controlling for other variables across locations, the study uses statistical methods to identify the role climate that plays. Specifically, the method tries to measure how climate will change the net revenue of herders. The impact from climate change can be measured by how it will impact herder incomes: if climate change causes herder incomes to fall, that lost income is a measure of the damage. In brief, the Ricardian approach allows one to make use of the spatial nature of household data (in particular land values and/or a suitable proxy) to determine the marginal value of various determinants of land values including climate attributes. The method assumes that the long-term productivity of land is reflected in prices (Ricardo, 1817).

One of the method's major advantages, especially in research on the impacts of climate change as opposed to impacts of weather, is that it does not rely on observing economic agents over time, but instead, across space. Other advantages include the flexibility of the model and ease of implementation. Collecting household data is relatively easier and more practical than collecting panel data over years. The approach also relies on drawing conclusions based on actual observed practices as opposed to experiments under ideal or simulated conditions. The Ricardian method takes adaptation into account and measures net effects, as well as the fact that herders will change how they raise animals as the climate changes. Most other methods simply measure potential effects, for example, what would happen if herders do not adapt to climate change in any way? Another advantage is that the Ricardian method focuses on changes in climate and not day-to-day weather. Although weather is important per se, weather changes may or may not have the same impacts as climate change. Finally, the method is that it is relatively easy to estimate than other methods, which can require much longer study periods and larger budgets.

There are limitations to the Ricardian method that can pose problems in adequately estimating the impact of climate change. A drawback of the Ricardian model is the omission of variables, which is found in all cross-sectional analysis. The model is proposed for comparative analysis and not for dynamic analysis (Van Passel, Mendelsohn and Masetti, 2012). Mendelsohn and Nordhaus (1996) indicate that in the case of limited price data, underestimation of benefits resulting from climate change and overestimated damages could result. Important control variables that are correlated with both net revenue and climate can lead to biased results. Past studies have revealed there are a number of control variables that ought to be included in the analyses, such as geography, soil type and market access.

Another limitation is that prices are assumed to remain constant, which is likely to be a strong assumption. If climate change causes large swings in prices, these effects need to be taken into account. Much like agronomic studies, the consequence of price changes can be taken into account by post-processing the results with an agricultural general equilibrium model. Notwithstanding these limitations, there are means to test the influence of these assumptions on the final result and draw meaningful insights into the implications of climate change on the agriculture sector.

The Ricardian model is used to assess the magnitude of likely damage from climate change. In addition, cross-sectional adaptation studies are used to understand how the livestock sector is likely to change. The studies explore how climate currently affects herder decisions about the size of their herd and its composition (the portfolio of animals). Both decisions are found to be sensitive to climate. These analyses provide insight into how the livestock sector is likely to change as climate changes.

Photo credit: UNDP

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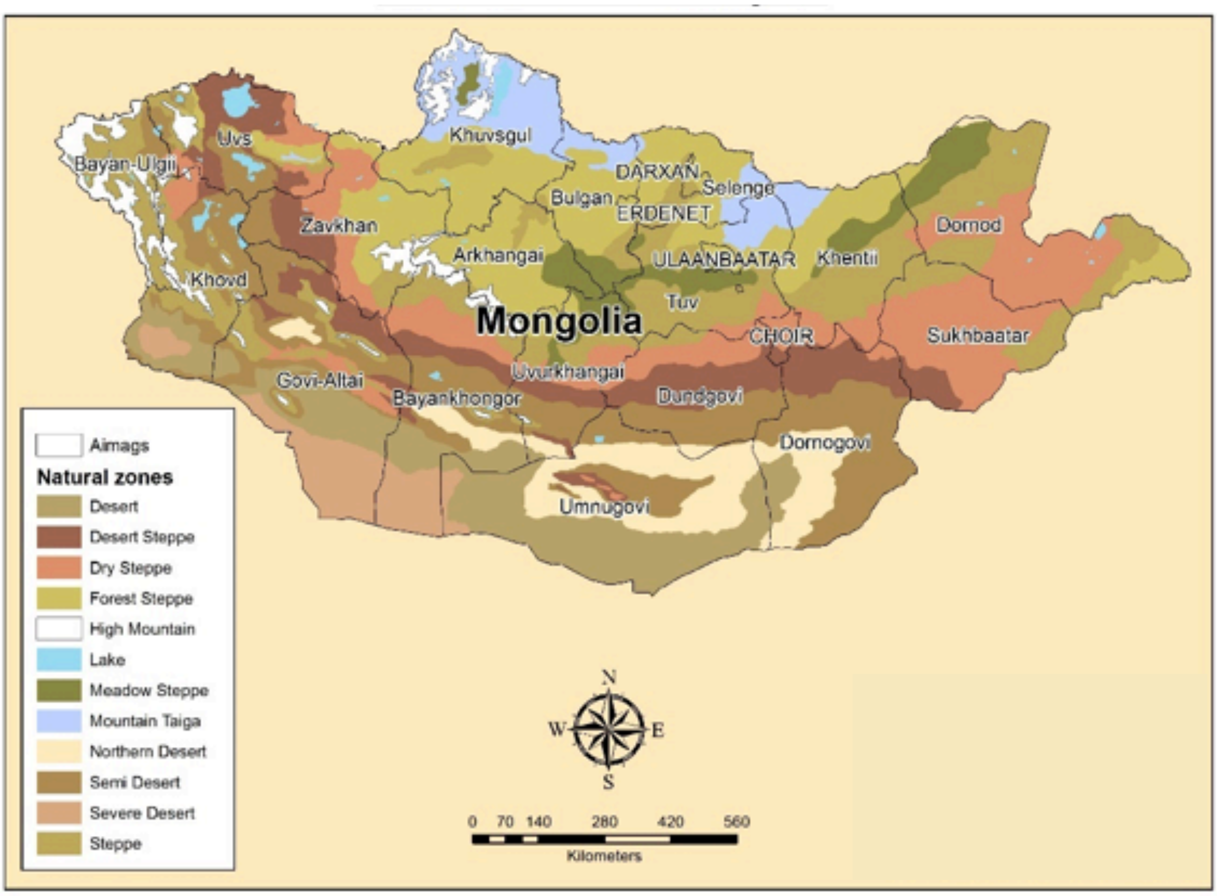
PHYSICAL AND SOCIO-ECONOMIC CHARACTERISTICS OF MONGOLIA

GEOGRAPHIC DESCRIPTION

Mongolia is a landlocked country covering 1.56 million km2, located in East and Central Asia and bordered by Russian Federation and China. The geography of Mongolia is wide-ranging, with the Gobi Desert in the south and three major mountains in the northern and western regions.[5] Mongolia is an mountainous country, as 85 per cent of its area is more than 1,000 m above sea level. Most of Mongolia is between 1,000 and 1,500 m. The Salt Lake Kohko Nuur is Mongolia's lowest point, 552 m above sea level. The peaks of the Tavan Bogd range in the west reach 4,354 m.

Figure 1: Ecological zones in Mongolia



Source: Droege and Gaver. Data sources: USGS, MOR2 Project.

5 The Althaï chain in the west, the Khangaï Range in the central part, and the Khentii mountains to the north.

Mongolia can be divided into six ecological zones - alpine, mountain taiga, forest steppe, steppe, desert steppe and desert. These zones differ in terms of soil quality and composition of plants and animal species (See Figure 1). The alpine zone is characterized by a constant cold climate and strong winds while the mountain taiga zone, with around 5 per cent coverage of the total land area, is characterized as having a relatively cold and humid climate. The forest steppe zone is bordered by the mountain taiga and steppe zones and accounts for around 25 per cent of the total land area. The steppe zone covers almost all of the Eastern and Central Mongolian flat plain covering around 25 per cent of total land area. The desert steppe and desert zones are found in the southern and southern-west parts of Mongolia and cover almost half of the total land area. The climate in these regions is relatively dry and hot, with annual total precipitation of less than 220 mm in the desert steppe and 100 mm in the desert (The GEF, Ministry for Nature and the Environment, UNDP, 1998:3-4).

SOIL CHARACTERISTICS

The Food and Agriculture Organization (FAO), (1996) estimates that from the total area of 1,565 million hectares (ha) available in Mongolia, 1,280 million ha, or 81 per cent, could be utilized for livestock production or for crop production. The soil characteristics are essential for any agricultural activity, as they determine the type of crops that can be grown in a particular region. Mongolian soil is divided into two soil-bio-climate regions, Northern and Southern. The northern region is characterized by high quality dark brown and brown soil. The region harvests two or three times the number of species found in other locations across Mongolia. The most common species found in the northern region are cereals (from which wheat takes the biggest part – 80 per cent) along with others such as rye, oats, barley, potato and vegetables. The southern, southwestern and western parts of the country contain light chestnut, light gray and gray steppe soils. The most common species across these parts is the grass steppe flora (Global Environment Facility. 1998.).

A soil survey conducted during 1983 to 1985 distinguished 34 types of soils across Mongolia. Forty per cent of these are dry-steppe chestnut soils, 17 per cent are brown desert steppe, and 9 per cent are grey brown desert soils. Cultivated soils are found to be dark chestnut and chestnut soils with potential hydrogen (pH) of 6.0 to 7.0 and organic matter content of 3-4 per cent, with 30 cm of depth. These types of soils are more disposed to soil erosion, as they cannot retain much moisture.

Crop production has significantly declined because of climate change and soil erosion. Soil fertility has decreased and soil decay has been reduced by 37 to 52 per cent due to the lack of soil moisture.[6] A study by Stumpp et al. (2005) analysed the impact of grazing on land degradation in Mongolia and found that in the Gobi Gurvan Syhan region, vegetation is at its normal level and has not been negatively impacted by grazing. The study hypothesizes that this is the case because replacements of non-grazing resistant plantation took place in the past. These replacements resulted in the current grassland being grazing-induced pseudo climax that is grazing-resistant (Stumpp et al., 2005:244-251).

6 Engineering problems of crop farming in Mongolia for climate change, http://un-csam.org/Activities%20Files/A0711/02mn.pdf

SOCIO-ECONOMIC CHARACTERISTICS

Data from United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) statistics for the 2007 to 2013 period reveal that GDP per capita has been progressively increasing, with the exception of 2009. However, the level of growth in GDP differs across provinces. Ulanbataar, where most of the high-value industrial development takes place, leads the way. Agriculture accounts for a large share of Mongolia's GDP, and in 2014 accounted for 15.75 per cent.

Figure 2: GDP per capita, 2007-2014

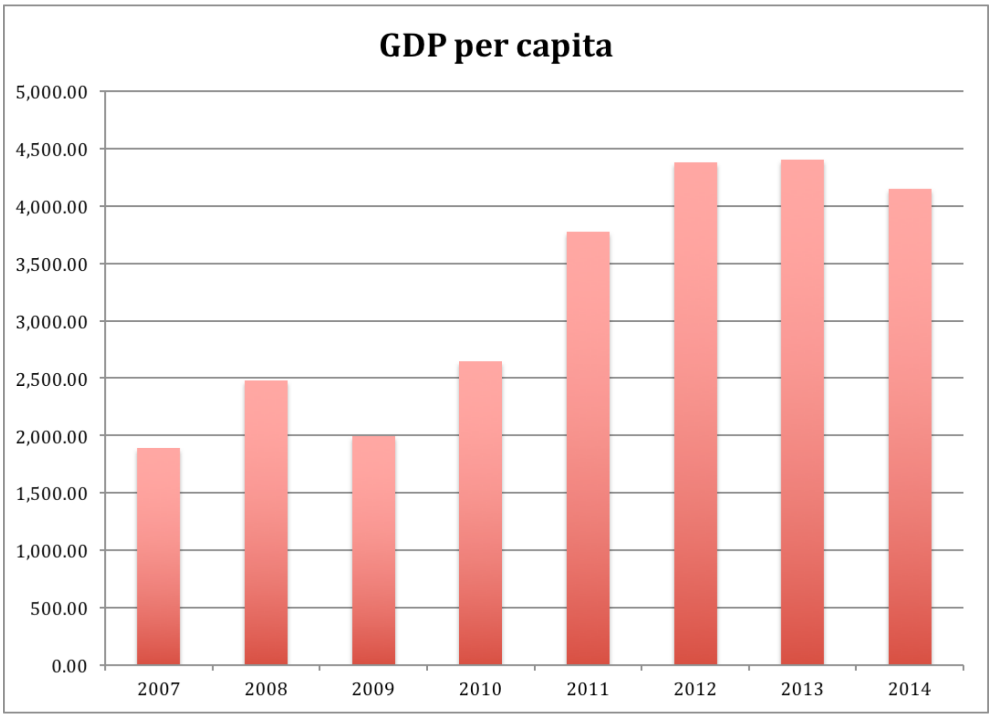
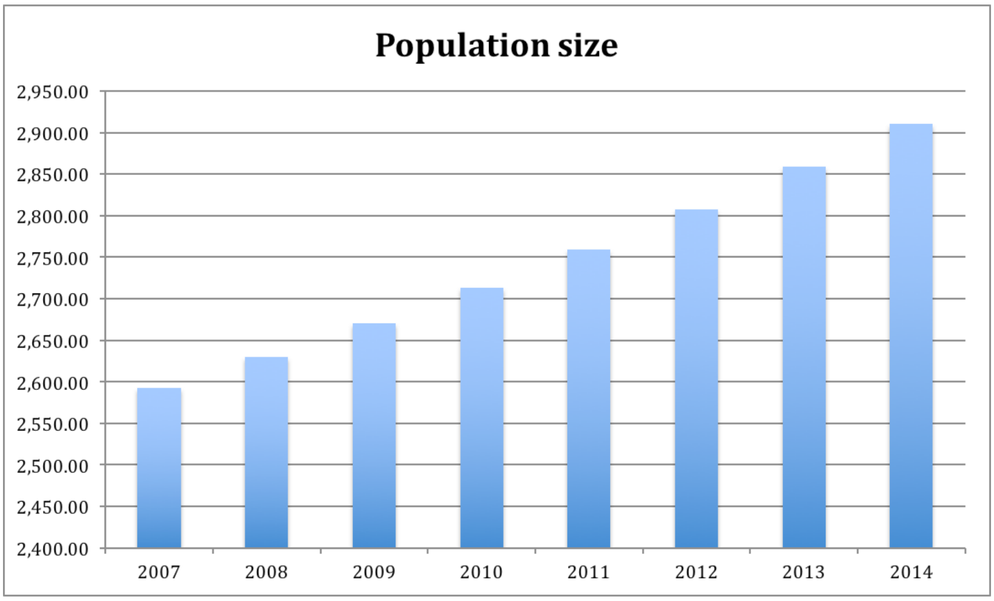


Figure 3: Population size, 2007-2014



Source: UNESCAP database.

Griffin (2002) estimates that from 1989 to 1998, the agriculture sector's share of total employment increased from 32 per cent to 49 per cent.

Figure 4 reveals that employment in the agriculture sector continues to be of great importance for Mongolia and its growth has kept pace with the population increase. Out of the total labour force, agriculture employs 28.6 per cent of the population as of 2014 estimations (World Bank, 2014). Moreover, nearly 30 per cent of Mongolian exports come from agriculture (WTO, 2005).

Figure 4: Employment in agriculture sector, 2007-2013 (%)

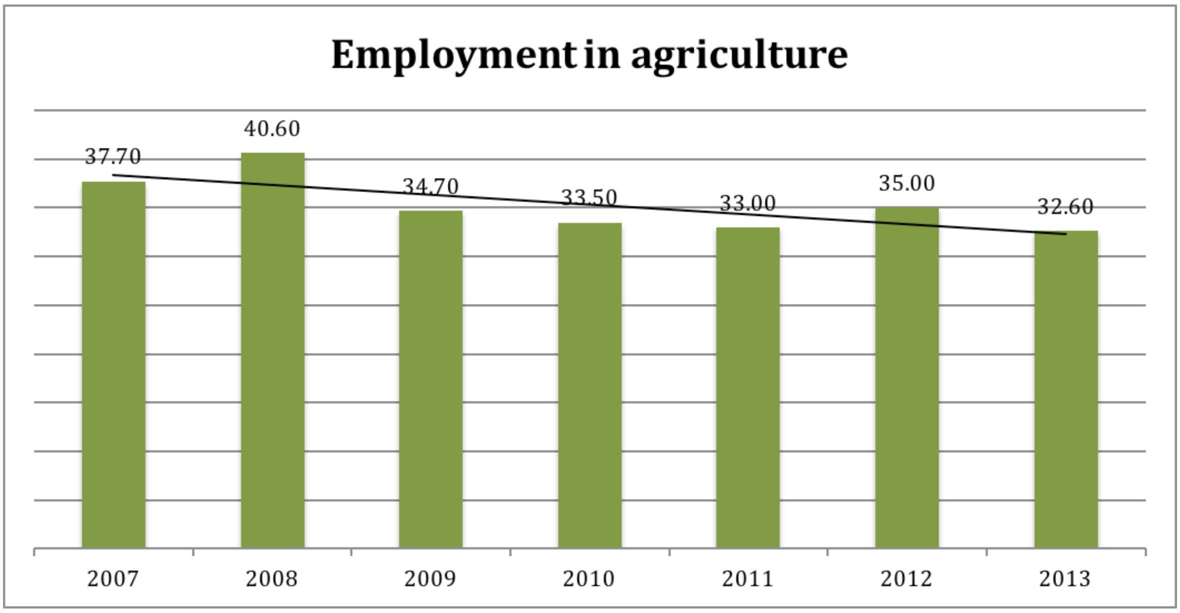
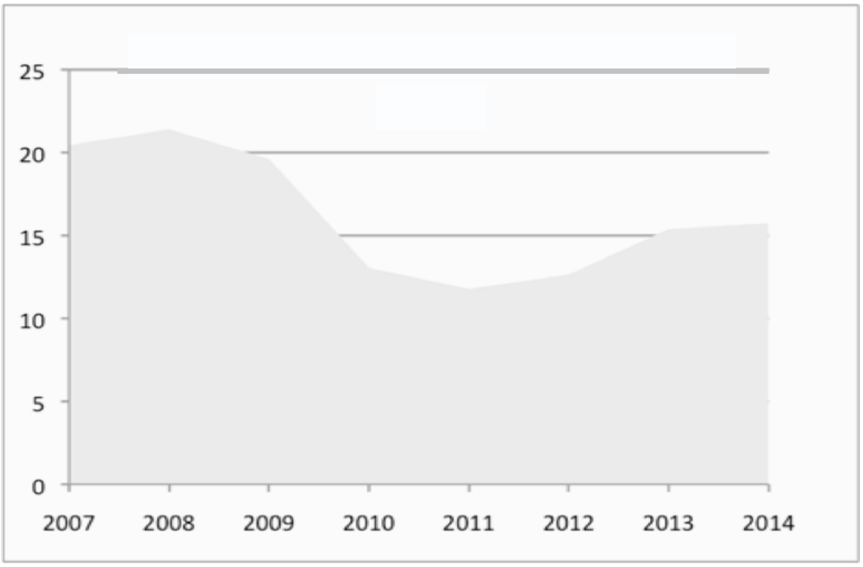


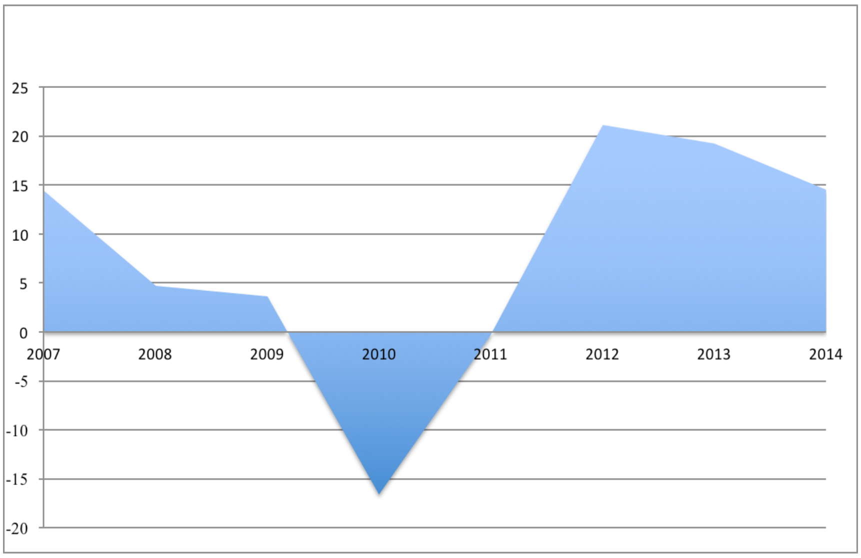
Figure 5 reveals that agriculture as a percentage of GDP has been growing since 2011. Figures for 2014 are nearly 15 per cent, although lower than previous levels of relative importance of over 20 per cent of GDP. The growth of agricultural value added (Figure 6) has decreased from 19.2 per cent in 2013 to 14.5 per cent in 2014. The agricultural policy of Mongolia is to address the decline in productivity and aim for higher efficiency by encouraging private investments. The strategic products are considered to be meat, flour, salt, cereal seeds, wheat and drinking water (WTO, 2012).

Figure 5: Value added of agriculture (%)



Source: Kushmir (n.d.).

Figure 6: Percentage of agriculture value added in constant prices



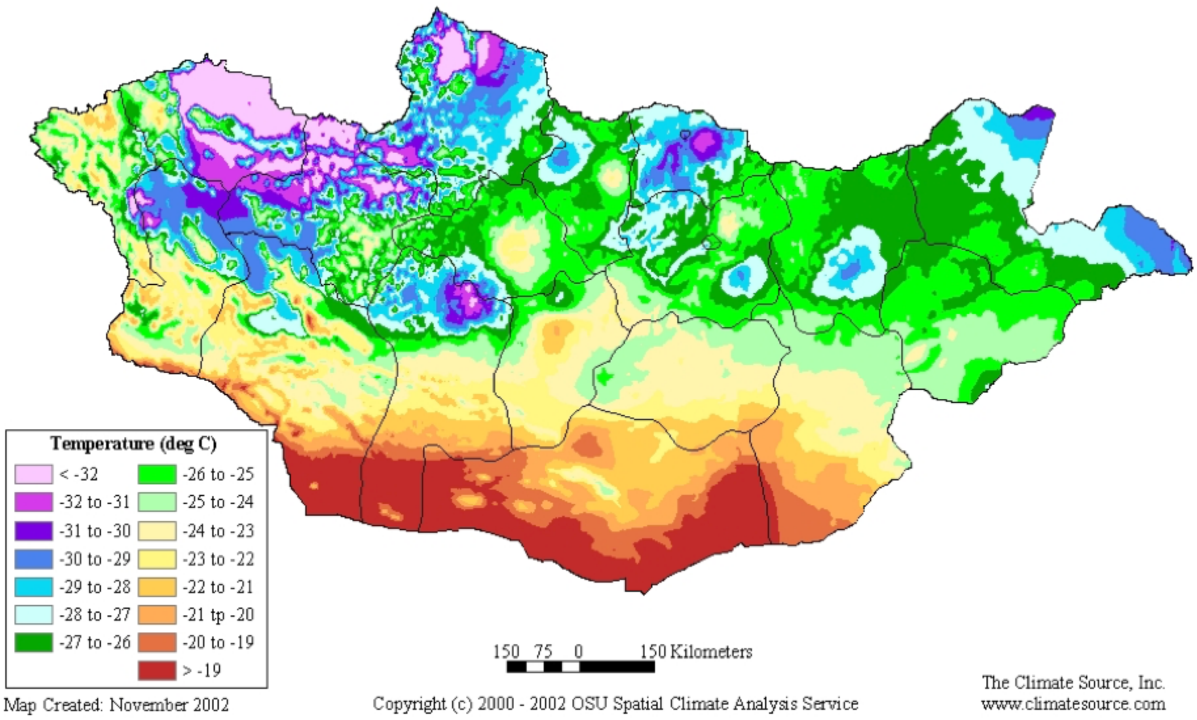
Source: Kushmir (n.d.).

CLIMATIC CONDITIONS IN MONGOLIA

PAST CHARACTERISTICS

Mongolia is affected by climate change and is vulnerable to extreme weather conditions, which impact and threaten its economic and sustainable development. Over the last 60 years, Mongolia's average temperature has increased by 1.9°C, which is more than the world average of 0.6°C to 0.7°C (UNFCCC, 2001). The location of the country, within a narrow inland transition zone between the great Siberian taiga and the Central Asian desert, and more than 1,284 m above sea level, explains some of the observed changes in temperature.

Figure 7: January mean minimum temperature, 1961-1990

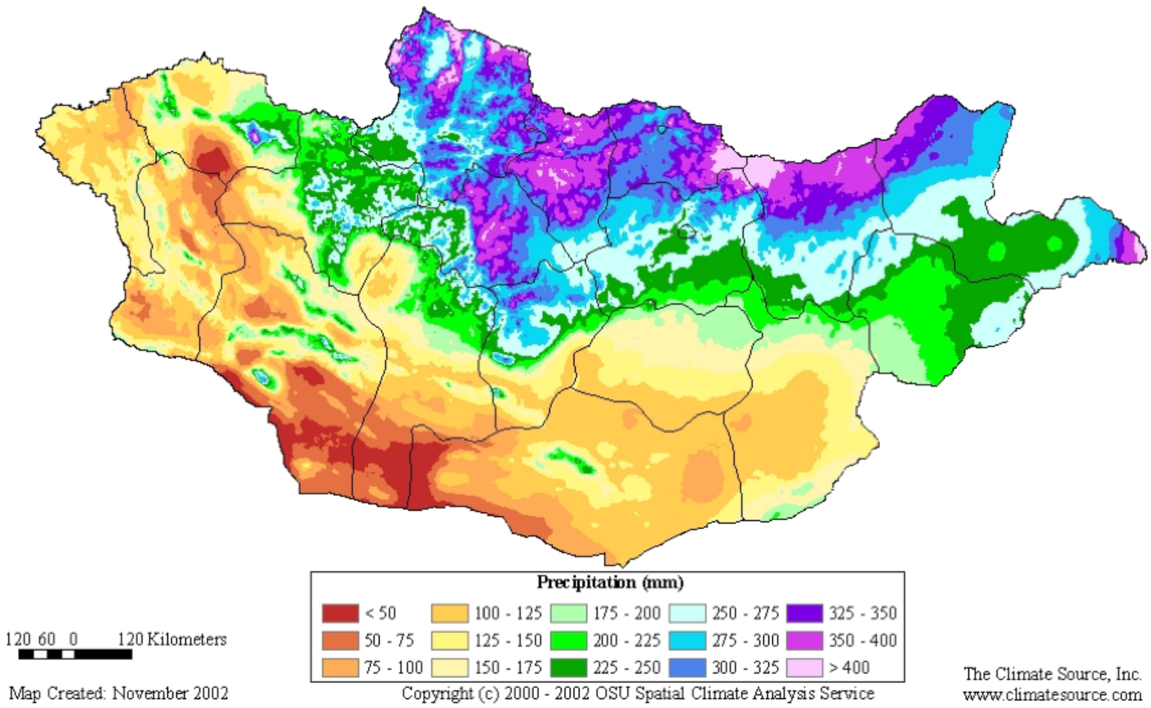


Source: The Climate Source.

The Mongolian climate is extremely continental with a short, hot summer and a long, cold winter, high temperature fluctuation (both daily and seasonal) and a relatively high number of cloudless days. The average annual temperature is between -7.8°C and +8.5°C. July is the warmest month, with mean temperatures between 15°C in the mountains and 20 to 30°C in the southern desert. The lowest temperatures are recorded in January, with monthly averages of under 15°C and minimum temperatures as low as -40°C. In the past 60 years, the annual average temperature has increased during the winter period by 3.6°C, during the spring and fall period by 1.3-1.8°C, and in summer time by 0.5°C (Mongolia's Initial National Communication).

Photo credit: UNDP

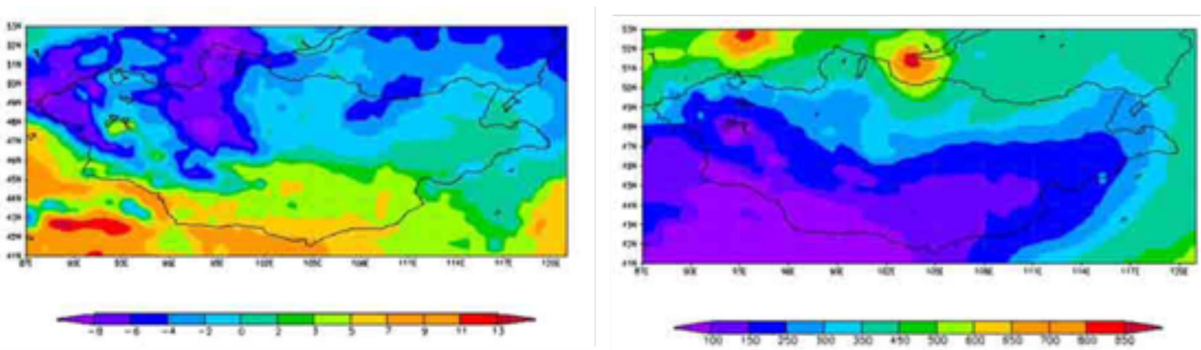
Figure 8: Mean annual precipitation, 1961-1990



Source: The Climate Source.

The annual average precipitation is low: 300-350 mm in Khangai, Khentii and Khuvsgul mountain ranges; 250-300 mm in Mongol Altai and forested areas; and 50-150 mm in the Gobi Desert area. In the past 60 years, the annual average precipitation has decreased by 10 per cent nationally. The annual precipitation has decreased by 8.7 to 12.5 per cent in the central and desert regions, respectively, and increased by 3.5 to 9.3 per cent in the western and eastern regions, respectively. Due to higher temperatures, it is expected that more water will be lost to the atmosphere through evapotranspiration. The impact will be less severe in the western and eastern regions, where there has been increased rainfall (Government of Mongolia, 2012).

Figure 9: Distribution of temperature and precipitation in Mongolia



Source: Government of Mongolia (2012).

CLIMATE PROJECTIONS

Chapter 6 of the National Communication of Mongolia (NACM) provides a brief overview of climate projections in Mongolia, where since 1940 the mean temperature has increased and the precipitation decreased. Over the last 60 years, the annual mean temperature has increased by 1.9°C, particularly in mountainous areas of the country. Overall, there were no significant changes in the amount of annual precipitation. In the Gobi and steppe areas, annual precipitation has decreased. The extreme climate index registered an increase in the number of hot days from 16 to 25 days and the duration of the warm season by 8 to 13 days (maximum air temperature is above 26°C). The number of cold days has decreased by 13-14 days and the duration of the cold season has decreased by 7-11 days. In addition, the growing period for plantations increased by 14 to 19 days (maximum air temperature is above 26°C).

The NACM has used the Hadley Centre Coupled Model, Version 3 (HadCM3) to project future climate change scenarios. The projections have been estimated based on period-wise averaging for 2011-2030, 2046-2065 and 2080-2099 periods versus the baseline climate values for 1980-1999 (FAR, IPCC).[7] Results demonstrate that from 2011 to 2030, the temperature will increase by 1.1°C to 1.4°C, while from 2046 to 2065, it will increase by 2.7°C to 3.6°C, and from 2080 to 2099, the temperature increase will be in the range of 3.7°C to 6.3°C. The respective temperature increases during the winter season alone are projected be 0.2°C to 0.7°C, 1.6°C to 2.5°C, and 3.0°C to 3.8°C. Precipitation is expected to increase during every season apart from summer, which will see a decrease by 2 to 4 per cent from 2011 to 2030. There is a projected increase of up to 4 per cent in 2046-2065 and 7 to 11 per cent in 2080-2099. Estimates for winter precipitation show an increase by up to 14 per cent, 14 to 23 per cent, and 32 to 55 per cent for the same timeframes.

The climate projections from the State Meteorological Institute of Mongolia estimated that air temperature will increase by 3.530°C during the summer season of 2020 and by 6.350°C during the summer season of 2080. The estimates for annual precipitation during the summer season show a decrease by 5.2 mm by 2020 and 13.6 mm by 2080.

OVERVIEW OF CLIMATE CHANGE VULNERABILITIES

Mongolia is subjected to extreme weather conditions, with the most significant climate constraint being the cold weather and semi-arid climate. The harshness of the weather has led to lower productivity, and it has drained rivers and caused vegetation and livestock shortages (UNFCCC, 2001). Following various analyses outlined in the National Communications and the recently submitted Intended Nationally Determined Contribution (INDC), the Government has already acknowledged that climate change will become a significant barrier to its growth (UNFCCC, n.d.). The goal of the Green Development Policy of Mongolia is to ensure environmental sustainability through efficient and effective use of natural resources and through green development concepts and green growth.

A study by Leary et al. (2008) argues that the most concerning change is that which results in either more frequent, longer-lasting drought or more intense drought, both of which could result in: (i) the decrease of pasture plants; (ii) the decrease of palatable species of pasture plants; (iii) reduced water availability; or (iv) the absence of grass on pasture. Droughts also prevent herders from preparing hay

7 HadCM3 Climate Scenario Data, http://www.ipcc-data.org/sres/hadcm3_download.html

and other supplementary feed for animals and dairy products for themselves, and restrict animals' ability to build up the necessary strength (i.e., calories/fat) during the summer drought to cope with the harsh winter and spring windstorms. Without this strength, the animals are more likely to die in large numbers (Leary, 2008).

One of the most common vulnerabilities to climate change is dzud, which occurs during the winter months in Mongolia.[8] *Dzud,* or `livestock famine', is marked by the widespread death of animals because of hunger, freezing and exhaustion. The larger the scale and the longer the duration of *dzud,* the higher the mortality of the livestock. Dzud represents a high risk to humans in the affected areas: it prevents animals from looking for fodder and reduces their access to grazing, which negatively impacts the food security of livestock and human populations. The NACM estimated a loss of eight million livestock during the winter dzud of 2009 to 2010, a number representing approximately 20 per cent of the total livestock as of 2009. As a result, 8,700 herding households remained with no livestock and living conditions worsened, resulting in migration to the cities. Since January 2010, the NACM has registered a sharp fall in temperatures below -40 °C in 19 out of the total 21 provinces.

Photo credit: UNDP

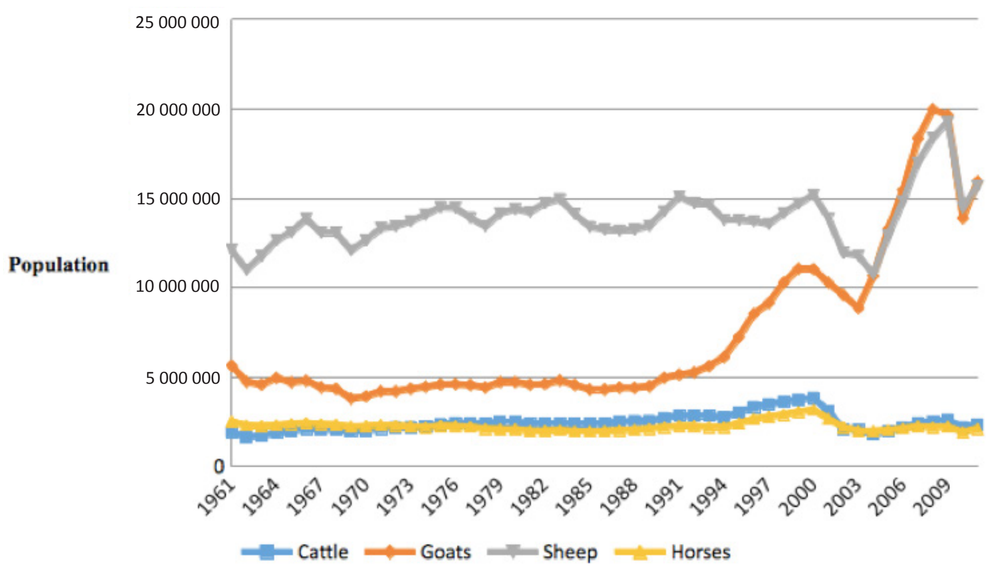
8 Dzud is a Mongolian term for one very complex and long-lasting phenomenon that is mainly caused by natural elements, such as sudden spurts of heavy snowfall, long-lasting or frequent snowfall, extremely low temperatures and drifting windstorms. There are several forms of dzud, depending on the characteristics, contributing factors and causes: Tsagaan (white); khar (black); tumer (iron); khuiten (cold); and khavsarcan (combined).

THE ROLE OF AGRICULTURE AND THE SITUATION ANALYSIS OF THE SECTOR

Mongolia relies heavily on agriculture, and livestock in particular, and in 2014 agriculture accounted for 15.75 per cent of its GDP. The development of the agriculture sector in Mongolia grew moderately at 9.4 per cent in comparison with the mining sector, which grew at 11.1 per cent in the first quarter of 2015. The World Bank forecasts for agriculture in 2016 are lower due to the expectation of harsher weather conditions during the winter. Estimates suggest that a further drop of 20 per cent in crop harvest could result in a reduction of 0.4 per cent of the country's GDP growth.[9] As seen in Figure 2, there has been an overall increase in livestock population over the last 50 years. However, this increase hasn't been uniform across all species, as the populations of horses, cattle, and camels have not increased. There has been a small increase in the sheep population from about 12 million head to 15 million head. The largest change has been the increase in goats from about 5 million head to 15 million head, which is closely related to the increased prices for cashmere. There are other aspects that might have prevented the expansion of livestock populations in the past, such as export restrictions and animal diseases.

Because of the country's strong dependence on the agriculture sector, and particularly herding, Mongolia initiated an index-based livestock financial insurance in 2005. This insurance aims to be particularly helpful for herders located in the drought areas of the country. It has been designed as a buffer against both climate hazards and the risks posed by extreme weather conditions that directly affect livestock mortality (World Bank, 2007).

Figure 10: Mongolian livestock population, 1961-2011



Source: NSO (2012).

9 World Bank Group. Mongolia Economic Update, http://pubdocs.worldbank.org/ pubdocs/publicdoc/2015/11/920971447119845335/meu-nov2015-en.pdf

The sudden changes in livestock population are largely explained by the occurrence of winter dzuds during the periods of 1999 to 2002 and 2009 to 2010. However, while the dzuds caused annual losses, their overall impact was contingent on the species composition decided by the farmers. This is because the dzuds affected different species in different ways. Some species, such as goats and sheep, quickly recovered from these setbacks, which may explain why the number of goats and sheep increased over time. One hypothesis is that if farmers invest in goat and sheep, climate change impact would not be so damaging in the long term as it would be if they were to invest in horse and cattle.

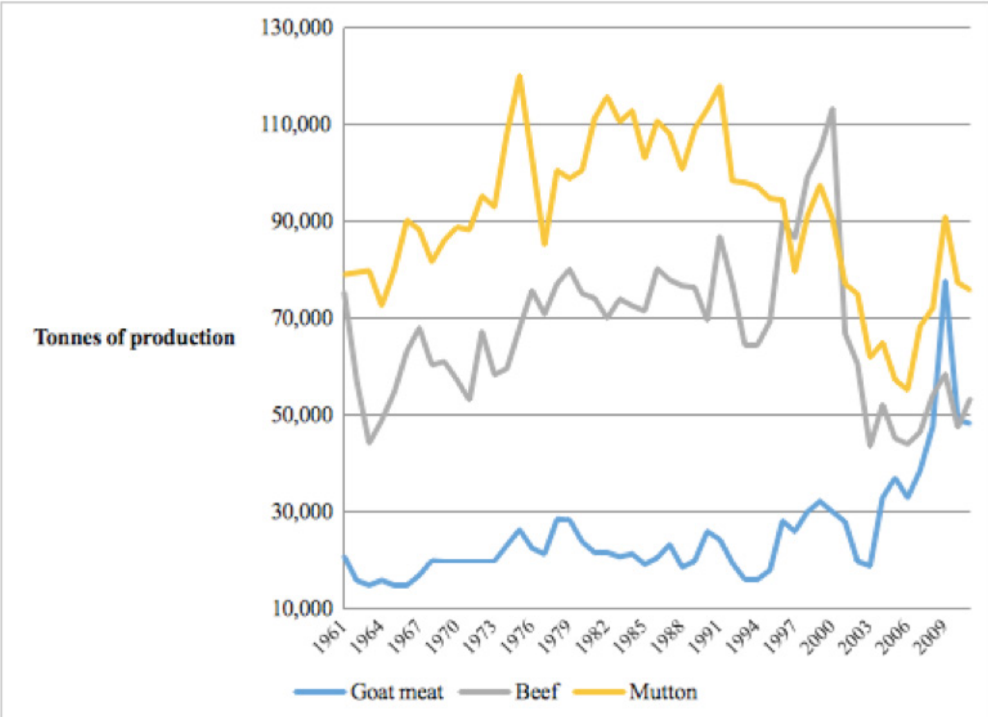
In order to understand the shifts in livestock species composition over time and as a result of climate change, this study focuses on the likely changes in economic incentives for farmers to adopt a specific variety of livestock. In this context, it is important to understand the revenues that herders receive per animal. Figure 10 depicts the annual meat production across Mongolia. It shows that cattle meat production increased from 1964 through to 2000 but then abruptly fell. This could be partially explained by the winter dzud of 1999 to 2002, although it appears that herders made no attempt to rebuild their cattle herds. During that period, Mongolia's national currency, the tughrik, depreciated by an average of 5.4 per cent annually. One hypothesis is that the resultant lower export receipts and lower purchasing power likely accounted for the non-replacement of cattle. Figure 10 also shows that mutton (sheep meat) increased from 1961 through to 1976 until levelling off in 1990 and then falling abruptly.

In order to better understand the importance of meat versus cashmere for Mongolia, Figure 12 presents meat and cashmere prices from 1990-2002. From the figure, it is clear that cashmere is significantly more profitable in comparison to beef and mutton meat. This could suggest the sharp increase in goats from 2003 onwards, as revealed in Figure 11.

Mongolia has a history of animal diseases, and a big concern with the meat from livestock in Mongolia relates to the highly infectious foot and mouth disease (FMD). It affects camels, yaks, sheep, goats and wild animals. There have been several outbreaks of FMD in Mongolia, namely in 1931-1935, 1941-1948, 1963-1974, 2000-2002, 2004-2006 and 2010 and most recently in July 2013 in Bayan Ulgi (Batsukh, Tsedenkhuu and Togoonyam, 2013). The impact of FMD severely affected Mongolia's economy because a number of bans were imposed on the country's exports. The Russian Federation, for instance, imposed a ban on Mongolian meat imports in 2010 due to an FMD outbreak, though it lifted the ban in 2014 (RT News, 2014).

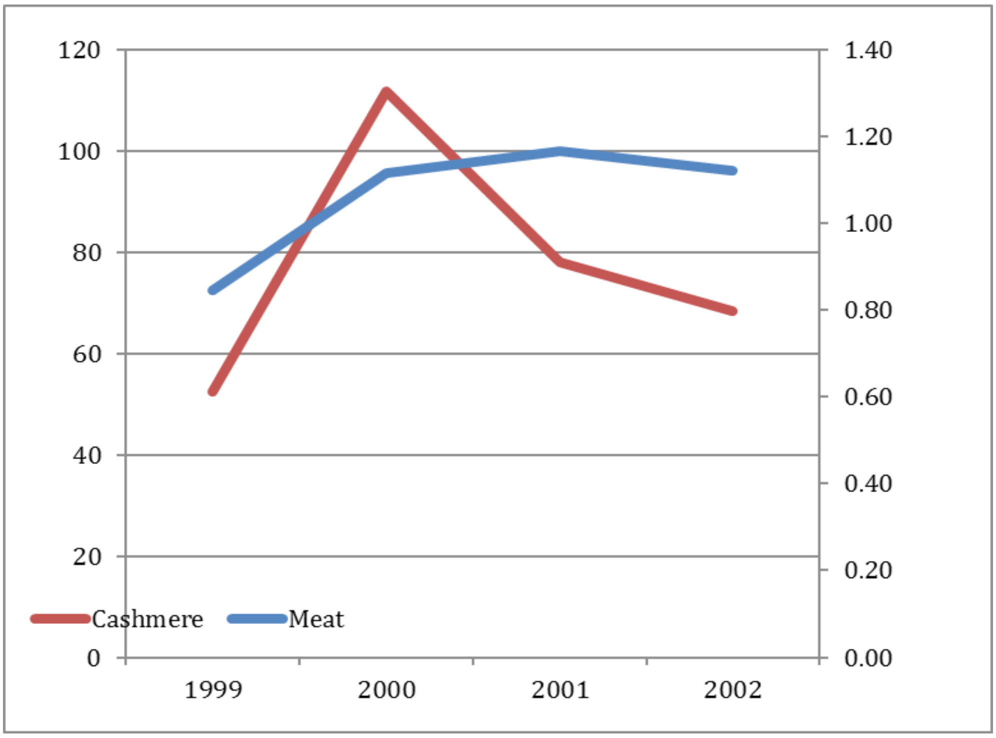
Batsukh, Tsedenkhuu and Togoonyam (2013) provide a number of recommendations to the Government of Mongolia, such as: involving improving herders' knowledge of the consequences of diseases; improving information sharing among herders; and fostering multilateral cooperation with border countries and international organizations, such as the Food and Agriculture Organization of the United Nations (FAO) and the World Organization for Animal Health (OIE). OEI has a vaccination programme for livestock in risky areas and highlights the need for herders to have access to proper veterinarian services.

Figure 11: Mongolia annual meat production, 1961-2011



Source: NSO (2012).

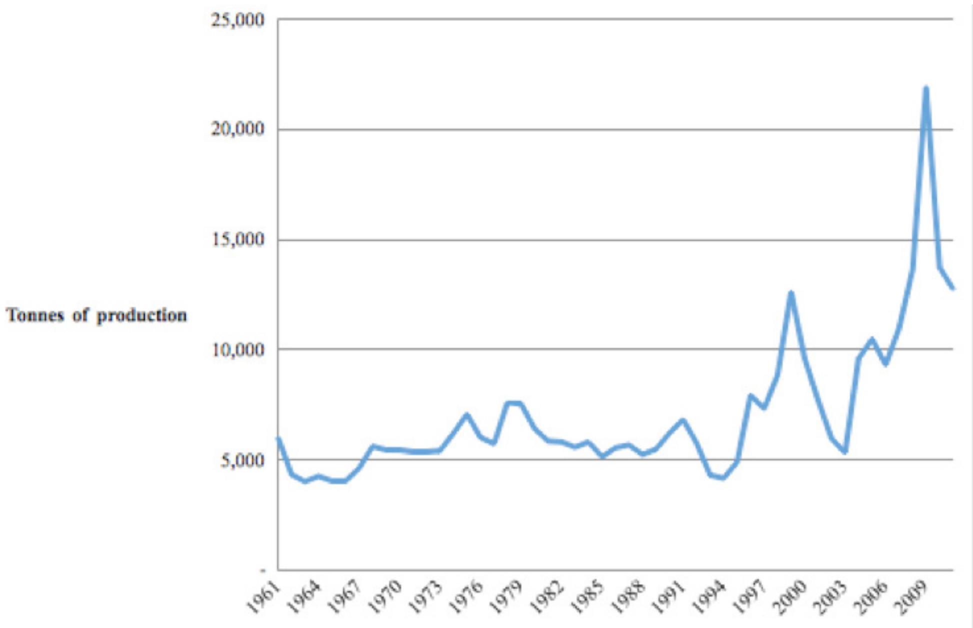
Figure 12: Meat (beef and mutton) and cashmere prices, 1999-2002



Source: NSO, (2002) and World Bank (2003).

In contrast to the overall decrease in the production of sheep and cattle meat, goat meat production rose sharply starting from 2003 (Figure 11). Intuitively, if the setback were a broad reduction in the demand for meat, goat meat would not have risen over the same period as other meat production was declining. The trend in goat meat appears to be driven by demand for another goat product, cashmere. As seen in Figure 13, there has been a dramatic increase in cashmere production starting in 2003. It is very likely that the lucrative market for cashmere is responsible for the large increase in goat in the Mongolian livestock herds. It should be noted that the market for cashmere, well known as one of the warmest materials available also reveals the influence of the winter dzuds in 1999-2002 and 2009-2010.

Figure 13: Cashmere production in Mongolia, 1961-2011



Source: NSO (2012).

DATA DESCRIPTION

SURVEY AND SAMPLING METHODOLOGY

The analysis contained in this report is based on data collected from a customized survey that was implemented in Mongolia in 2013. In total, the survey covered 96 *soums* in 20 provinces (representing six agro-ecological zones). Within each *soum*, five households were selected based on a stratified random selection approach. Distance to the *soum* center and farm size were both factors in selection. The following is the sample distribution in six agro-ecological zones of all 20 provinces.

Table 1: Sample selection in Mongolia

Agro-ecological zones	No. of *soums*	No. of *soums* with meteorology and hydrology stations	No. of selected *soums*
Gobi Desert steppe	73	20	17 (2/15)**
Steppe	125	44	28 (14/14)
Forest steppe	76	22	16 (7/9)
Alpine	8	1	1 (0/1)
Desert	23	10	10 (5/5)
Taiga	15	7	7 (0/7)
Total	320	104	79 ***

Notes:
** In the parenthesis, first number represents the number of *soums*, which had only one zone as specified in relevant rows. The second number is number of *soums* with mixed zones but the dominant zone is the one specified in the row.
*** 17 *soums* in three provinces were not surveyed. Data for households from these *soums* were nevertheless used. The data came from a survey undertaken by a UNDP-supported project on Ecosystem-based Adaptation financed by the Adaptation Fund.

Photo credit: UNDP

COUNTRY SPECIFIC SURVEY ADMINISTRATION

From 12 August to 1 September 2013, a Mongolian team of researchers conducted field surveys in 17 *soums* in three provinces. From 2 September to 1 October, local engineers of the Institute of Meteorology and Hydrology of Mongolia conducted field surveys in 79 *soums* in 20 provinces. All the survey questions covered the activities of households engaged in livestock farming for the period from January to December in 2012.

The National Institute of Meteorology and Hydrology, with a nationwide network, conducts monitoring on hydrology, meteorology and the environmental conditions throughout its network. The agricultural survey was also conducted using its vast network, as it has the technical capacity to collect, monitor and process information. Outlined below are details of the survey team and schedule.

Leaders of the survey:

Erdenetsetseg Baasandai, Institute of Meteorology and Hydrology, soil/grassland expert
Tsendsuren Batsuuri, Ministry of Environment and Green Development.

Timeframe for conducting the survey (in 2013):

- Preparing the survey questionnaire: 13-19 June.
- Testing the survey instrument: 20-30 June.
- Defining survey boundary and representativeness: 10-15 June.
- Preparing guidance on how to conduct the survey and sending it to local hydrology and meteorology engineers along with the questionnaire: 1-8 July.
- Conducting the survey: 10-30 August.
- Compiling survey results and preparing data for analysis: 1 September to 30 October.
- Pre-evaluating the results and correcting the errors in data recording: 1 to 20 November.

The Institute of Meteorology and Hydrology organized training, as part of its regular capacity building programme, for all the local engineers from provinces and counties between 20-22 April, 2013. During the training, a special session was dedicated to introducing the agriculture survey questionnaire and to providing guidance to engineers who would be involved in the data collection exercise. The survey team leaders were at hand to answer questions asked by the engineers. Timely instructions and guidance were also provided to engineers who conducted the field surveys through telephone and email.

SECONDARY DATA SOURCES

Soum-level data on total livestock numbers were obtained from the National Statistical Office of Mongolia (NSO). The total livestock was calculated by multiplying each livestock with its conversion factor given by NSO. Total livestock data used in the analysis were expressed in sheep units. Data on estimated grassland area available in each *soum* were obtained from the Mongolian Land Authority. In addition, data on total area of the *soum*, together with number of wells and streams in each *soum*, were obtained from the Environmental Information Center (EIC). Data on population density were also obtained from NSO, while data on distance from Ulaanbaatar to *soum* centre were obtained from EIC.

Climate data for the equivalent of each district (second level administrative region) in Mongolia is from WorldClim-Global Climate data website. Climate data were downloaded using the latitude and longitude coordinates of each location (defined to be centroid of each second level administrative region). The climate data used in the analysis are the 30-year average temperature and precipitation values, which reflect the long-term climate for each location. The soil data used in the analysis are obtained from the FAO digital soil map database, which provides details on the texture of the soil and the dominant slope of the land at each location. This data also provide information on the dominant soil groups in each location.

SUMMARY STATISTICS

Summaries of the data used in the analysis are presented in Tables 2 and 3,. As shown in Table 2, the average total *soum* livestock in sheep units in Mongolia is 149.9 per square kilometer. Obviously this number differs by *soum*, where the minimum number in one *soum* is only 4.9 per square kilometer, while the maximum in another *soum* is as high as 1,664 per square kilometer. As expected, physical characteristics also differ significantly among *soums*. The household level data also reveal the significant difference in net revenue and household characteristics (Table 3).

Photo credit: UNDP

Table 2: Summary statistics for variables used at the *soum*-level analysis

	Mean	Standard error	Min	Max
Livestock density in 2012 (total *soum* livestock in sheep units by NSO conversion divided by total area, number/km²)	62.59	60.27	3.27	732.03
Percentage of cattle	0.429	0.113	0.0558	0.641
Percentage of horse	0.068	0.068	0.0009	0.496
Percentage of sheep	0.437	0.136	0.179	0.885
Percentage of goat	0.009	0.022	0	0.201
Percentage of camel	0.057	0.029	0.008	0.181
Annual mean temperature (0°C)	-0.918	3.019	-10.19	7.100
Annual total precipitation (mm)	212.4	81.40	58	483
Mean winter temperature (0°C)	-19.07	4.075	-30.27	-10.17
Mean summer temperature (0°C)	15.50	3.116	6.300	22.80
Mean autumn temperature (0°C)	-0.584	2.815	-9.167	7.067
Mean spring temperature (0°C)	0.482	3.085	-8.900	9.300
Total winter precipitation (mm)	6.722	4.142	1	27
Total summer precipitation (mm)	146.0	56.73	37	297
Total autumn precipitation (mm)	33.32	14.48	9	101
Total spring precipitation (mm)	26.34	10.70	6	64
Population density (number/km)	1.377	5.172	0.0800	84.71
Distance from *soum* center to Ulaanbaatar city (km)	1,095	653.3	69.66	2,646
Number of streams per square km of *soum* area	0.0111	0.0129	0	0.0793
Desert steppe zone	0.232	0.423	0	1
Desert	0.0686	0.253	0	1
Forest steppe zone	0.239	0.427	0	1
Steppe zone	0.441	0.497	0	1
High mountain taiga zone	0.0196	0.139	0	1
Undulating land 8%< slope <30%	0.516	0.501	0	1
Flat land 0 < slope <8%	0.0621	0.242	0	1
Hilly land slope >30%	0.451	0.498	0	1

Note: The total number of observations is 304.

Table 3: Summary statistics for household level analysis

	Mean	Standard error	Min	Max
Net revenue of livestock per farm (US$)	24 114	275 871	-54 035	5.604e+06
Net revenue of livestock per livestock (US$)	49.57	522.6	-89.91	11 355
Value of owned livestock per farm (at the end of the year, US$)	49 561	50 716	0	514 016
Experience of household head in herding (total years)	20.77	10.84	0	60
Dummy variable for getting agricultural extension service (yes=1; no=0)	0.667	0.472	0	1
Population density in 2012 (number/km)	12.66	67.19	0.100	702.9
Number of wells per square km of *soum* area	0.00986	0.0114	0	0.0497
Number of streams per square km of *soum* area	0.00909	0.0102	0	0.0577
Desert steppe zone	0.218	0.414	0	1
Desert	0.0939	0.292	0	1
Forest steppe zone	0.208	0.406	0	1
High mountain taiga zone	0.0102	0.101	0	1
Undulating land 8%< slope <30%	0.563	0.496	0	1
Flat land 0 < slope <8%	0.0612	0.240	0	1

Note: The total number of observation is 304 households.

EMPIRICAL RESULTS

The results in this section are based on a series of econometric regressions. In each of the models outlined below, a dependent variable is regressed against a series of independent variables. Various statistical tests are also conducted to determine the robustness of the regressions.

The models in this study aim to bolster understanding of the relationship between a livestock measure and climate variables. The first set of analyses focus on understanding the impact of climate change on a measure of livestock outcome (livestock density, livestock shares, and net revenue). To this end, the analysis focuses on the following key steps. First, using several model specifications, the current variation in livestock outcome observed in the data collected is explained. The model specification also defines the response function for livestock against key climate variables, temperature and precipitation. Once the most appropriate model is identified, the second step in the analysis focuses on understanding the marginal impact of climate on livestock density.[10] This information is important because it provides an indication of the likely change in livestock density if temperature were to change by 1 degree or (separately) precipitation were to change by 1 mm. Using the model, it is then possible to estimate the livestock outcome assuming climate does not change. This predicted value should be close to the observed average livestock outcome measure. A simple t-statistic test can indicate if there is any statistical difference between the observed and predicted livestock outcome measure.

Once confidence in the model is established, it is possible to analyse the impact of climate change on livestock outcome. To arrive at this, the team introduces alternative climate change scenarios (based on the climate scenario data from WorldClim) and examines what the livestock outcome would be if climate alone changes, while all other variables remain the same. The predicted livestock outcome (e.g. density) less the estimated current livestock outcome (e.g. density) using the model provides an indication of the change in livestock outcome as climate changes.

MODEL SPECIFICATION FOR THE DETERMINANTS OF LIVESTOCK DENSITY AT THE *SOUM* LEVEL

The following econometric models are used for analyzing the determinants of livestock density:

$$L_k = \alpha_1 + \beta_1 C_k + \beta_2 P_k + \beta_3 D_k + \beta_4 W_k + \beta_5 E_k + \varepsilon_k \quad (1)$$

$$L_k = \alpha_1 + \gamma_1 C_k + \gamma_2 P_k + \gamma_3 D_k + \gamma_4 W_k + \gamma_5 S_k + \varepsilon_k \quad (2)$$

$$L_k = \alpha_1 + \delta_1 C_k + \delta_2 P_k + \delta_3 D_k + \delta_4 W_k + \delta_5 E_k + \delta_6 S_k + \varepsilon_k \quad (3)$$

These models share many independent variables in common. *C* represents the different climate specifications (seasonal temperature and precipitation), *P* is population density of the *soum* in 2012 (controlling for potential urbanization and constraints on livestock production), *D* is distance from *soum* center to Ulaanbaatar city (km) (a proxy for access to market), and *W* is the number of streams per square km of *soum* area (a proxy for access to water). The models differ depending upon whether they include only *E* (agro-ecological zones), or only *S* (slope) or both variables. It is helpful to compare the model with and without agro-ecological zones because these zones are correlated with climate.

In each of the three models above, the dependent variable, *Lk*, is similar and represents the livestock density in the *kth soum* in Mongolia. It is measured by the total *soum* livestock in sheep units divided by the total area (i.e. number/km2). The team explored different measures to combine animals. The first method used the price of each animal relative to the price of sheep. The second approach merely measured the percentage of each animal of all animals. The third approach used the equivalent impact

10 The marginal impact is the derivative of the livestock outcome measured with respect to the climate variables.

an economic one. After testing the regressions for the three different dependent variables, the team found that the results are robust and the regression using the NSO conversion explained the data the best. The results presented in this report are therefore based on the regressions using the NSO conversation factor.

Table 4 presents a full description of all the independent variables used to explain the observed livestock density.

Table 4: Implication of dependent and independent variables in the models 1 to 3

Variable name	Variable implication
Dependent variable	
L_k	Livestock density in 2013 (total value of livestock in *soum* and sheep unit by NSO conversion divided by total area, number/km^2)
Independent variables	
C_k	Annual mean temperature in the past 50 years (^{0}C)
	Annual mean temperature in the 50 years (^{0}C) (squared)
P_k	Annual total precipitation in the past 50 years (mm)
	Annual total precipitation in the past 50 years(mm) (squared)
	Population density of the *soum* in 2012
D_k	Distance from *soum* center to Ulaanbaatar city (km)
W_k	Number of streams per square km of *soum* area
E_k	Desert steppe zone (1=Yes; 0=No)
	Desert (1=Yes; 0=No)
	Forest steppe zone (1=Yes; 0=No)
	Steppe zone (1=Yes; 0=No)
S_k	Undulating land 8%< slope <30%
	Flat land 0 < slope <8%
	Hilly land slope >30%

Equations (4) to (6) present a similar model as (1) to (3), this time using seasonal climate variables instead of annual values. The seasons are presented in Table 5.

$$L_k = \alpha_1 + \varphi_1 CS_k + \varphi_2 P_k + \varphi_3 D_k + \varphi_4 W_k + \varphi_5 E_k + \varepsilon_k \quad (4)$$
$$L_k = \alpha_1 + \omega_1 CS_k + \omega_2 P_k + \omega_3 D_k + \omega_4 W_k + \omega_5 S_k + \varepsilon_k \quad (5)$$
$$L_k = \alpha_1 + \phi_1 CS_k + \phi_2 P_k + \phi_3 D_k + \phi_4 W_k + \phi_5 E_k + \phi_6 S_k + \varepsilon_k \quad (6)$$

Table 5: Implication of seasonal climate variables in the models 4 to 6

Variable name	Variable implication
C_S_k	Mean winter temperature (^{0}C)
	Mean summer temperature (^{0}C)
	Mean autumn temperature (^{0}C)
	Mean spring temperature (^{0}C)
P_k	Total winter precipitation (mm)
	Total summer precipitation (mm)
	Total autumn precipitation (mm)
	Total spring precipitation (mm)

on the grasslands relative to sheep (NSO conversion coefficient). It is more of a biological measure In the regressions for models (1) to (6), the team adopts an Ordinary Least Square (OLS) approach to estimate the results. Table 8 shows the results for models (1) to (3), and Table 9 shows the results for models (4) to (6).

MODEL SPECIFICATION FOR THE CHOICE OF LIVESTOCK AT THE *SOUM* LEVEL

In addition to exploring how aggregate stocking might change, it is also important to see how the composition of the livestock might change with climate change. This section examines whether the share of specific livestock is dependent on climate.

For adaptation-specific policy responses, the team examines the different choices that herders would make in picking species of livestock as the climate changes. The logic in examining these choices is simple: if climate changes, it stands to reason that the choices people make will also change. There is no reason to assume that rational producers or suppliers will make the same set of choices when a key factor in making those choices also changes. These choices will be captured in the changes in the composition of different livestock at the *soum* level.

The following econometric models were used for analyzing the determinants of livestock shares:

$$Cattle_k = \alpha_1 + \beta_1 C_k + \beta_2 W_k + \beta_3 E_k + \beta_4 S_k + \varepsilon_k \quad (7)$$
$$Horse_k = \alpha_1 + \gamma_1 C_k + \gamma_2 W_k + \gamma_3 E_k + \gamma_4 S_k + \varepsilon_k \quad (8)$$
$$Sheep_k = \alpha_1 + \delta_1 C_k + \delta_2 W_k + \delta_3 E_k + \delta_4 S_k + \varepsilon_k \quad (9)$$
$$Goat_k = \alpha_1 + \varphi_1 C_k + \varphi_2 W_k + \varphi_3 E_k + \varphi_4 S_k + \varepsilon_k \quad (10)$$

Table 6: Implication of livestock variables in the models 7 to 10, and 14 to 17

Variable name	Variable implication
$Cattle_k$	Percentage of cattle number
$Horse_k$	Percentage of horse number
$Sheep_k$	Percentage of sheep number
$Goat_k$	Percentage of goat number

The dependent variable for each of the above models is the percentage of livestock as defined in equations (7) – (10), representing the shares of each type of livestock of the total livestock. The share of any kind of livestock is not an independent activity and relates to the share of other kinds of livestock. In order to account for the relationship between the shares, the SURE (Seemingly Unrelated Regression Estimation) procedure is used to run equations (7) to (10) as a system of equations.[11] The base case for comparison is the share of camels. The results reflecting the relationships in models (7) to (10) are presented in Table 6, while the regression results are found in Table 10.

11 The SURE model encompasses systems of equations where the parameters vary by equation but where correlation across the errors in different equations can provide links that can be exploited in estimation.

Photo credit: UNDP

MODEL SPECIFICATION FOR THE DETERMINANTS OF LIVESTOCK NET REVENUE AT THE HOUSEHOLD LEVEL

The third set of analyses is a Ricardian model, using net revenues from livestock as the dependent variable. The purpose of this analysis is to measure the net impact of climate change on each herder. The analysis determines whether the range of climates in Mongolia lead to different incomes. This can be used to infer what the results would be if a *soum*'s climate becomes more like the climate in another *soum*.

Similar to the first analysis where the researchers explain the current variation in livestock density, the attention here turns to revenues from livestock observed in the household level data. The team calculates the marginal impact of climate on livestock revenues and estimates the revenues from livestock assuming climate does not change. Next, the analysis focuses on the impact of climate change on livestock revenues based on alternative climate change scenarios. The predicted livestock revenues (under alternative climate change scenarios) less the predicted current livestock revenues provides insight into how livestock revenues may change as climate changes. The magnitude of this change suggests how one of the ingredients of poverty reduction (income generation) is likely to be affected by climate change. This provides insight into the profound impacts on targets that the Mongolian Government has set on Sustainable Development Goals (SDGs) 1 and 2 for Mongolia by measuring the aggregate impact of climate change on herders.

The team specifies the following econometric models for analysing the determinants of livestock net revenue:

$$RH_{ik} = \alpha_1 + \beta_1 C_k + \beta_2 H_{ik} + \beta_3 P_k + \beta_4 WH_k + \beta_5 S_k + \varepsilon_{ik} \quad (11)$$
$$RL_{ik} = \alpha_1 + \gamma_1 C_k + \gamma_2 H_{ik} + \gamma_3 P_k + \gamma_4 WH_k + \gamma_5 S_k + \varepsilon_{ik} \quad (12)$$
$$RV_{ik} = \alpha_1 + \delta_1 C_k + \delta_2 H_{ik} + \delta_3 P_k + \delta_4 WH_k + \delta_5 S_k + \varepsilon_{ik} \quad (13)$$

Table 7: Determinants of livestock net revenue variables in the models 11 to 13

Variable name	Variable implication
RH_{ik}	Net revenue of livestock per farm at the *ith* farm household in the *kth soum*
RL_{ik}	Net revenue per livestock in *ith* farm household and in *kth soum*
RV_{ik}	The value of owned livestock per farm at the end of the year in *ith* farm household and in *kth soum*.

The dependent variable *RHik* in model (11) represents the net revenue of livestock per farm at the *ith* farm household in the *kth soum*. Net revenues are calculated by taking the difference between gross revenue from the sale of livestock products and variable input (such as cost of hired labour and material inputs). Family labour cost has not been included in the cost estimation. The dependent variable *RLik* in model (12) represents the net revenue of livestock per livestock in the *ith* farm household and the *kth soum*. Finally, the dependent variable *RVik* in model (13) represents the value of owned livestock per farm at the end of the year in the *ith* farm household and the *kth soum*.

The independent variables C, P and S are as defined in Table 4 above. The independent variable Hik represents two sets of household characteristics, one measuring the number of years of experience in herding of the household head (in years) and another measured by a dummy variable to denote whether or not the household received agricultural extension support services (yes=1; no=0). Several definitions of the variable are tested, including one where water access was measured in terms of the number of streams per square km in the *soum* area (as shown in Table 4) and another that tracked the number of wells per square km in the *soum* area.

The analysis adopted an OLS approach to estimate the above models (11) to (12). The regression results are included in Table 11.

MODEL SPECIFICATION FOR THE CHOICE OF LIVESTOCK AT THE HOUSEHOLD LEVEL

Following a logic similar to that outlined in the section above, the team specifies the following econometric models for analyzing the determinants of livestock choice at the household level:

$$Cattle_{ik} = \alpha_1 + \beta_1 C_k + \beta_2 D_k + \beta_3 E_k + \beta_4 S_k + \varepsilon_k \quad (14)$$

$$Horse_{ik} = \alpha_1 + \gamma_1 C_k + \gamma_2 D_k + \gamma_3 E_k + \gamma_4 S_k + \varepsilon_k \quad (15)$$

$$Sheep_{ik} = \alpha_1 + \delta_1 C_k + \delta_2 D_k + \delta_3 E_k + \delta_4 S_k + \varepsilon_k \quad (16)$$

$$Goat_{ik} = \alpha_1 + \varphi_1 C_k + \varphi_2 D_k + \varphi_3 E_k + \varphi_4 S_k + \varepsilon_k \quad (17)$$

The dependent variable for the above models is the share of each livestock of total livestock of the farmer. Similar to models 7 to 10, the team applies seemingly unrelated regression procedure to the above models. The team also uses the share of camel as the baseline choice to compare the results against. The model regression results are included in Table 12.

DISCUSSION OF THE RESULTS

ECONOMETRIC RESULTS FOR THE DETERMINANTS OF LIVESTOCK NUMBER AT THE *SOUM* LEVEL

As evident from Table 6, models (1) to (3) perform well, with about 55 per cent of the dependent variables explained by the data as indicated by the R-squared statistic. The results also indicate that the explanatory variables are important determinants of the dependent variable. In addition, the regression results are consistent across all the three models, implying that there is no significant correlation between the variable presenting ecological zone and topography. When annual climate variables are replaced by seasonal climate variables (models 4 to 6), the fit of the model to the data improves (with the R-squared statistic improving in terms of its performance, as shown in Table 9). This implies that seasonal climate is important. One cannot just look at the average annual temperature and rainfall to understand impacts on Mongolian livestock.

The model results suggest the following conclusions. The total impact of annual temperature on livestock density is not constant across different temperatures. The result shows that as temperature increases, livestock density will continue to decrease. The impact of seasonal temperature variables provides a different perspective – the impact of temperature on livestock density is negative and constant across different temperature levels in each of the seasons (here the non-linear term is not different from zero). It is only the magnitude and signs of the impacts that are different. Unit increases in winter and summer temperatures have a negative relationship with livestock density, while unit increases in autumn and spring temperature increase the livestock density (Table 9).

It was also evident that an increase in the mean annual precipitation benefits the livestock density. The coefficient of mean annual precipitation is positive and statistically significant. However, too much of an increase results in a reduction of livestock density in Mongolia, as indicated by the non-linear term (squared annual mean precipitation) which is negative and statistically significant. A more detailed analysis shows that minor increases of precipitation during winter and summer are beneficial for livestock density, as indicated in Table 9. However, as precipitation increases, especially during the seasons of winter and summer, livestock density falls. Results for autumn, on the other hand, suggest a U-shaped relation: while precipitation below the marginal level is harmful for livestock density, an increase above the marginal level is positively associated with it.

Additional insights from Table 8 include that human population density is positively related to livestock density, while distance to the city is negatively related to livestock density.[12] This is in line with the team's prior expectations. These results are seen in the positive coefficient of population density and the negative coefficient of distance from the *soum* center to Ulaanbaatar city, with both results being significant at more than 95 per cent confidence. These findings give imply that if the *soum* is more densely populated, the local demand for livestock will be higher and there will be more livestock per square km in the *soum*. Conversely, the further away the *soum* is from Ulaanbataar city, the smaller is the density of livestock. These findings are not surprising given that the main market destination for livestock products is Ulaanbaatar.

12 It is typically hard to interpret human population density in this model because the causality direction is difficult to pin down – do more people mean more animals or do more animals mean more people? The authors interpret this result as correlation.

Finally, livestock density is also positively related with water conditions and local physical characteristics (Table 8). As shown in Table 8, the coefficient of number of streams per square km of *soum* area is positive and statistically significant. This implies that the more streams there are in the *soum*, the denser the livestock will be. This is also understandable given that number of streams could be a good proxy for the availability of surface water in the *soum*. It is assumed that when there is more surface water available in the *soum*, the more livestock the grassland is able to sustain. Stream density is important because without water, grasslands cannot support livestock. Compared with the steppe zone, livestock density is lower in the high mountain zone and desert steppe zone. When the undulating land slope is between 8 per cent and 30 per cent, the livestock density is significantly lower than it is in hilly regions whose land slope is more than 30 per cent. One possible reason that explains why the mountainous regions have better grassland conditions is that they have more precipitation and more suitable temperatures.

Photo credit: UNDP

Table 8: Regression results on the determinants of livestock density at the *soum* level (with annual climate variables)

Variable	**Livestock density (total *soum* livestock in sheep units by NSO divided by total *soum* area)**		
	(1)	(2)	(3)
Mean annual precipitation	1.790***	2.002***	1.633***
	(4.473)	(5.339)	(4.224)
Mean annual precipitation squared	-0.035***	-0.044***	-0.034***
	(-4.051)	(-4.978)	(-3.978)
Mean annual temperature	0.078	0.102	0.056
	(0.316)	(0.466)	(0.230)
Mean annual temperature squared	-0.058**	-0.082***	-0.071***
	(-2.537)	(-3.553)	(-2.949)
Population density of the *soum* in 2012	5.913***	5.585***	5.658***
	(4.939)	(4.994)	(4.860)
Distance from *soum* center to Ulaanbaatar city	-0.002	-0.002**	-0.002**
	(-1.588)	(-2.347)	(-2.284)
Number of streams per square km of *soum* area	138.793***	134.909***	132.814***
	(2.884)	(2.825)	(2.729)
Forest steppe zone	-1.862		-2.495
	(-0.994)		(-1.245)
High mountain taiga zone	-7.559***		-7.715***
	(-4.827)		(-4.233)
Desert steppe zone	-2.264*		-2.409**
	(-1.944)		(-2.114)
Desert	-0.789		-1.838
	(-0.446)		(-1.022)
Flat land 0 < slope <8%		1.833	1.411
		(0.722)	(0.542)
Undulating land 8%< slope <30%		-2.517*	-2.970**
		(-1.966)	(-2.073)
Constant	-6.424	-5.829	-1.089
	(-1.438)	(-1.409)	(-0.237)
Observations	301	301	301
R-squared	0.557	0.555	0.567
Marginal effects of temperature and precipitation at current mean			
Mean annual precipitation	0.538***	0.458***	0.418***
	(3.803)	(3.647)	(3.084)
Mean annual average temperature	0.187	0.256	0.189
	(0.813)	(1.180)	(0.828)

Notes: Robust t-statistics in parentheses. (***), (**) and (*) significant at 1%, 5% and 10%, respectively.

Table 9: Regression results on the determinants of livestock density at the *soum* level (with seasonal climate variables)

Variable	Total *soum* livestock in sheep unit by NSO divided by total *soum* area		
	(4)	(5)	(6)
Total winter precipitation	5.857***	7.160***	6.004***
	(2.792)	(3.344)	(2.790)
Total winter precipitation squared	-0.665***	-0.813***	-0.683***
	(-2.819)	(-3.312)	(-2.818)
Total summer precipitation	0.565**	0.873***	0.590**
	(2.193)	(3.404)	(2.260)
Total summer precipitation squared	-0.004**	-0.007***	-0.005**
	(-2.069)	(-3.445)	(-2.139)
Total autumn precipitation	-1.819**	-2.358**	-1.988**
	(-2.081)	(-2.559)	(-2.190)
Total autumn precipitation squared	0.053**	0.061**	0.056**
	(2.292)	(2.454)	(2.315)
Total spring precipitation	1.557	1.191	1.456
	(1.471)	(1.100)	(1.361)
Total spring precipitation squared	-0.072	-0.040	-0.066
	(-1.565)	(-0.829)	(-1.392)
Mean winter temperature	-6.957**	-6.304*	-6.854**
	(-2.115)	(-1.837)	(-2.036)
Mean winter temperature squared	-0.061	-0.059	-0.062
	(-0.832)	(-0.756)	(-0.821)
Mean summer temperature	-16.253***	-14.069***	-15.358***
	(-3.535)	(-2.844)	(-3.202)
Mean summer temperature squared	0.136	0.116	0.121
	(0.835)	(0.658)	(0.711)
Mean autumn temperature	10.602***	8.468***	10.303***
	(3.432)	(2.760)	(3.353)
Mean autumn temperature squared	-0.057	-0.125	-0.060
	(-0.178)	(-0.392)	(-0.187)
Mean spring temperature	5.809***	5.825***	5.514***
	(4.438)	(4.068)	(3.996)
Mean spring temperature squared	-0.075	-0.029	-0.068
	(-0.408)	(-0.155)	(-0.360)
Population density of the *soum* in 2012	1.093***	1.081***	1.094***
	(15.547)	(15.901)	(15.921)
Distance from *soum* center to Ulaanbaatar city	-0.009***	-0.008***	-0.009***
	(-5.299)	(-5.246)	(-5.236)
Number of streams per square km of *soum* area	24.967	42.586	26.478
	(0.519)	(0.882)	(0.545)
Forest steppe zone	-2.448		-2.588
	(-1.525)		(-1.519)
High mountain taiga zone	-12.448***		-12.055***
	(-5.215)		(-4.984)

Table 9: Regression results on the determinants of livestock density at the soum level (with seasonal climate variables) (cont.)

Variable	Total *soum* livestock in sheep unit by NSO divided by total *soum* area		
Desert steppe zone	-2.625**		-2.698**
	(-2.342)		(-2.345)
Desert	-0.510		-0.873
	(-0.301)		(-0.505)
Flat land 0 < slope <8%		1.822	0.971
		(0.900)	(0.465)
Undulating land 8%< slope <30%		-1.242	-1.255
		(-0.992)	(-0.934)
Zone and Soil interaction	NO	NO	NO
Constant	120.210**	96.554	113.911*
	(2.134)	(1.591)	(1.947)
Observations	303	303	303
R-squared	0.712	0.698	0.713
Marginal effects of temperature and precipitation at current mean			
Total winter precipitation	2.881**	3.522***	2.947**
	(2.501)	(3.037)	(2.506)
Total summer precipitation	0.136	0.156	0.139
	(1.365)	(1.450)	(1.386)
Total autumn precipitation	-0.634	-1.006**	-0.748
	(-1.393)	(-2.133)	(-1.586)
Total spring precipitation	0.290	0.495	0.303
	(0.604)	(1.022)	(0.635)
Mean winter temperature	-4.646***	-4.072***	-4.497***
	(-6.509)	(-6.357)	(-6.671)
Mean summer temperature	-12.053***	-10.488***	-11.598***
	(-7.725)	(-7.349)	(-7.860)
Mean autumn temperature	10.668***	8.615***	10.373***
	(3.809)	(3.096)	(3.724)
Mean spring temperature	5.738***	5.798***	5.450***
	(4.231)	(3.961)	(3.825)

Notes: Robust t-statistics in parentheses. (***), (**) and (*) significant at 1%, 5% and 10%, respectively.

ECONOMETRIC RESULTS FOR THE CHOICE OF LIVESTOCK AT THE *SOUM* LEVEL

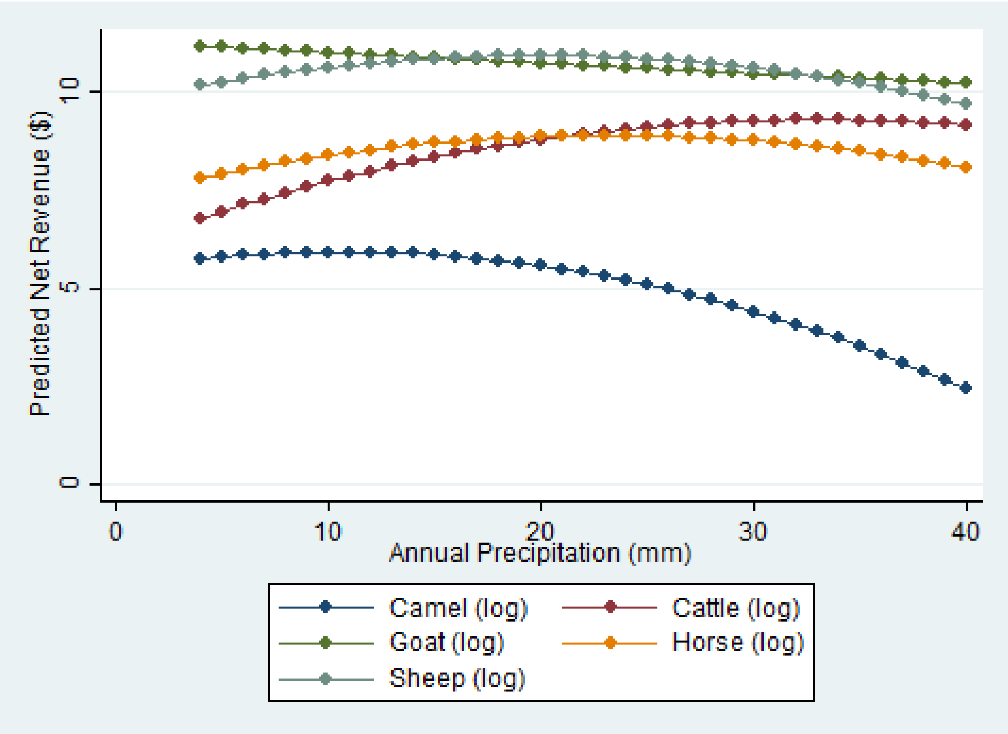
As shown in Table 10, Models (7) to (9) perform well, because of the independent variables are statistically significant and consistent with our expectations. Based on the regression results, the following results can be outlined.

An increase in temperature is beneficial to households that maintain horses and camel as livestock. Warmer annual temperature increases the number of horses and camel, but is not significant for other species. Traditionally, Mongolians would consider camels are better suited to hot temperatures. This is confirmed by the results. However, horses are more suited to "hot" temperatures. Wetter annual conditions increase the number of cattle, horses and sheep. The results for the other two livestock regressions (camel and goats) are not significant (Table 10). The results are better presented in Figure 14. Here, it is clear that precipitation level beyond 15 mm leads to a decline in the choice of camel, while the likelihood of choosing cattle continues to increase until more than 30 mm of precipitation. The choice of horse is peaks at around 20-25 mm of precipitation, and the relationship is similar to that of sheep, with a peak around the same level of precipitation.

The results also suggest that while an increase in precipitation causes an increase in the number of horses and sheep, it reduces the share of goats. While the shares of horses and sheep are positively influenced by an increase of precipitation, a further increase above the break-even point affects the choice negatively. The opposite holds true for goats, which has a U-shaped relation with annual precipitation. From Figure 14, as precipitation increases, the share of horses continues to increase until it peaks at about 29 mm precipitation when it starts to decline (the current mean precipitation is 17.7 mm). A similar relationship is observed for sheep, except that the peak for sheep is at about 25 mm. The relationship between precipitation and the share of goats at the *soum* level is in contrast to that of sheep. This is interesting given that sheep and goat are correlated. The peak precipitation where the share of goats starts to increase is about the same point where sheep starts to decline.

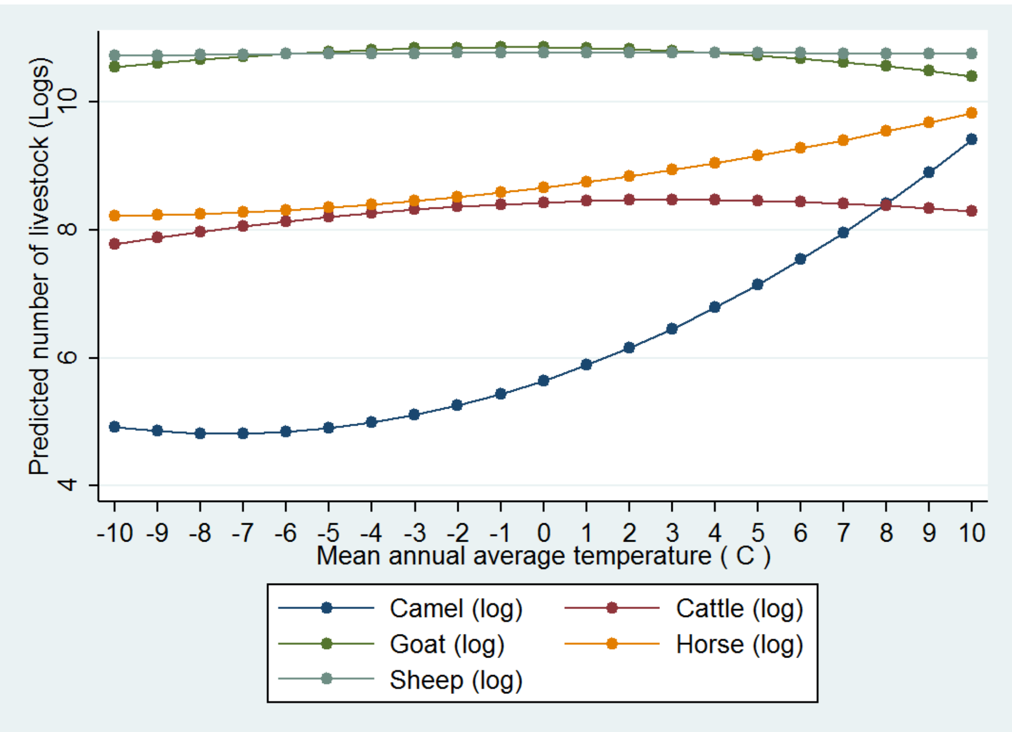
Photo credit: UNDP

Figure 14: Impact of precipitation on livestock shares at the *soum* level



Source: Author's computation based on results from the SURE (Seemingly Unrelated Regression Estimation) procedure.

Figure 15: Impact of temperature on livestock shares at the *soum* level



Source: Author's computation based on results from the SURE model.

Finally, the likelihood of selecting goats as livestock is significantly related with local water condition and physical characteristics (Table 10). The coefficient of number of streams per square km of *soum* area is negative and statistically significant in the cattle regression and positive and statistically significant in the goat regression, which indicates that compared to camels, having more available surface water resources is not beneficial to cattle, but beneficial to goats – higher stream density increases goat shares and decreases cattle shares. Compared to camels, cattle, horses and sheep are less likely to thrive in the desert steppe zone or desert zone, which is an intuitive conclusion. Finally, high mountain taiga zones and steppe are good for cattle and bad for sheep.

Distance to Ulaanbaatar city is important for cattle and camel. The likelihood of owning camel increases in the desert area but is reduced for the other animals. Finally, the number of streams per square km is important for horse, goat and sheep.

Table 10: Regression results on the determinants of livestock shares at the *soum* level (seemingly unrelated regression, comparing basis is camel)

Variable	Log cattle	Log camel	Log horse	Log goat	Log sheep
Annual precipitation	0.197***	0.086	0.134***	-0.028	0.121***
	(3.593)	(1.024)	(3.321)	(-0.761)	(3.172)
Annual precipitation sq.	-0.003**	-0.004**	-0.003***	0.000	-0.003***
	(-2.242)	(-1.970)	(-2.941)	(0.035)	(-3.281)
Mean annual average temperature	0.026	0.224***	0.080***	-0.007	0.001
	(0.796)	(4.535)	(3.380)	(-0.314)	(0.059)
Mean annual average temperature sq.	-0.004	0.015**	0.004	-0.004	-0.000
	(-0.956)	(2.393)	(1.195)	(-1.376)	(-0.094)
Number of streams per square km of *soum* area	-3.868	-15.712**	6.814**	7.180***	7.149**
	(-0.959)	(-2.542)	(2.290)	(2.683)	(2.553)
Desert steppe zone	-0.852***	2.011***	-0.396***	0.076	-0.210
	(-4.214)	(6.489)	(-2.657)	(0.566)	(-1.494)
Desert	-1.048***	2.197***	-0.575**	0.282	-0.591***
	(-3.397)	(4.648)	(-2.528)	(1.377)	(-2.762)
Steppe zone	-0.217	1.002***	0.087	0.078	0.053
	(-1.444)	(4.342)	(0.780)	(0.780)	(0.508)
High mountain taiga zone	-0.181	0.616	-0.136	-0.209	-0.628*
	(-0.382)	(0.850)	(-0.388)	(-0.667)	(-1.912)
Distance from *soum* center to Ulaanbaatar city	0.000***	0.000**	-0.000	-0.000	-0.000
	(2.641)	(2.398)	(-1.504)	(-0.475)	(-1.254)
Flat land 0 < slope <8%	0.138	-0.412	-0.113	-0.028	0.014
	(0.657)	(-1.279)	(-0.727)	(-0.198)	(0.096)
Undulating land 8%< slope <30%	-0.201*	0.009	-0.061	-0.092	-0.071
	(-1.702)	(0.049)	(-0.696)	(-1.174)	(-0.864)
Constant	6.309***	3.996***	7.564***	11.240***	9.872***
	(10.264)	(4.243)	(16.682)	(27.562)	(23.136)
Marginal effects of temperature and precipitation at current mean					
Cumulative precipitation	0.098***	-0.048*	0.038***	-0.027**	0.020*
	(5.877)	(-1.866)	(3.122)	(-2.414)	(1.725)

Table 10: Regression results on the determinants of livestock shares at the soum level (seemingly unrelated regression, comparing basis is camel) (cont.)

Variable	Log cattle	Log camel	Log horse	Log goat	Log sheep
Cumulative temperature	0.032	0.200***	0.075***	-0.001	0.002
	(1.091)	(4.471)	(3.462)	(-0.040)	(0.086)
Observations	268	268	268	268	268
R-squared	0.531	0.644	0.391	0.122	0.339

Notes: t-statistics in parentheses. (***), (**) and (*) significant at 1%, 5% and 10%, respectively.

ECONOMETRIC RESULTS FOR THE DETERMINANTS OF LIVESTOCK NET REVENUE AT THE HOUSEHOLD LEVEL

As shown in Table 11, Models (11) to (13) perform well, with most of the independent variables statistically significant and consistent with our expectations. Based on the regression results, the following conclusions can be drawn.

At the current mean annual temperature, higher temperatures would increase the value of owned livestock but reduce net revenue per livestock, both by a statistically significant amount (Table 11). In sum, there would be no statistically significant impact on net revenue per household. This is likely because any expected increase in revenue from farmers owning more livestock would be offset by a lower net revenue per livestock.

Net revenue per livestock is also negatively correlated with an increase in precipitation. The value of owned livestock is positively affected by increase in precipitation although only at 10 per cent significance. The non-linear relationships between precipitation and net revenue per livestock show that precipitation is an increasing function of net revenue per livestock that peaks at about 28.2 mm before decreasing. Therefore, a unit increase in precipitation increases net revenue per livestock up until 28.2 mm. The relationship between precipitation and value of owned livestock at the end of the year is, however, positive but decreasing (more precipitation beyond the average is not good), up to a point where additional precipitation becomes beneficial to the value of owned livestock.

The household results support the *soum* results that more precipitation means fewer animals. However, the household analysis shows warmer temperatures results in more animals, while the *soum* analysis shows less animals. This may imply warmer temperature leads to more animals per herder but fewer herders overall.

Finally, farmers' net revenue also is influenced by the number of years of herding experience, water endowment, and availability of agricultural extension service. For example, if farmers have more experience in herding, they are more likely to own a higher value of livestock. When farmers receive agricultural extension services, they are not only more likely to have higher value of livestock, but they also have higher livestock net revenues (Table 11). Access to surface or groundwater conditions, increases farmers' livestock revenue per household. The number of streams per square km of *soum* area increases both the value of owned livestock, but also the net revenue per household.

Table 11: Regression results on the determinants of livestock net revenue (OLS regression results)

Variable	Net livestock revenue per household US$	Net income per livestock US$	Value of owned livestock at the end of the year US$
Annual average precipitation	213.228	-2.820***	4,790.225***
	(1.056)	(-2.975)	(2.725)
Annual average precipitation squared	-7.810	0.050**	-112.953**
	(-1.461)	(2.205)	(-2.488)
Annual mean temperature	166.962	-1.972***	3,733.599***
	(1.269)	(-2.929)	(2.943)
Annual mean temperature squared	-14.652	-0.319***	97.575
	(-0.700)	(-2.653)	(0.473)
Experience of household head in herding (total years)	28.601	-0.106	636.269***
	(1.284)	(-0.987)	(2.589)
Dummy variable for getting agricultural extension service if yes=1, if no=0	1,288.567***	-3.872	8,307.083*
	(2.613)	(-1.432)	(1.848)
2012	-8.206***	0.021	-28.868
	(-3.080)	(0.557)	(-1.448)
Number of wells per square km of *soum* area	45,372.166*	188.022	57,686.094
	(1.875)	(1.610)	(0.265)
Number of streams per square km of *soum* area	61,208.437**	-134.702	519,846.689**
	(2.135)	(-1.586)	(2.309)
Flat land 0 < slope <8%	41.383	-3.022	1.134
	(0.045)	(-0.723)	(0.000)
Undulating land 8%< slope <30%	277.354	-4.951	3,153.723
	(0.483)	(-1.632)	(0.548)
Constant	3,684.587**	61.161***	-21,111.344
	(2.065)	(4.625)	(-1.267)
Observations	442	442	442
R-squared	0.105	0.078	0.098
Marginal effects of temperature and precipitation at current mean			
Annual average precipitation	-62.679	-1.068***	799.903*
	(-1.532)	(-3.334)	(1.702)
Annual mean temperature	189.884	-1.473***	3,580.945***
	(1.625)	(-2.628)	(3.367)

Notes: Robust t-statistics in parentheses. (***), (**) and (*) significant at 1%, 5% and 10%, respectively.

ECONOMETRIC RESULTS FOR THE CHOICE OF LIVESTOCK AT THE HOUSEHOLD LEVEL

The last set of models (14) to (17) tested by the team are summarized in Table 12. The models perform well and most variables are statistically significant and consistent with theory. The following conclusions can be drawn from this set of results.

From the results in Table 12, it is apparent that a marginal increase of annual mean temperature is likely to result in herders adopting cattle meat, cattle dairy and camel. The choice of adopting horse, goat and sheep is not responsive to temperature. Thus, warmer temperatures are good for camel, with the household survey supporting the *soum* level results.

A marginal increase in annual mean precipitation is also beneficial to the selection of cattle meat, cattle dairy and sheep. There is a hill-shaped relationship between precipitation and the selection of sheep, cattle milk, sheep, and horse but increasing in cattle meat (Figure 15). Cattle for dairy peaks around 25 mm of precipitation before declining. The results show that at peak precipitation, cattle for meat, followed by goat and sheep are one of the best options for the farmer (Figures 16 and 17).

Other variables that determine the choice of livestock are the zones of desert, steppe, desert steppe, and high mountain taiga. The desert steppe zone and the steppe zone have positive effects on the selection of goats and sheep with negative effects for cattle for dairy. The desert zone is suitable for camel, but not for cattle for meat and dairy. Finally, the high mountain taiga zone is not suitable for goat.

Figure 16: Impact of precipitation on livestock shares at the household level

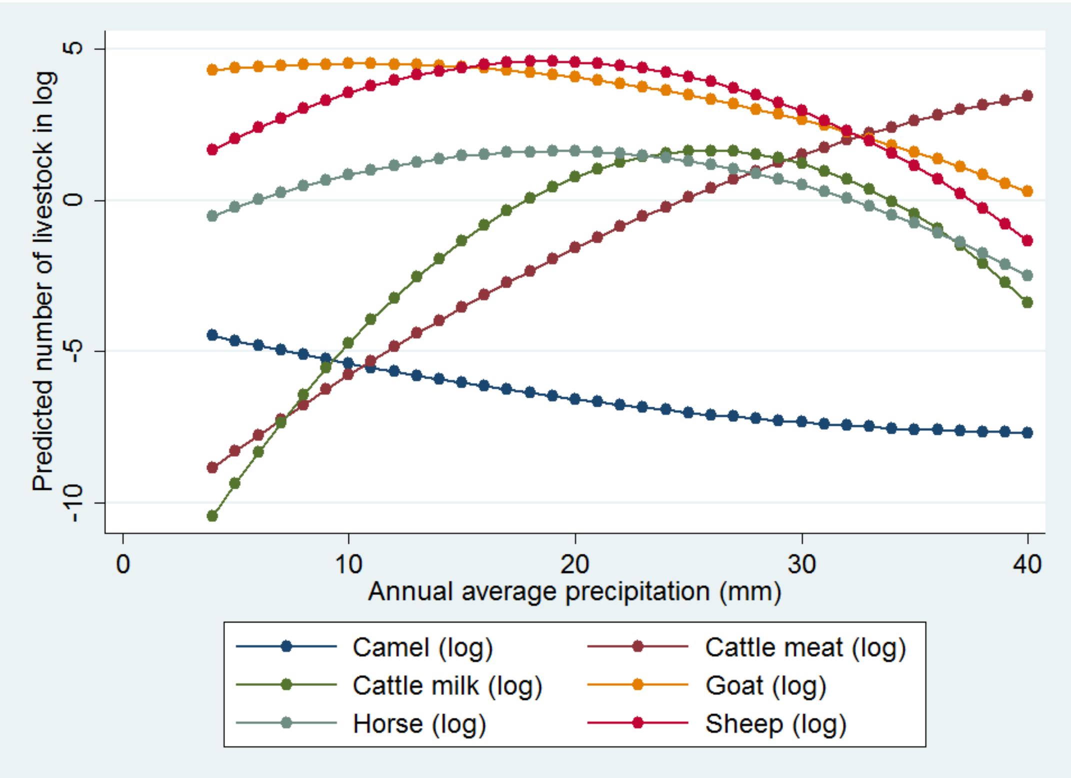


Figure 17: Impact of temperature on livestock shares at the household level

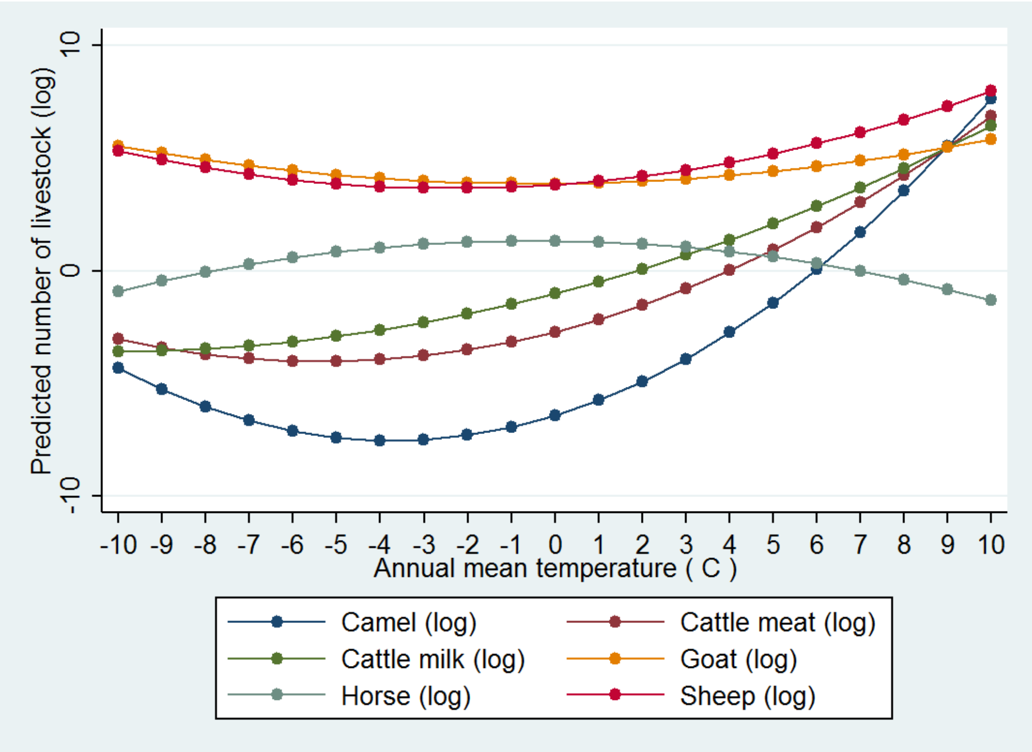


Table 12: Determinants of choice of livestock at the household level (seemingly unrelated regression, comparing basis is camel)

Variable	Cattle meat	Cattle dairy	Horse	Camel	Goat	Sheep
Annual average precipitation	0.587**	1.305***	0.357*	-0.181	0.100	0.500***
	(2.508)	(6.217)	(1.819)	(-0.938)	(0.745)	(3.278)
Annual precipitation square	-0.006	-0.025***	-0.009*	0.002	-0.005	-0.013***
	(-0.952)	(-4.790)	(-1.900)	(0.432)	(-1.424)	(-3.461)
Annual mean temperature	0.495***	0.500***	-0.021	0.597***	0.015	0.133
	(3.267)	(3.679)	(-0.161)	(4.767)	(0.168)	(1.346)
Annual temperature square	0.046**	0.025	-0.025	0.081***	0.018	0.028*
	(1.964)	(1.164)	(-1.239)	(4.163)	(1.336)	(1.843)
Desert steppe zone	-1.006	-1.396*	0.826	1.762***	1.182**	1.074**
	(-1.241)	(-1.920)	(1.214)	(2.629)	(2.532)	(2.030)
Desert	-1.734*	-2.777***	-0.609	3.041***	0.778	-0.305
	(-1.732)	(-3.093)	(-0.725)	(3.676)	(1.350)	(-0.467)
Steppe zone	-0.941	-1.957***	0.021	-0.113	1.046***	0.695*
	(-1.560)	(-3.617)	(0.042)	(-0.227)	(3.013)	(1.766)
High mountain taiga zone	2.307	-0.780	1.902	0.083	-3.839***	0.471
	(1.034)	(-0.390)	(1.015)	(0.045)	(-2.989)	(0.324)
Distance to UB	0.000	0.001**	-0.001**	0.001*	-0.000	-0.000
	(0.714)	(2.415)	(-2.210)	(1.651)	(-1.087)	(-0.540)
Flat land 0 < slope <8%	0.336	-0.264	-1.038	0.780	-0.046	-0.769
	(0.336)	(-0.294)	(-1.236)	(0.943)	(-0.079)	(-1.178)

Table 12: Determinants of choice of livestock at the household level (seemingly unrelated regression, comparing basis is camel) (cont.)

Variable	Cattle meat	Cattle dairy	Horse	Camel	Goat	Sheep
Undulating land 8%< slope <30%	-1.302**	-2.133***	0.182	0.905*	0.883***	0.791**
	(-2.291)	(-4.186)	(0.382)	(1.928)	(2.700)	(2.135)
Constant	-10.051***	-13.780***	-0.704	-5.967***	2.999**	-0.951
	(-4.008)	(-6.128)	(-0.334)	(-2.879)	(2.077)	(-0.581)
Marginal effects of temperature and precipitation at current mean						
Annual precipitation	0.389***	0.413***	0.026	-0.107**	-0.070**	0.032
	(6.501)	(7.693)	(0.521)	(-2.168)	(-2.027)	(0.810)
Annual temperature	0.423***	0.462***	0.018	0.471***	-0.014	0.089
	(3.139)	(3.821)	(0.157)	(4.226)	(-0.176)	(1.012)
Observations	490	490	490	490	490	490
R-squared	0.247	0.332	0.055	0.376	0.173	0.089

Notes: t-statistics in parentheses. (***), (**) and (*) significant at 1%, 5% and 10%, respectively.

ESTIMATING THE IMPACT OF CLIMATE CHANGE

Finally, the analysis looks at the impact of future changes in temperature and precipitation on farmers' net revenue. Future changes in precipitation and surface temperature were simulated using coupled ocean-atmosphere General Circulation Models (GCMs), data from which were downloaded from the Coupled Model Inter-comparison Project (CMIP5) website (Taylor, Stuffer and Meehl, 2012).[13] Details of the GCMs used in this study, and its associated institution, are provided in Table 11 Simulated daily surface precipitation and mean temperatures from each model were averaged to produce estimates of monthly mean climatological changes for the periods 2031-2060, 2051-2080 and 2071-2100, relative to the historical 1971-2000 period, under an assumed Representative Concentration Pathway RCP8.5 (van Vuuren et al., 2011). Here, the temperature changes are given in absolute terms, while the precipitation changes are given in terms of relative percentage changes. It should be noted that the RCP8.5 assumes a very high emission scenario, which is on the very high end of plausible business-as-usual (no mitigation) scenarios. The temperature change by 2100 is assumed to be between 1.5°C and 4.5°C (IPCC) above preindustrial era, which is 0.5°C-3.5°C above 2010 temperatures.

The WUX package,[14] implemented using the statistical open source package R, was used to both calculate the average changes and spatially aggregate the district-level data. The spatial aggregation was performed over the extent of each district in each country as defined by shapefiles of global administrative areas downloaded from www.gadm.org/country. The fractional area of each district falling within each GCM grid cell was used to weight the calculation of the mean for a particular district.

13 CMIP5 - Data Access - Data Portal, http://cmip-pcmdi.llnl.gov/cmip5/data_portal.html
14 Package 'wux', https://cran.r-project.org/web/packages/wux/wux.pdf

Table 13: Beijing Normal University (BNU) coupled atmosphere-ocean model from the CMIP5 archive, which provided precipitation and surface temperature data used to estimate average changes in each district, under an assumed RCP8.5 scenarios[15]

Modelling centre (or Group)	Institute ID	Model name
College of Global Change and Earth System Science, Beijing Normal University	GCESS	BNU-ESM
Canadian Centre for Climate Modelling and Analysis	CCCMA	CanESM2
Centro Euro-Mediterraneo per I Cambiamenti Climatici	CMCC	CMCC-CESM

The projections based on the BNU-ESM model show that temperature in Mongolia is expected to change by about 3.5°C for 2031-2050 and about 5.12°C for 2071-2100. The highest projected increase in temperature comes from the CMCC model, which projects an increase of 6.13°C for 2071-2100. The models also predict significantly higher precipitation levels, with a minimum of a 15.11 per cent increase in the 2031-2050 period under the BNU-ESM model and a maximum of a 72 per cent increase by 2071-2100 under the CMCC-CESM model.

Table 14: Climate change projections for Mongolia under BNU, CanESM2 and CMCC-CESM models

Model name	Climate change measure	20312050 projection	2051-2080 projection	2071-2100 projection
BNU	Temperature change	3.5	3.75	5.12
	Percentage change in precipitation	15.11	26.5	34.7
CanESM2	Temperature change	2.802	4.2	5.94
	Percentage change in precipitation	15.28	26.5	35.78
CMCC-CESM	Temperature change	3.311	4.67	6.13
	Percentage change in precipitation	32.6	52.6	72.00

The changes in net revenue resulting from the projected changes in temperature and precipitation are measured by the difference in the predicted net revenue per livestock based on the different scenarios presented in Table 14. The predictions assume that the other variables in the model remain the same in all the periods.

The results in Table 15 present the impact of climate change based on changes in precipitation and temperature. For each climate scenario, the predicted change in temperature and percentage change in precipitation are applied to the current temperature and precipitation levels. As seen in the 2031-2060 projected impacts based on the BNU model, the projected temperature increase plays a major factor in reducing the net revenue per livestock of farmers (-9.060) in the country, accounting for about 78 per cent of the total reduction in net revenue per livestock (-11.558). The same pattern is seen in the other climate projection models.

15 The authors acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for CMIP, and we thank the climate modeling groups for producing and making available their model output. For CMIP, the U.S. Department of Energy's Program for Climate Model Diagnosis and Inter-comparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals.

The impact of climate change on net revenue per livestock continues to increase in 2071-2100 across the three models. It is important to note that the current average net revenue per livestock in the data is US$ 21.24, which indicates that the average livestock farmer will lose about 50 per cent of his/her income between 2031 and 2060 if the projected temperature and precipitation levels are realized. The farmers will only break even by 2071-2100, with all profits eroded, as indicated by the estimates in 2071-2100.

There are a number of conclusions that can be reached based on these climate impacts. First, it should be noted that the model assumes the same level of technology across the different scenarios and market price dynamics are not taken into consideration in the predictions. These notwithstanding, the erosion of profits will result in a reduction in livestock farmers that could have an impact on unemployment levels in the country. The results presented above could serve as a warning for national agencies and the local government, by demonstrating out the disastrous outcome that climate change would cause to herders and the agriculture sector of Mongolia in the absence of suitable adaptation measures. This outcome is only made worse by: (i) the importance that livestock and agriculture have in the overall economy of Mongolia; and (ii) the fact that the poverty headcount ratio at national poverty lines has been measured at 21.6 per cent of the population (World Bank, 2014).

Table 15: Impact of climate change on net revenue per livestock

Variable	BNU_rcp85	CMCC_rcp85	CanESM2_rcp85
2031-2060 Climate impact			
Cumulative precipitation	-2.498***	-2.523***	-4.508**
	(0.818)	(0.827)	(1.753)
Cumulative temperature	-9.060***	-6.630***	-8.371***
	(2.976)	(2.194)	(2.754)
Climate change	-11.558***	-9.152***	-12.879***
	(3.559)	(2.787)	(3.970)
2051-2080 Climate impact			
Cumulative precipitation	-3.915***	-3.915***	-5.619*
	(1.420)	(1.420)	(2.914)
Cumulative temperature	-10.005***	-11.808***	-13.829***
	(3.281)	(3.865)	(4.523)
Climate change	-13.920***	-15.723***	-19.448***
	(4.267)	(4.844)	(6.321)
2071-2100 Climate impact			
Cumulative precipitation	-4.686**	-4.772**	-5.567

Table 15: Impact of climate change on net revenue per livestock (cont.)

Variable	BNU_rcp85	CMCC_rcp85	CanESM2_rcp85
	(1.870)	(1.932)	(4.500)
Cumulative temperature	-15.896***	-19.993***	-21.004***
	(5.200)	(6.551)	(6.887)
Climate change	-20.581***	-24.765***	-26.571***
	(6.427)	(7.795)	(9.258)
Observations	442	442	442

Notes: Standard errors in parentheses. (***), (**) and (*) significant at 1%, 5% and 10%, respectively.

Photo credit: UNDP

CONCLUSION AND POLICY RECOMMENDATIONS

Mongolia appears to be especially vulnerable to climate change. Between its dzud periods and droughts, it frequently experiences extreme weather conditions, and its average temperature has increased by 1.9°C over the last 60 years, nearly triple the world average of 0.6°C-0.7°C. This study has used empirical analysis to estimate the impact of climate change on Mongolia's agricultural sector, in particular on herders of livestock. This study has examined the impact of climate change on both revenues from herding and choice of livestock. The livestock sector was selected because it is a primary source of the country's income and agricultural growth, especially for the rural poor. This analysis aims to answer the interconnected questions, What potential impacts will climate change have on the livestock sector? Given the projected nature and magnitude of these impacts, how can government officials and policymakers provide policy and strategic direction that will help the country's population better adapt to climate change?

Based on an application of the Ricardian method to assess the impact of climatic and non-climatic variables on livestock density, the research indicates that as temperature increases by 1 degree, livestock density would decrease by 12 levels in the summer and 4.6 levels in the winter. The research indicates that as precipitation increases by 10 mm in the winter, livestock density will increase by 2.8 per cent. Further, an increase of 1°C would cause the net income per livestock to decrease by US$1.473, whereas a 1 mm increase of annual average precipitation would reduce it by US$1.068. The implication of this change on poverty levels in Mongolia and progress towards SDG1 (Poverty Reduction) could result in a decrease by 50 per cent and lead to a significant setback in the progress towards poverty reduction. Policy responses such as extension support, which was shown to be effective, should be strengthened during these periods. The impact of precipitation is nonlinear such that it influences the livestock density positively up to a point where further precipitation increases reduce the density of farm animals. On this basis, it is clear that herders will require support to maintain livestock density during periods of increased precipitation (above 25 mm), especially for species such as horse, sheep and cattle for dairy. Possible policy support responses that will allow herders to build resilience of their livestock system to climate change vulnerabilities could include: providing stronger extension support (which was shown to be effective); improving natural resources management; improving meteorological services; and ensuring that information is timely and accurately provided to farmers, particularly in rural areas.

Other relevant non-climatic variables are human population density, which is positively related to livestock density, and distance to the city, which is negatively related to livestock density. These findings imply that cities such as Ulaanbaatar, which are highly populated and dense, have a higher demand for livestock. However, given that Ulannbaatar is the source of most of the country's GDP, investments and economic development, the Government needs to ensure that there is good access to products and markets, particularly in rural areas. A study by the World Bank (2006) indicates that from 1993 to 2002, Mongolia constructed 1,183 km of new rural roads; in contrast, Cambodia built 13,000 km of rural roads during the same period. Moreover, because of Mongolia's severe weather conditions, particularly during the winter dzud, 7 per cent of its rural roads are closed for nearly two months (World Bank, 2006). Based on these findings, it is important that the Government tackles these issues by ensuring year-round access to products and markets for herders and the rural population of Mongolia.

In the past 60 years, the annual average precipitation in Mongolia has decreased by 10 per cent. Due to lack of rainfall and harsh winter dzud, livestock production has been constrained. This study shows that water resources are essential for livestock density. An increase in mean annual precipitation benefits livestock density. This is particularly true for the seasons of summer and autumn. An increase of 10 mm in mean spring precipitation would result in 5.73 per cent increase in livestock density, while an increase of 10 mm in mean autumn precipitation would increase livestock density by 10.66 per cent. This study also shows that water conditions and local physical characteristics are positively related to livestock density. Efficiently managing the provision of water is an essential task for government officials. Given both the importance of agriculture in the total labour force of the country and the livestock dependence of the agriculture sector, local government needs to work towards the improvement of water access and better infrastructure. Stress on water resources due to competing demands, from cities, mining and other uses, therefore needs to be managed carefully in order to minimize harm to livestock herders.

Based on climate projections, the team was able to analyze the impact of future changes in temperature and precipitation on farmers' net revenue. Results indicate that temperature is expected to rise by 3.5°C in the 2031-2050, by 3.75°C in 2051-2081, and by 5.12°C in the 2071-2100 period. The level of precipitation, as measured in percentage points, would grow significantly in 2031-2050 by 15.11, in 2051-2081 by 26.5, and in 2071-2100 by 34.7 (based on BNU-ESM estimator). These changes would result in dramatic losses in farmers' net revenue. The impact of climate change in the 2031-2060 projections would result in a loss of US$11,558 in net revenue. Losses would increase over time, reaching a peak value of US$ 20,581 in 2071-2100 projections. Temperature also plays an essential role in reducing farmers' net revenue and accounts for 78 per cent in the 2031-2060 projections, 71 per cent in the 2051-2081 projections, and 77 per cent in the 2071-2100 projections.

One implication arising from these results concerns the impact of climate change on the agriculture sector. Given the absolute dependence of the economy on the livestock sector and the projected losses in farmers' earnings, the sector will contract by 2030 if no measures are taken. Climate change would inevitably impact the labour market by gradually reducing farmers' net revenue up to a point where they would start looking for new opportunities. Government agencies should ensure that non-farm employment opportunities are available across the country. Actions need to be taken in order to anticipate and proactively respond to climate change-induced impacts. One such action could be to develop new types of crops resistant to extreme weather conditions, low temperatures and droughts. It is important that the Government provide support directed at strengthening research capacities to develop cultivars and techniques appropriate to local shifts in climate. Establishing early warning systems for extreme weather events as well as for droughts is also a necessary measure.

HOW SHOULD THE RESULTS IN THIS PAPER BE USED?

This analysis sheds light on the vulnerabilities of the livestock sector in Mongolia to climate change. The analysis examines the determinants of livestock net revenue for households including the marginal impact of climate change on revenues. The results suggest that if no efforts are undertaken by 2060 to combat climate change and its adverse effects, farmers in Mongolia would lose as much as 50 per cent of their earnings. The results also suggest that the choices that livestock farmers will make will also change with climate change. It is very likely that farmers will begin to focus more on species such as horses over others, as they have shown to be the ones, who are positively affected by an increase in temperatures.[16] If they make this switch, the impact of climate change on incomes will be US$1.43 of loss per type of livestock. As seen earlier, agriculture employs 28.6 per cent of the

16 This example considered goats because they have been shown to be negatively affected by a rise in temperatures.

total population (as of 2014), which indicates that climate change could have a direct impact on the country's labour market. These results could serve as a guide to policy makers, who need to focus on supporting livestock farmers with adaptation measures. Such adaptation measures could be the improvement of livestock health and reproduction, as shown earlier in the study.

The Capacity Building Programme on the Economics of Climate Change Adaptation was aimed at strengthening the capacities of technical officers in Mongolia. The programme provided training on cost-benefit analysis and evaluation of adaptation investment options. Given the results of this study, it could be seen that more needs to be done at a national level. Livestock farmers need strong support from the local government in combating climate change impacts. Strengthening research capacities for a better understanding of the economic impact of climate change is an ongoing process. Policymakers need to continue the work in the same direction.

Photo credit: UNDP

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