ASSESSMENT OF DZUDS IN MONGOLIA • *Methodology & Findings*

Data analysis

Both the literature analysis and the expert talks as well as the requirements by the economic model led to the identification of the requirement of the creation of a composite risk score to adequately portray both the complexity and diversity of Dzuds in Mongolia. Data constraints were of importance, as not all relevant data was readily available and factors that are more difficult to quantify, such as cultural and social aspects, could not be admitted to the study. Furthermore, the data had to ideally be open-source and easily accessible to be considered.

The data to be obtained and the hazard model had to fit the following criteria to be taken into consideration:

- Simulation of future values and interpretation of historical values for variables that are relevant to Dzuds in Mongolia.
- Differentiation of spatial grids with sufficient spatial resolution, i.e. grids that do not only show one value per country.
- Daily or monthly values that can be calculated into an annual probability of occurrence of three different hazard classifications.
- Establishment of three hazard classifications: low hazard, medium hazard, high hazard.
- Future projections from 2024-2080 or longer.
- Provision of annual projections.
- Possible recreation of data manipulation by future policymakers using open-source data and easily replicable workflows.
- Full projections for the following scenarios
  - Shared Socioeconomic Pathways (SSP) 1- Representative Concentration Pathway (RCP) 2.6 (Sustainability – Low Emissions, Paris Agreement),
  - SSP 2- RCP 4.5 (Middle of the Road – Intermediate Emissions), and
  - SSP 5- RCP 8.5 (Fossil-fueled Development – High Emissions).

Data sources

The aim of this part of the study is the full manipulation of raw data from an appropriate and common international climate model. The choice of the climate model was Meteorological Research Institute (MRI)- Earth System Model (ESM) version 2, abbreviated MRI-ESM2-0. The MRI-ESM2-0 is a climate model developed by the Meteorological Research Institute (MRI) in Japan (Yukimoto et al., 2019). It's part of the Coupled Model Intercomparison Project (CMIP) 6th suite of models, used widely for climate projections under various future scenarios. This model includes advanced representations of atmospheric, oceanic, and land processes, which makes it well-suited for exploring regional climate impacts, particularly for central Asian climates like that of Mongolia.

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For the region, MRI-ESM2-0 is beneficial due to its detailed simulation of mid-latitude weather patterns and its strong performance in capturing temperature and precipitation variability in continental and semi-arid climates. These characteristics make it a useful tool for understanding potential impacts on agriculture, water resources, and ecosystems in the face of climate change in Central Asia and surrounding areas. Another deciding factor was the fact that a lot of models had to be excluded due to a lack of available data and/or scenarios.

The spatial resolution of MRI-ESM2-0 is approximately 110 km x 110 km. The historical baseline used is 1981-2010. In recent years it has become more common to use baselines of 1991-2020, but this was not an option for the chosen model as the baseline data only stretched to 2014. The baseline 1981-2010 offers a good combination of climatic relevance and a sufficiently large data set.

The data was retrieved from Copernicus Data Climate Store (CDS). The CDS provides free and open access to climate data, offers a comprehensive climate data collection, has a user-friendly interface and provides access to a variety of CMIP6 climate projections, which were published in 2021. Furthermore, the CDS is regularly updated and can be tailored for different applications. Lastly, the option exists to apply spatial and temporal subsets to data requests, which made it more efficient in downloading the required data.

The original project scope required that the data had already been cleared for bias and manipulated for further research (such as with Aqueduct and CCKP) and that no programming skills are required. This, however, proved impossible if also taking spatial and temporal differences into account and allowing for the fact that the study aims to identify extreme events and the likelihood thereof. In order to fulfil a projection of this scope on an annual basis, both the use of international climate data and the ability to work with Python are necessary.

Scenarios

The project originally left the choice of climate scenarios open, but subsequently favoured the more commonly used 6th generation SSP scenarios (SSP1-2.6, SSP2-RCP 4.5 and SSP5-RCP 8.5) for a seamless integration into the economic model. Furthermore, these SSP scenarios were chosen over the earlier scenarios as they offer a more comprehensive framework that better integrates socioeconomic conditions with climate projections. The 6th generation of climate scenarios, known as SSPs, couples socioeconomic development narratives with radiative forcing levels to create a more comprehensive framework for climate projections. These SSP scenarios integrate socioeconomic factors such as population growth, urbanization, and economic development with corresponding greenhouse gas emission pathways, allowing for a more nuanced exploration of potential climate futures and their associated societal challenges. While RCPs focus solely on different greenhouse gas concentration trajectories, SSPs incorporate multiple dimensions of societal development—such as economic growth, population dynamics, technological advancements, and policy implementation—that influence and respond to climate outcomes. This integration allows SSPs to represent the interplay between socioeconomic factors and climate impacts, providing a broader context for understanding potential futures. Furthermore, SSPs are structured to work alongside RCPs, linking climate outcomes with realistic, differentiated socioeconomic contexts, thus enabling researchers to explore a wider range of climate adaptation and mitigation strategies. This flexibility makes the new SSPs superior for studying both climate risks and the capacities of societies to address these risks under varied development pathways, offering a more holistic tool for policy-relevant climate research.

Data manipulation

The final required data from the CDS was downloaded on November 19, 2024, subsequently manipulated and the relevant indicators were modelled. Access to the data can be done manually and does not require a specific program, i.e., an Application Programming Interface. Temporal and spatial sub-setting can be chosen manually.

Following the download of the data, the programming language Python (open-access) was used to run all calculations and visualizations. Individual packages and libraries in Python are necessary and have to be installed accordingly and as needed, the most important examples include xarray, pandas, netCDF4, matplotlib and cartopy.

All calculations and modelling presented here, can be executed and replicated with the use of open-source software, but requires programming skills and knowledge of data science.

Calculation and modelling

For the projection of possible Dzuds in Mongolia, several variables had to be considered to fully portray the risk of the most common types of Dzud to occur. Due to the complexity of Dzuds, various factors such as livestock characteristics, land use and vegetation, social and economic factors such as herding practices, access to veterinary care and economic resilience should be taken into consideration, as Dzuds are not only related to climate, but it's almost impossible to do so on a large-scale basis. Additionally, data shortages and restrictions only allowed for a specific selection of variables. The following variables were chosen and subsequently categorized into a composite risk score to project possible future Dzuds in each grid point:

► **Number of windstorm days per winter:** The underlying variable used for this calculation is daily near surface wind speed, calculating the number of windstorm days by setting a threshold for windspeed (10m/s) to give an indication of how frequently severe wind events occur during the winter. Windstorms can cause the formation of snow drifts that can hinder livestock mobility and make grazing areas inaccessible (Sayed 2010; Fernández-Giménez 2012).

► **Extreme cold days**: The underlying variable was daily near-surface minimum air temperature. The number of extreme days was subsequently calculated by setting a threshold of –30 degrees Celsius. This threshold was chosen as cold becomes life-threatening below this point for livestock. It is a common threshold for extreme cold both globally and in Mongolian Dzuds (WHO 2024; GIZ 2023).

► **Monthly snow depth:** Snow depth is a commonly used variable when looking at Dzuds. A deep snow cover restricts access to forage, creates mobility restrictions, increases energy expenditure and carries an increased mortality risk (Nandintsetseg et al. 2018).

► **Average summer SPEI:** The Standardized Precipitation Evapotranspiration Index (SPEI) was selected as the primary parameter for the drought calculations of this project as it offers a comprehensive approach to assessing water balance, making it a highly effective tool for capturing drought conditions. Unlike indices that rely solely on precipitation, SPEI incorporates both precipitation and potential evapotranspiration, allowing it to account for the influence of temperature and other climatic variables on water availability. Droughts are one of the main drivers of Dzuds in Mongolia because of reduced pasture growth, weakened livestock conditions, decreased fodder production and pasture degradation. When the summer preceding the Dzud winter is a drought summer, the Dzud is expected to get considerably worse (Haraguchi et al. 2022).

► **Wind chill**: The underlying variable for this wind chill calculation is daily near surface average temperature and the near-surface wind speed. Wind chill was picked it represents the perceived decrease in air temperature due to the effects of wind and high wind speeds combined with cold temperatures significantly increase livestock stress and energy expenditure. The calculation of the wind chill index only becomes relevant when temperature is below 10 degrees and wind speed is above 4.8 kilometres per hour. Subsequently the mean wind chill for the winter season was calculated (Fernández-Giménez 2012)

► **Number of freeze-thaw cycles per winter**: The underlying variables for this calculation are minimum near-surface air temperature and the maximum near-surface air temperature as well as daily precipitation. The number of days were counted per winter that had a maximum temperature above zero and a minimum temperature below zero. The number of cycles was only calculated when winter precipitation was present on any given day, as the process of freezing and thawing only becomes relevant with precipitation. This calculation is the main indicator for iron Dzud, which is one of the defined Dzud types (UNDRR 2024).

► **The longest cold spell per winter:** The underlying variables used was near-surface minimum air temperature. The longest number of consecutive days below –30 degrees Celsius was calculated per winter to also consider the persistence of cold conditions, as long periods of consecutive extreme cold limits the ability of livestock to recover. It helps to distinguish between winters with short but severe cold events and winters with prolonged periods of extreme cold (Wignaraja 2024; IFRC 2022).

► **Total winter precipitation**: The underlying variable was daily precipitation between November and March. Heavy snowfall can contribute to the Dzud risk by creating thick snow cover that restricts grazing. Adding winter precipitation allows for a better understanding of how snow depth is formed and works well with mean snow depth to understand both the depth and the rate of snow accumulation (FAO 2018).

In the composite risk score four primary factors were considered: precipitation, drought, wind and temperature. These four factors were subsequently turned into different risk variables to create a risk score. The reasoning behind this was to give each factor approximately similar weights after comparing them to historical events. The risk score variables were thus given the following weights:

- Total winter precipitation: 15% (0.15)
- Longest cold spell per winter: 5% (0.05)
- Number of freeze/thaw cycles: 5% (0.05)
- Wind chill: 5% (0.05)
- Average summer SPEI: 30% (0.30)
- Monthly snow depth: 10% (0.10)
- Extreme cold days: 15% (0.15)
- Number of windstorm days: 15% (0.15)

Categorization of risk score variable to factor:

- Temperature: Extreme cold days, wind chill, longest cold spell, freeze/thaw cycles (30%)
- Wind: Windstorm days, wind chill (20%)
- Precipitation: Snow depth, total precipitation (25%)
- Drought: SPEI (30%)

The reasoning behind drought and temperature having a slightly higher weighting is that these are commonly referred to as the two main drivers of Dzud.

Following that, the risk score was calculated for the baseline and future periods to create an annual risk score. It is important to note that years represent winter seasons and the summer preceding it in this calculation. The data is therefore structured as the following: The year 2024 represents the winter season 2023/2024 (starting in November 2023 and ending in March 2024). To enhance the analysis of Dzuds, we further classified each event by its percentile in the historic baseline period. Dzuds were categorized into three hazard levels: low hazard for the 80th percentile, medium hazard for the 90th percentile and high hazard for the 98th percentile. In order to identify the probability of occurrence for each hazard classification as well as the mean probability of occurrence for the historic baseline period, a gradient boosting regressor was run. The gradient boosting regressor method produces a continuous output that can directly be interpreted as the probability of occurrence. The project required the final presentation of the data to be in a Microsoft Excel format. As a last step, the data was thus saved as a NetCDF file and was then subset to the individual countries and exported to a CSV file.

Findings

The mean probability of occurrence during the baseline period for low-hazard Dzud events was 20% in Mongolia and 10% for medium-hazard Dzud events and just above 2% for high-hazard Dzud events, corresponding approximately to 5-year Dzud risks, 10-year Dzud risks and 50-year Dzud events in the baseline period. These numbers change to an average of around 25% by 2024, depending on the scenarios, which were modeled starting with the year 2014 to have consistent time series, and to 15% and 5% by 2024, with variations depending on the scenario. In the SSP 1-2.6 scenario, the risk for Dzud events decreases slowly throughout the century and reaches similar levels again between 25% and 30% by 2100 for low-hazard events, and 18% for medium-hazard events and 5% for high-hazard events compared to 2024. In the SSP 2-4.5 scenario, the probability for all three hazard classifications rises steadily throughout the century, ending the projection at around 40% for low-hazard Dzud events and at 27% and 10% for the other classifications. This shows that this scenario will increase all hazard Dzud events. In the SSP 5-8.5 scenario, the probability for all three Dzud classifications rises significantly in the second half of the century, ending the projected period at just below 60% for low-hazard events, approximately 45% for medium-hazard events and 25% for high-hazard events, which could have devastating effects.

The findings correspond to international projections and estimations that Dzuds will deteriorate in Mongolia, in particular if global efforts are not increased to fight the effects of climate change, which can be seen for the SSP5-8.5 scenario in the second half of the century. The effects become particularly visible beyond 2050 due to cumulative emissions and delayed responses in climate system. Furthermore, there exists an assumption that the rising temperatures forecasted in SSP5-8.5 lead to a decrease in Dzud risks in the shorter term, but this effect is drastically overturned in the second half of the century.

This investigation of Dzuds was an initial, very short study that shows an initial trend in the composite risk score. Based on this, more calculations should be carried out to verify the results and to further explore the effects of each individual variable.

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