The Mongolian electricity sector in the context of international climate mitigation efforts

Emission pathway projections for the electricity sector and analysis of associated health impacts

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On behalf of:
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
of the Federal Republic of Germany

NewClimate Institute

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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Capacity Development for climate policy in the countries of South East, Eastern Europe, the South Caucasus and Central Asia, Phase III

This project is part of the International Climate Initiative (IKI). The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) supports this initiative on the basis of a decision adopted by the German Bundestag.

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Background of this research

Mongolia ratified the Paris Agreement in 2016, confirming its intended Nationally Determined Contribution (NDC) of 2015 to reduce greenhouse gas emissions by 14% below the business-as-usual scenario in the year 2030, equivalent to an annual reduction of approximately 7.3 MtCO2e of economy-wide emissions in 2030. The Paris Agreement calls upon all Parties to prepare an updated NDC for submission to the UNFCCC by 2020.

Commissioned by German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and NewClimate Institute cooperated with the Ministry of Environment and Tourism of Mongolia, the Ministry of Energy of Mongolia, and national experts to support the integration of energy and heating sector strategy with climate change planning at the national level through the *Capacity Development for climate policy in the countries of South East, Eastern Europe, the South Caucasus and Central Asia, Phase III* project. The project consortium provided targeted advisory support to Mongolian stakeholders to inform sectoral-level discussions and decision-making in the context of the national NDC review and revision process from 2018 to 2020. This study presents main findings of the sector-level analysis on the Mongolian electricity supply sector led by NewClimate Institute.

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Abbreviations

AIRPOLIM-ES	Air Pollution Impact Model for Electricity Supply
CDS	Current Development Scenario
CHP	Combined Heat and Power
CTI	Carbon Transparency Initiative
EIM-ES	Economic Impact Model for Electricity Supply
IPCC	Intergovernmental Panel on Climate Change
LTS	Long-Term Strategy
LULUCF	Land Use, Land-Use Change and Forestry
MET	Ministry of Environment and Tourism
MoE	Ministry of Energy
NDC	Nationally Determined Contribution
PA	Paris Agreement
PAS	Paris Agreement Scenario
PROSPECTS	Policy-Related Overall and Sectoral Projections of Emission Curves and Time Series
UNFCCC	United Nations Framework Convention on Climate Change

Summary for policy makers

The benefits of long-term planning towards a low-carbon economy in Mongolia

Sectoral long-term planning is imperative for policy makers around the world considering the upcoming submissions of both Nationally Determined Contributions (NDCs) and Long-Term Strategies (LTS) by all Parties to the Paris Agreement in 2020.

A robust analysis of sectoral pathways enables policy makers in Mongolia and elsewhere to understand the implications of different levels of mitigation ambition in terms of technologies, emissions, and socio-economic impacts. This allows developing countries to identify technology, financial and capacity support needed from the international community to effectively increase mitigation action in their country. Such forward-looking analysis thus helps to determine appropriate sectoral mitigation targets for 2030 and 2050. Our analysis presents a first input to understand the implications of international climate mitigation efforts mandated by the Paris Agreement on the Mongolian electricity supply sector.

A non-binding long-term vision towards 2050 in line with the Paris Agreement

The Paris Agreement stipulates the overall long-term temperature goal of "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change" (UNFCCC, 2015).

Latest scientific evidence unambiguously shows the need to initiate rapid and successful sector transition towards a low-carbon economy by mid-century. Global CO_2 emissions on average need to reach net zero by 2050 or shortly thereafter to be in line with 1.5°C (IPCC, 2018). The development and analysis of Paris Agreement-compatible pathways for specific sectors can enhance the understanding of the most important short and medium-term actions and foster debate between key actors.

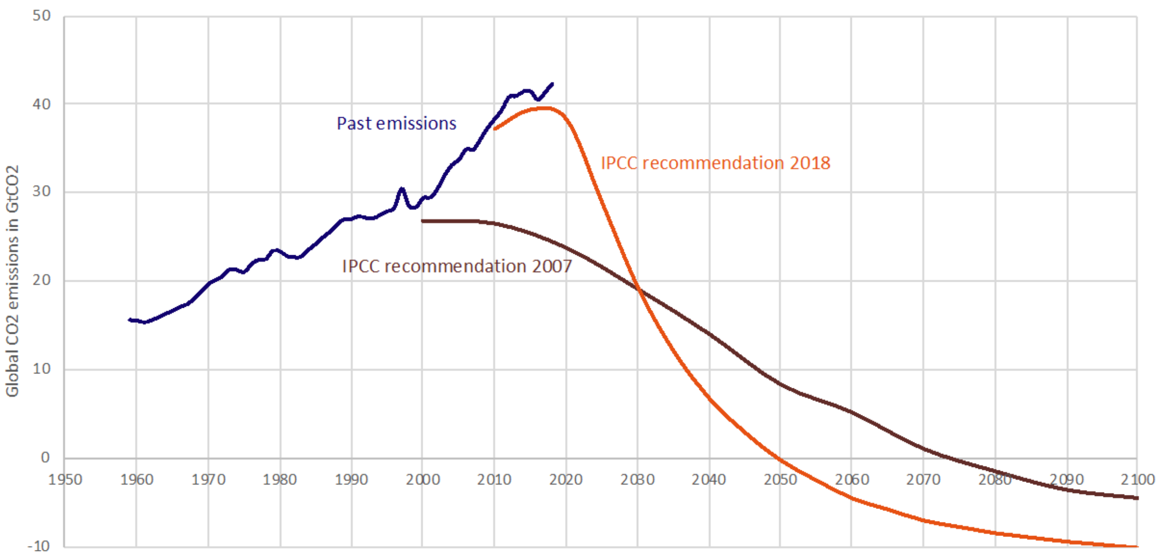

Figure 1: Pathways of global CO_2 emissions recommended by IPCC in the Fourth Assessment Report of 2007 (445 to 490 ppmCO2eq leading to 2-2.4°C) and by the IPCC special report on 1.5°C in 2018 for low- and no-overshoot scenarios leading to 1.5°C (only the average of the ranges are shown). Overshoot implies a peak followed by a decline in global warming, achieved through the anthropogenic removal of CO_2 in excess of remaining global CO_2 emissions.

In this context, the Paris Agreement Scenario (PAS) range of our analysis aims to inform an alternative long-term vision for Mongolian electricity supply towards 2050, in line with Mongolia's commitment to implement the Paris Agreement after its ratification in September 2016. The proposed vision builds upon (a range of) available literature on the decarbonisation of the electricity supply sector globally as well as in the particular case of Mongolia. A similar long-term analysis for Mongolian heating supply and the decoupling of electricity and heating supply remains outside the scope of this study.

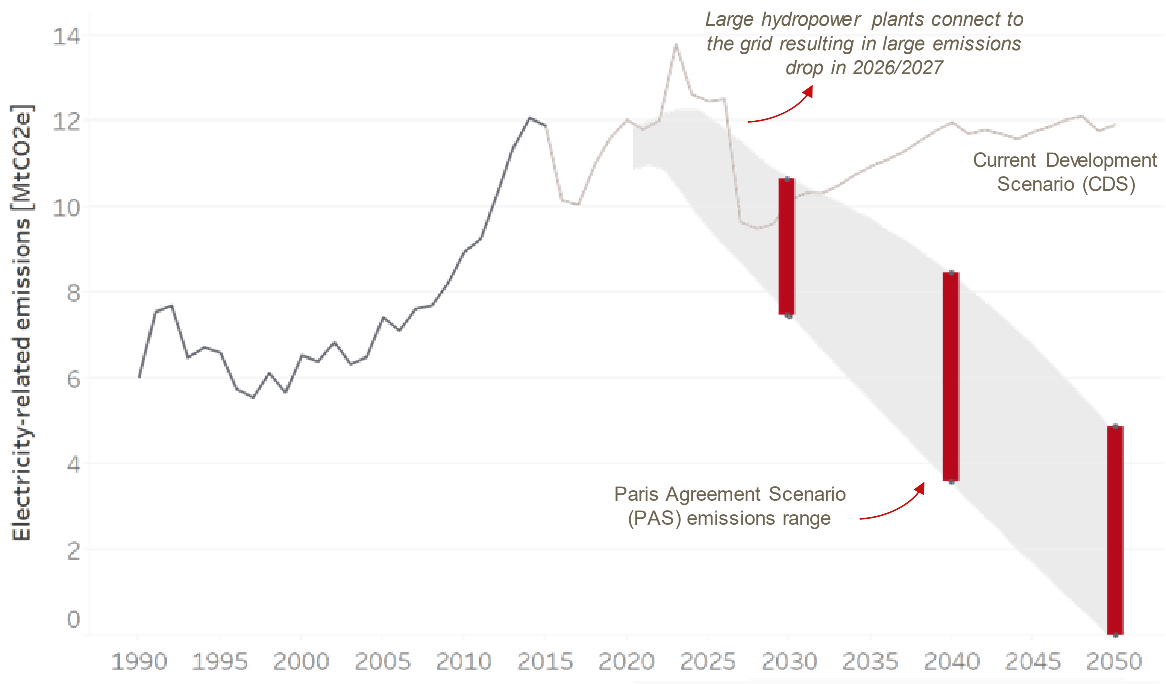

Figure 2: Emission pathways for the Mongolian electricity supply sector considered 'Paris Agreement-compatible' (first estimate) informing the selection of emission ranges in 2030, 2040 and 2050. The Current Development Scenario presents the expected evolution of the electricity supply sector in Mongolia assuming the successful implementation of existing sectoral policies and the most recent capacity expansion plans.

The following **key messages** summarise our findings and can help to inform Mongolian policy makers in their approach to sector planning and underlying analysis of socio-economic and technical aspects related to accelerated climate mitigation action.

1. The current capacity expansion plans published by the Ministry of Energy in October 2018, if implemented, are sufficient to meet Mongolia's projected electricity demand up to 2050.
2. The planned expansion of renewable-based capacity of 1.4 GW, however, remains highly uncertain given the high dependence on large hydropower projects.
3. The implementation of the coal expansion plans (1.7 GW, excluding Shivee Ovoo plant) will prolong the country's coal dependency for electricity generation or create costly stranded assets in case of early retirement before 2050.
4. An increasing body of recent academic literature on the implications of the Paris Agreement for the Mongolian electricity supply suggests that emissions need to decrease sharply by 60-100% up to 2050 compared to 2015 levels, a decrease driven by an accelerated uptake of renewable technologies.

5 Under the Mongolian government's current plans, emissions will remain inconsistent with the Paris Agreement temperature target in the long-run due to the expansion of coal-fired power plants and uncertainty around the development of new hydropower projects.

While an in-depth assessment of technological solutions is outside the scope of this report, our analysis identifies several actionable next steps in the medium-term to accelerate mitigation ambition in the future. Such actions can include, among others, the implementation of pilot projects for renewable-based heating in Ulaanbaatar and *aimag* centres to decouple heat and electricity supply, the improvement of electricity transmission network and grid operation capacities for integration of (variable) renewables, as well as further development of national research, planning and training capacities for renewable energy development.

Mongolia faces substantial challenges "to reach global peaking of greenhouse gas emissions as soon as possible" (Art. 4 § 1), as mandated by the Paris Agreement, given its geographical location, climatic profile and socio-economic status. For this reason, Mongolia will require continuous and reliable financial and technical support by the international community to successfully initiate and implement such concrete measures and to transition towards a fully decarbonised economy. Such international support should be acknowledged under the Paris Agreement principle of "common but differentiated responsibilities" (Art 4 § 3), reflecting countries different national circumstances and capacities to increase their mitigation ambition.

Realising health benefits by phasing-out coal power plants over time

Analysing socio-economic impacts - such as public health or employment - of different future scenarios can help inform energy sector planning to incorporate wider sustainable development considerations. We investigate health impacts associated with operating the existing (~1 GW) and newly proposed coal power plants (~7 GW, including Shivee Ovoo plant, with a capacity of 5.3 GW) in line with the latest expansion plans communicated by the Ministry of Energy as of January 2020.

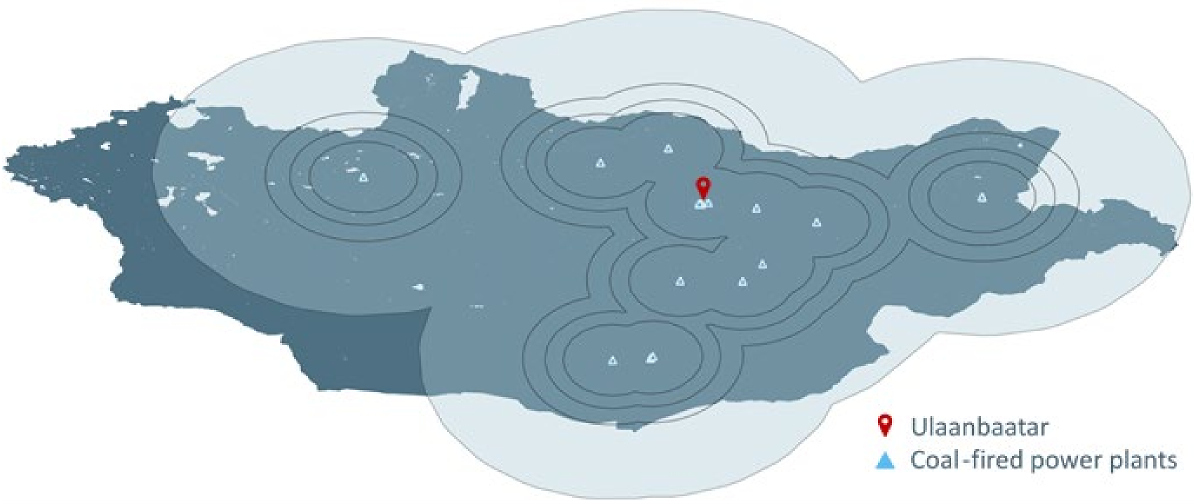

Figure 3: Existing and planned coal-fired power plants in Mongolia and distance bands affected by the air pollutants emitted by each coal-fired power plant within the country. Each triangle represents one coal-fired power plant.

The following **key messages** summarise our findings on health benefits:

1. Coal-fired power plants accounted for roughly 6% of national air pollution in 2016, providing the third-largest source of particulate matter in Mongolia.
2. Continued operation of coal-fired power plants could cause almost 1,600 premature deaths / 42,000 years of life lost in Mongolia between 2020 and 2050 (see Figure 4).
3. Around 70% of these premature deaths and years of life lost will be caused by power plants not yet in operation but included in the coal capacity expansion plans of the Mongolian Ministry of Energy as of January 2020.
4. The proposed Shivee Ovoo power plant alone would cause more premature deaths (640) and years of life (17,380) lost by 2050 than all other proposed new coal plants together (470 and 12,640 respectively). Shivee Ovoo's pollution will directly affect the Mongolian population while exclusively producing electricity for use in neighbouring China.

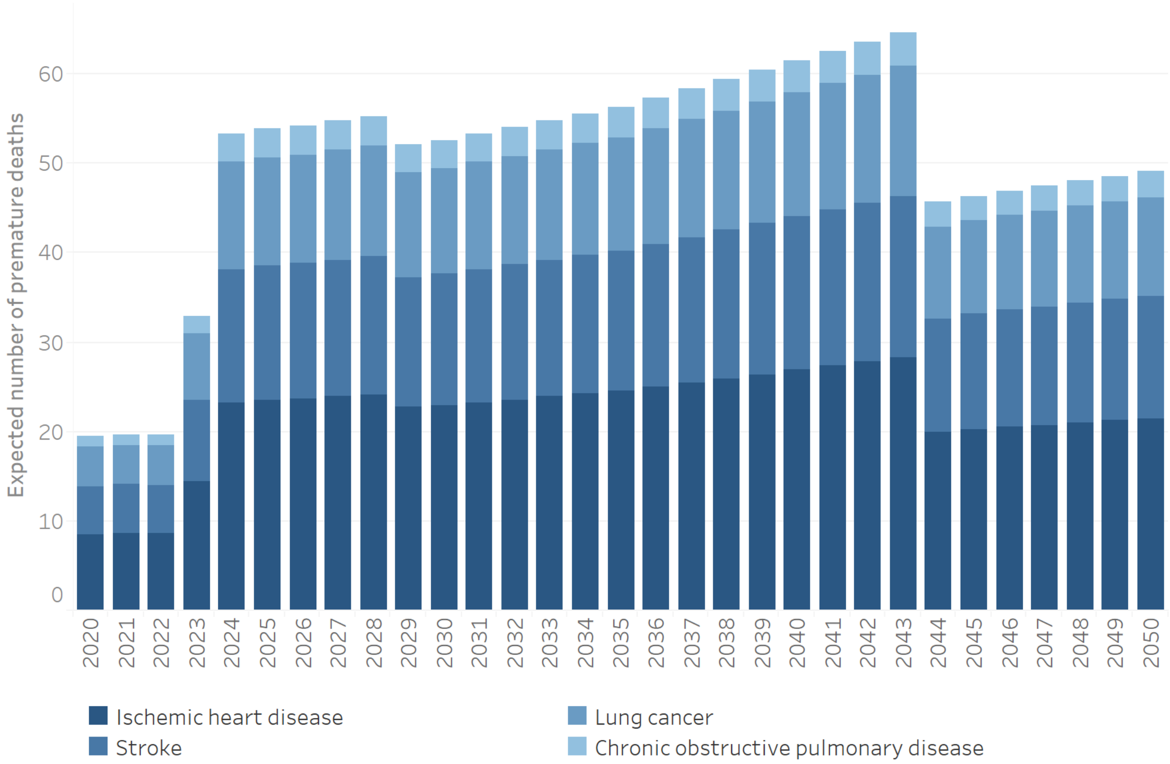

Figure 4: Annual premature deaths caused by coal-fired power plants in Mongolia between 2020 and 2050 per cause

The potential negative impacts caused by existing and future coal power plants illustrate the importance of integrating considerations on health and other socio-economic impacts into Mongolia's future energy sector planning. Further analyses can enable Mongolian policy makers to better understand the synergies between climate action and sustainable development; and integrate these insights into planning and decision-making processes.

1 Introduction: Setting the stage for the decarbonisation imperative

The Paris Agreement stipulates the overall long-term temperature goal of ”holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change” (UNFCCC, 2015). The Paris Agreement long-term temperature goal is more ambitious than the previously agreed 2°C limit of the Cancun Agreements of 2009.

Latest scientific findings emphasise the urgency for steep emission reductions by 2050

At the same time, global emission reduction pathways to hold global warming below the temperature level of 1.5°C compared to pre-industrial levels are now steeper than they were at the time of the Fourth Assessment Report of 2007 (IPCC, 2007). Much of the remaining global budget has been depleted by steady annual emission increases over the last twelve years. Global CO_2 emissions today are around 60% higher than at that time. Now, global emissions must decline much faster to still meet the temperature level of 1.5°C compared to pre-industrial levels and avoid the most dangerous consequences of climate change. Figure 5 compares the recommendation of the IPCC’s Fourth Assessment Report of 2007 with IPCC’s special report on ‘Global Warming of 1.5°C’ published in late 2018.

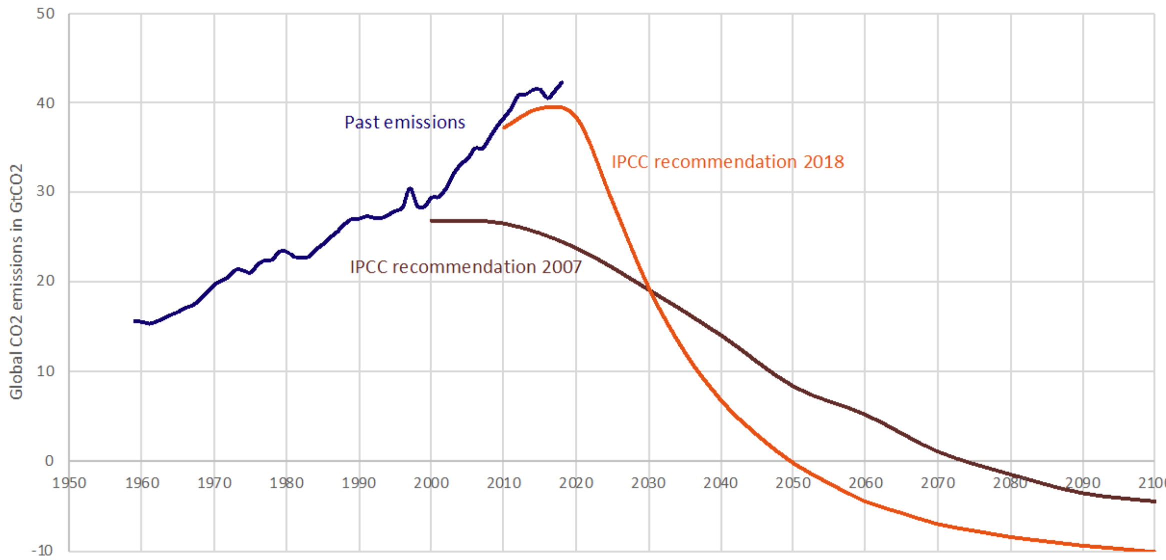

Figure 5: Pathways of global CO_2 emissions recommended by IPCC in the Fourth Assessment Report of 2007 (445 to 490 ppmCO2eq leading to 2-2.4°C) and by the IPCC special report on 1.5°C in 2018 for low and no overshoot scenarios leading to 1.5°C (only the average of the ranges are shown). Overshoot implies a peak followed by a decline in global warming, achieved through the anthropogenic removal of CO_2 in excess of remaining global CO_2 emissions.

The latest scientific evidence shows the need to initiate deep sector transitions as quickly as possible to successfully transition towards a low-carbon economy by mid-century. Global CO_2 emissions need to be net zero by 2050 to be in line with 1.5°C (IPCC, 2018). Paris compatible pathways for specific sectors can enhance the understanding of the most important short and medium-term actions and to foster debate between key actors.

With the global current policy trends, it is expected that annual average temperatures will increase by 3°C by 2100 (Climate Action Tracker, 2019). For Mongolia, the annual average temperature might increase by 2-3°C already by 2050 (USAID, 2017). Rainfall will become more variable with decreases during summer and increases during winter. Incidences of extreme events, including droughts, flash floods and *dzuds* will increase significantly. Those changes would impact Mongolian agriculture and traditional pastoralism, the availability and quality of water, the melting of permafrost areas, but also very much affect human health and ecosystems (USAID, 2017). There is a strong impetus for Mongolia that the world community succeeds to limit the consequences of climate change to bearable limits as anchored in the Paris Agreement.

The relevance of long-term planning in the context of the Paris Agreement

The Paris Agreement calls upon all Parties to "formulate and communicate long-term low greenhouse gas emission development strategies" (§ 4.19), also known as long-term strategies (LTS). While LTSs shall be submitted by Parties in separate submissions to the UNFCCC[1], Parties should ideally link their mid-term mitigation targets for 2030 to sector-level strategies outlining the vision for each sector's decarbonisation by mid-century or shortly thereafter. This allows to enhance transparency and credibility of Parties' (indicative) long-term planning and required financial and technical support by the international community. In addition, the long-term planning as part of the LTS development enables countries to mainstream their sustainable development agenda into their national long-term objectives as well as subsequently into their policies and short-term measures.

1.1 Future energy supply in the context of international climate mitigation efforts

The most rapid deep sector transition needs to occur in the energy supply sector given the sector's high global emission, available low-carbon technologies, and the need for low-carbon electricity to decarbonise demand sectors like transport or buildings. Global GHG emissions from electricity generation need to be reduced from around 12 $GtCO_2$/yr in 2010 to around 6–11 $GtCO_2$/yr in 2020, 2–5 $GtCO_2$/yr in 2030 and zero to –2.5 $GtCO_2$/yr in 2050 (Kuramochi *et al.*, 2018). This fundamental transition of the global energy system requires the rapid uptake of zero- and low-carbon electricity generation sources and phasing-out of carbon-based electricity generation, mainly from coal.

Sustain the growth rate of renewables and other zero and low-carbon power generation until 2025 to reach 100% share by 2050 globally

A full transition to low-carbon electricity supply by 2050 implies a rapid transition to renewables, other zero-carbon technologies such as nuclear, and low-carbon technologies sources such as fossil energy equipped with carbon capture and storage (CCS) (IPCC, 2018; Kuramochi *et al.*, 2018). This transition of the global energy system builds on continuous reductions of levelised cost of electricity (LCOE) for renewables, especially utility-scale solar photovoltaic and wind. The comprehensive literature review in the IPCC special report on 1.5°C identifies

[1] All submitted LTSs submitted to the UNFCCC can be accessed at https://unfccc.int/process/the-paris-agreement/long-term-strategies.

a range for the average share of renewables in electricity generation. Table 1 below provides an overview of the shares per technology in total electricity generation across all recently available scenario analyses presented in the IPCC special report on 1.5°C in ranges (Rogelj *et al.*, 2018).

Table 1: Global electricity generation shares of 1.5°C pathways taken from Figure 2.7 of Chapter 2 Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development for scenarios (Rogelj *et al.*, 2018)

Pathways	Technology	2030	2050
1.5°C compatible pathways with no or low overshoot (based on 50 scenarios)	Renewables (total)	37%-80%	59%-97%
	Wind and solar	1%-42%	2%-60%
	Biomass	1%-13%	0%-30%
	Nuclear	5%-32%	1%-28%
	Fossil technologies (total)	2%-53%	0%-25%
1.5°C compatible pathways with high overshoot (based on 35 scenarios)	Renewables (total)	25%-66%	36%-95%
	Wind and solar	1%-28%	9%-61%
	Biomass	1%-2%	0%-28%
	Nuclear	5%-24%	1%-40%
	Fossil technologies (total)	24%-59%	0%-33%

Apart from cost-competitiveness of zero- and low-carbon generation technologies, electric power systems need to be fundamentally modernised and overhauled to provide sufficient flexibility, transmission, demand-side management, and storage for high penetration of (variable) renewables (IRENA, 2019a). Many countries identify high demand for finance, technology and skill transfer to increase renewable electricity generation capacity and modernise their electric power systems in line with 1.5°C compatible energy supply scenarios.

No new coal power plants to be commissioned worldwide from 2019 onwards and emission reductions from existing coal fleet by 30% by 2025 globally

To limit warming to 1.5°C, no new coal capacity should have come online as of 2019 while emissions from coal combustion need to be reduced by at least 30% by 2025 and 65% by 2030 (Climate Action Tracker, 2018; Kuramochi *et al.*, 2018). This is in line with the most recent literature review by the IPCC Special Report on 1.5°C (de Coninck *et al.*, 2018). As of July 2019, an aggregated 227 GW of coal capacity is currently being constructed and an additional 311 GW has been announced, pre-permitted, or permitted (Global Energy Monitor, 2019b). A major challenge will be to deal with existing coal-fired power plants which need to be decommissioned before the end of their economic lifetime and to redirect investments from new coal-fired power plants to alternatives. This provides enormous challenges and opportunities for both policymakers and investors as coal owners could avoid the risk of stranding assets worth $267 billion by phasing-out coal in a below 2°C scenario (Carbon Tracker Initiative, 2018).

1.2 The status quo of the Mongolian energy supply sector

Mongolia’s lasting dependence on coal and other fossil fuels

The Mongolian energy supply sector is heavily dependent on coal. In 2017, 70% of the total primary energy supply was supplied by coal, followed by 26% of oil and 4% from other sources (IEA, 2019). The situation is worse when it comes to the electricity sector where coal was responsible for 89% of total electricity generation in 2017 (IEA, 2019). The high coal usage is interlinked with the domestic coal mining industry since Mongolia is a coal producer and exporter, which makes coal a readily available and cheap fuel.

Another core issue is the reliance on coal-fired combined heat and power technologies (CHP). Mongolia has extremely harsh climate conditions with average outdoor temperatures of -6°C between September and April and of -20°C between November and January (NOAA, 2019). CHP technologies supply both electricity and heat that can be fed into district heating networks. Alternative options for Paris compatible heating systems for buildings are not sufficiently explored yet in Mongolia (see Section 1.3).

As a result of the Mongolian fossil fuel dependency and economic growth, emissions have increased in the past three decades. Energy is responsible for the largest share of emissions in Mongolia currently and for some time into the future. As a result of the transition from a planned Soviet style economy in the 1990's, energy related emissions initially declined steeply from a peak in 1992. However, they started growing again in 1999 and have increased by 55% between then and 2014 (Ministry of Environment and Tourism, 2018).

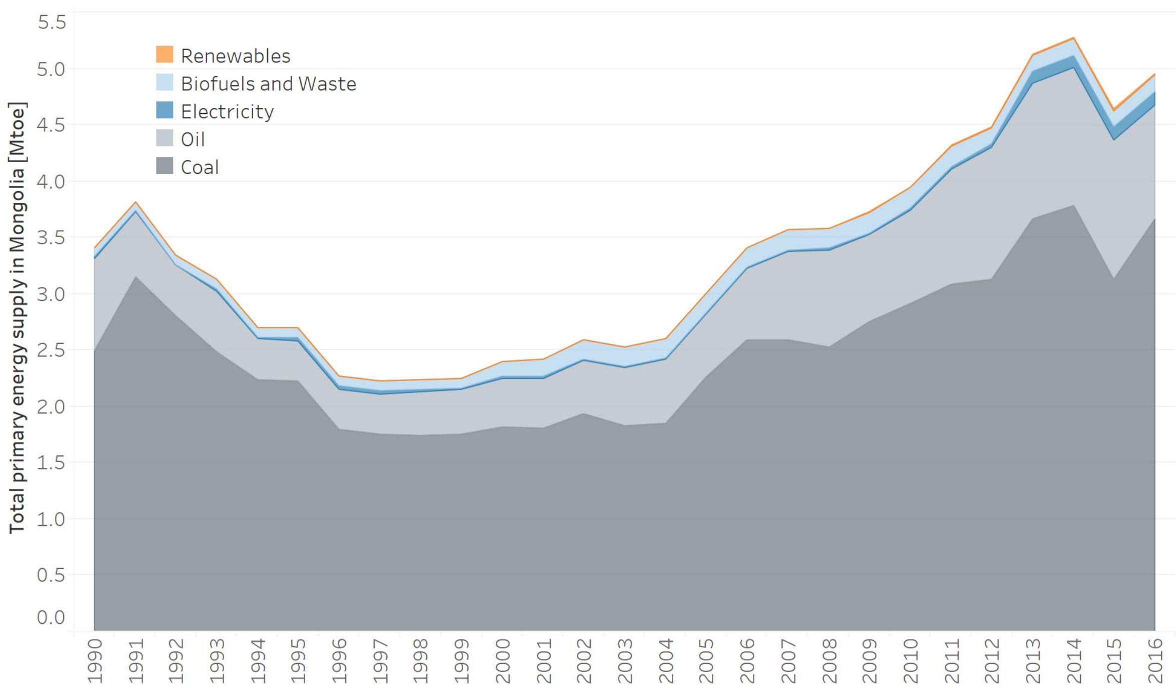

Figure 6: Total primary energy supply (TPES) by fuel source in Mongolia for the period between 1990-2016 (IEA, 2019)

Mongolia has implemented some initial policies to accelerate climate action in the energy supply sector recently, but ambitious long-term planning is still missing

The current planning of the electricity sector in Mongolia is anchored in three main legislation documents: The State Policy on Energy of 2015 (Resolution No. 63 of Mongolian Parliament), the Green Development Policy of 2014 (Resolution No. 43 of Mongolian Parliament), and the Mid-Term National Programme to Develop the State Policy on Energy (2018-2023) of 2018 (Resolution No. 325 of Mongolian Parliament). They define renewable expansion plans and targets as well as measures for improved energy efficiency in the energy supply sector, e.g. the reduction of transmission and distribution losses or own energy consumption.

To improve renewable integration, the government amended their Renewable Energy Act in 2019 to reduce the feed-in-tariff for all technologies and solidify the principles for a renewable auction scheme that is location-, capacity- and technology-specific. The government also undertakes planning exercises, that would specify *inter alia* the location and capacity of renewable projects, and aims to ensure that project developers prove access to finance to avoid licensed projects not getting implemented (MDSKhanlex, 2019).

1.3 The case for decarbonising electricity in Mongolia

Forward-looking planning enables the use of Mongolia's renewable energy resources

The Paris Agreement temperature limit has considerable implications for long-term energy sector planning in Mongolia considering the sector's current status quo. Compatibility with the Paris Agreement "to reach global peaking of greenhouse gas emissions as soon as possible" (Art. 4 § 1) constitutes substantial challenges for Mongolia given its geographical location, climatic profile, and socio-economic status.

These challenges mandate a forward-looking approach by policy makers to identify opportunities for Mongolia to tap into its rich renewable energy resources (IRENA, 2016). Sustained technology cost decline for electricity generation observed worldwide present an opportunity for Mongolia to reduce costs as well as sectoral emissions (IRENA, 2019c). Well-founded scenario analysis can support decision-making on how to structure a transition towards renewables given the country-specific circumstances.

Mongolia's opportunity to realise socio-economic benefits of less air pollution and green job opportunities

The transition towards a sustainable electricity supply also entails positive socio-economic implications, particularly the reduction in air pollution and creation of sustainable jobs in future oriented sectors of the economy (e.g. low-carbon energy generation). Critical levels of air pollution in Ulaanbaatar due to coal combustion for heating by private households and operation of CHP plants have direct consequences for residents' health and overall economic development (Davy *et al.*, 2011; Allen *et al.*, 2013; IRENA, 2016; Nakao *et al.*, 2017). The introduction of low-carbon technologies to effectively decouple electricity and heat supply in Mongolia can result in positive impacts on public health due to a lasting reduction in local air pollution levels.

Accelerated climate action in the electricity generation sector has the potential for significant domestic job creation in Mongolia, particularly in low-carbon-oriented fields. For example, a first analysis for Jacobson et al. (2017) estimates that a full low-carbon transition in the Mongolian energy sector by 2050 would create around 16,000 new permanent and full-time net jobs in construction and operation (job losses in fossil-fuel industries already subtracted). At the same time, policy makers need to actively manage a just transition for those communities affected by the reduction of coal-related jobs, given the uncertain future for coal mining jobs in Mongolia (and worldwide) as part of the global efforts to phase-out coal combustion.

Looking ahead: the need for comprehensive energy sector long-term planning

The analysis of this report investigates the impact of Mongolia's current energy sector planning on future electricity supply. These forecasted developments are then compared to an emission pathway range compatible with the Paris Agreement's temperature target as well as contextualized with analysis on respective health benefits from a transition away from coal.

Similar long-term analysis for Mongolian heating supply remains outside the scope of this analysis. Future long-term scenario analyses, however, should include the heating supply sector to enable fully comprehensive energy sector planning. This should address the uncertainty of feasible low-carbon technological solutions as alternatives to current combined heat and power (CHP) based systems to provide reliable heating in Ulaanbaatar and *aimag* centres, given Mongolia's climate conditions.[2] The transition towards decarbonising electricity and heating supply ultimately need to build upon fully comprehensive energy sector planning.

[2] For example, NewClimate Institute has recently published an analysis on '*Renewable Heating Virtual Article 6 Pilot - Ground source heat pumps in Khovd, Mongolia*' in cooperation with the Swedish Energy Agency (SEA). The analysis investigates the technical and financial potential of ground source heat pumps (GSHPs) in apartment buildings currently connected to coal-powered district heating grids. The analysis can be accessed under https://newclimate.org/2020/01/29/renewable-heating-virtual-article-6-pilot-ground-source-heat-pumps-in-khovd-mongolia/.

2 Methodological approach

The following analysis explores future developments of the Mongolian electricity supply sector under two scenarios.

The Current Development Scenario, or CDS, is the continuation of current trends. This scenario represents the evolution of the electricity supply sector under the assumption that current national policies and governmental plans are fully implemented. The Paris Agreement Scenario, or PAS, presents an alternative pathway for the Mongolian electricity supply sector in line with the goals of the Paris Agreement. The PAS builds on a cohort of literature on scenarios in line with the 1.5°C and 2°C temperature limits globally or nationally, as well as studies aiming for 100% low carbon electricity by mid-century.

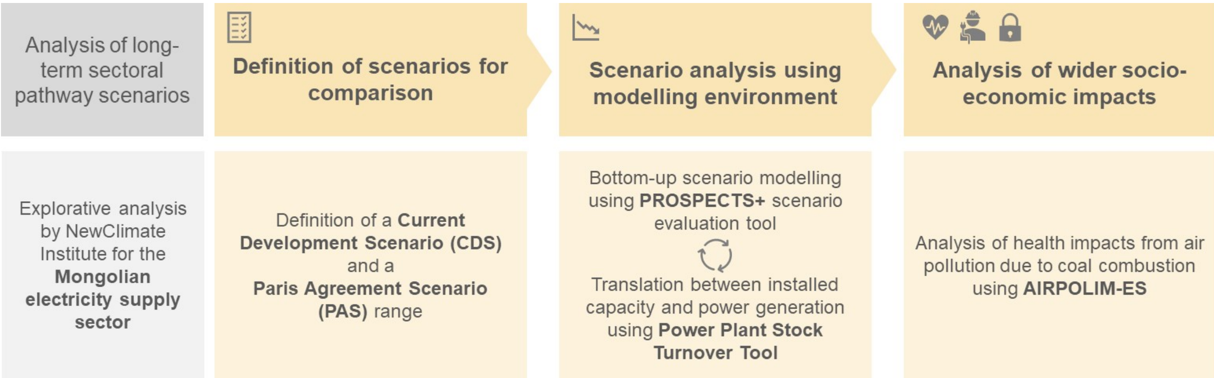

Figure 7: Methodological approach of explorative analysis for the Mongolian electricity supply sector

Considering the interlinkages between demand and supply sectors, efficiency measures, and economic and population growth, it is paramount to simultaneously evaluate the country's demand and supply in any analysis aiming to investigate the electricity supply subsector. We start our analysis by setting up a bottom-up model for Mongolia that considers these interlinkages. The sectoral resolution of such model allows for the calculation of electricity supply emissions consistent with national developments. The two scenarios, CDS and PAS, are developed using the PROSPECTS+ scenario evaluation tool.

The main emissions lever for the electricity supply sector is the fuel mix in electricity generation. We use this indicator to create the CDS – based on the Mongolian government's current capacity expansion plans as of October 2018 – and the PAS – based on literature on renewable generation shares compatible with the Paris Agreement. The conversion of installed capacity to power generation is done using the Power Plant Stock Turnover Tool, which allows the user to create tailor-made capacity expansion plans that match certain renewable targets.

After quantifying emission trajectories, each scenario can be assessed in terms of wider socio-economic impacts such as energy security, employment creation, or air pollution. In this study, we use the Air Pollution Impact Model for Electricity Supply (AIRPOLIM-ES) tool to quantify the potential health benefits from moving from CDS to PAS. The following paragraphs describe all tools and methodologies used for this study's scenario analysis in the Mongolian electricity supply sector in more detail.

PROSPECTS+ scenario evaluation tool

The PROSPECTS+ scenario evaluation tool[3] is a sector-level, bottom-up Excel tool which uses decarbonisation relevant activity and intensity indicators to track and project overall and sectoral GHG emissions trends. A simplified tool derived from the CTI tools, PROSPECTS+ covers all major emitting sectors, namely electricity, heat, buildings, transport, industry, waste, and agriculture (excluding forestry). Users can develop their own emissions scenarios up to the year 2050 by adjusting policy relevant indicators.

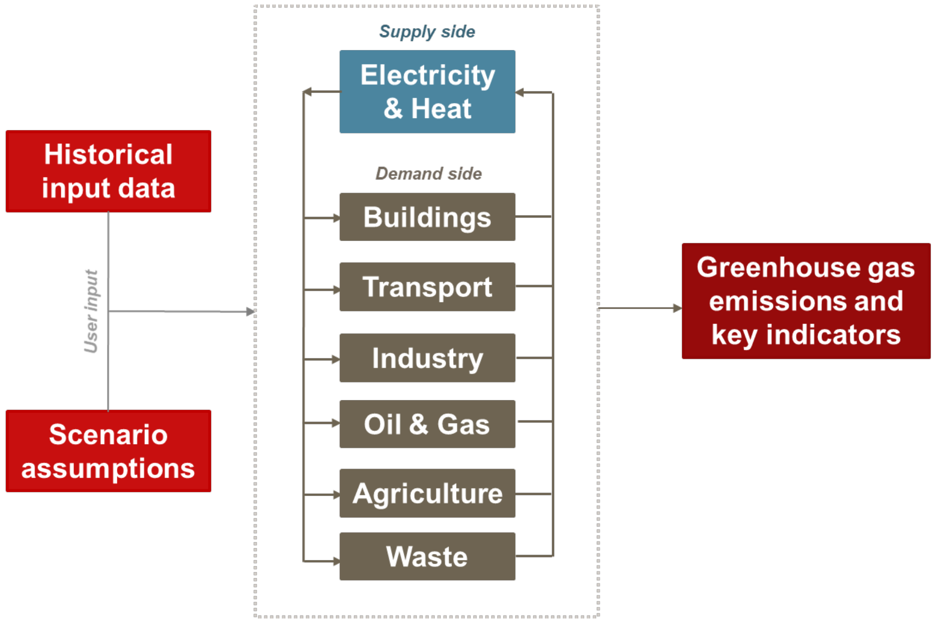

Figure 8: Overview of PROSPECTS+ scenario evaluation tool (own graph)

The PROSPECTS+ framework is developed under an indicator-led methodology, which measures key indicators that shape emission trends on sectoral level for each country (e.g. emission intensity of electricity generation for the power sector or passenger kilometres travelled per person for the transport sector). By breaking down macro-level emissions into sectoral-level indicators, the approach increases transparency on decarbonization in each sector and allows comparisons among regions and over time at multiple levels of the economy.

Power Plant Stock Turnover Tool

The Power Plant Stock Turnover Tool calculates the power generation shares of installed capacity in a country's power mix. The tool generates capacity additions necessary to supply demand while meeting reserve margin requirements based on demand projections and technology merit order defined by the user. Figure 9: presents an overview of the tool's calculation logic.

The tool calculates the total installed capacity required to fulfil the demand and, separately, the additional capacity needed to meet reserve margin requirements. One should note that reserve margin requirements could be met using multiple strategies and do not necessarily imply the construction of new power capacity; the requirements could be met by imports or shelved power plants.

[3] More information available at https://newclimate.org/2018/11/30/prospects-plus-tool/.

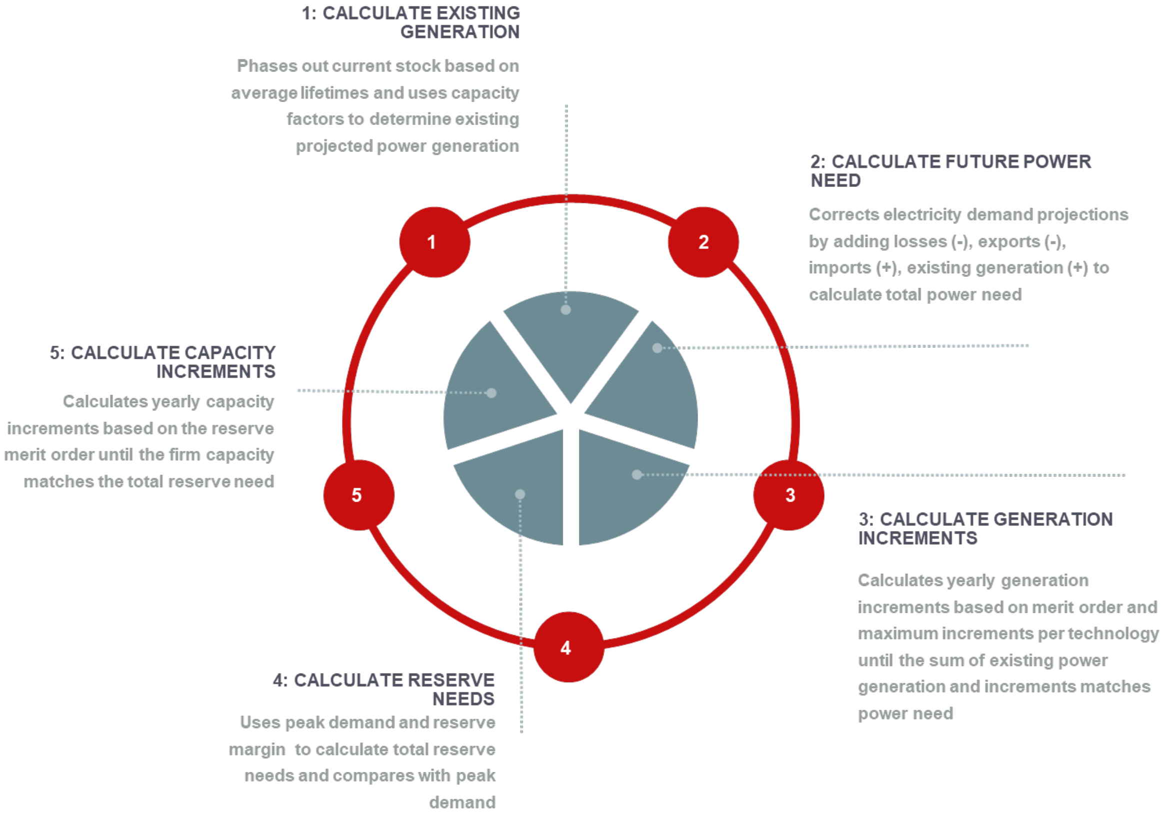

Figure 9: Power plant stock turnover calculation logic (own illustration)

Air Pollution Impact Model for Electricity Supply (AIRPOLIM-ES)

The AIRPOLIM-ES[4] is a spreadsheet-based model that uses an accessible methodology for quantifying the health impacts of air pollution from different sources of electricity generation and other fuel combustion. It calculates the impacts on mortality from four adulthood diseases: lung cancer, chronic obstructive pulmonary disease, ischemic heart disease and stroke, all of whose prevalence is increased with the intake of pollution.

The health impact assessment is based on emissions of particulate matter ($PM_{2.5}$); nitrogen oxides (NO_X); and sulphur dioxide (SO_2). The model estimates the annual and lifetime electricity generation (GWh) for each plant as well as the corresponding emissions of air pollutants using plant-specific data and emission factors. Depending on the type of emissions control equipment installed the model multiplies the estimated fuel consumption with the corresponding country-specific emission factor. Where more detailed information is available plant-specific emission factors can be entered into the model to improve accuracy.

The population exposed to each power plant is estimated using an open-source geographical information system (GIS) software also considering population growth. The model uses the intake fraction concept to estimate the change in $PM_{2.5}$ concentration in the ambient air dependent on the calculated pollutant emissions. To calculate the increased mortality risk per

[4] The AIRPOLIM-ES tool and its documentation are available at: https://newclimate.org/2018/11/30/airpolim-es-air-pollution-impact-model-for-electricity-supply/.

additional tonne of pollutant emissions, the estimated change in $PM_{2.5}$ concentration is multiplied with the respective concentration-response function.

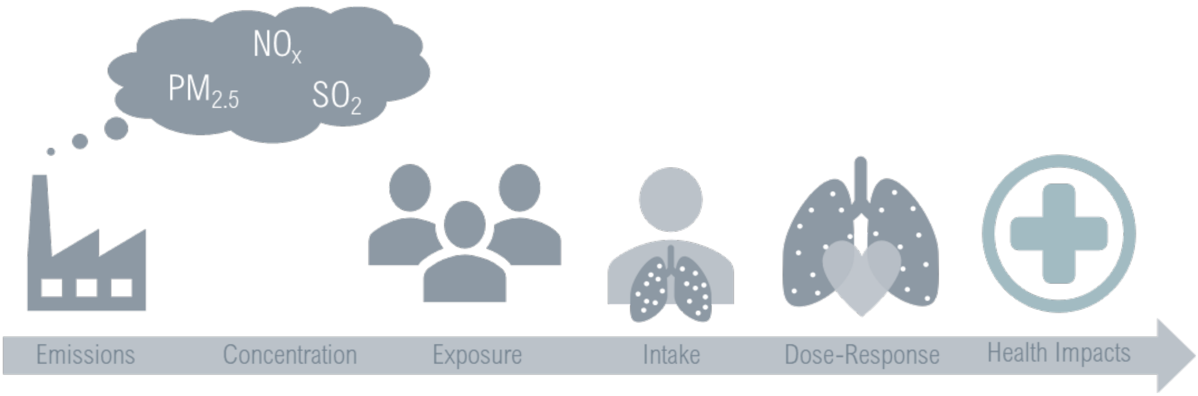

Figure 10: Overview of AIRPOLIM-ES methodology (own illustration)

The Global Burden of Disease project provides mortality rates by disease for different age groups at the country level (Global Burden of Disease Collaborative Network, 2018). The model obtains age-weighted mortality rates by disease by using the share of the country's population in each age class. Premature death refers to deaths that are attributed to exposure to a risk factor, i.e. air pollution, and that would be preventable in the sense that they would occur later in life if air quality was improved. The risk estimates, the age-weighted mortality rates and the exposed population are combined to calculate the number of premature deaths per tonne of pollutant, per cause, as well as the estimated number of years of life lost by multiplying with the respective life expectancy value at the moment of death.

3 Current Development Scenario: A future locked into carbon

Current Development Scenario: Key messages

- ⇨ The current capacity expansion plans published by the Ministry of Energy in October 2018, if implemented, are sufficient to meet Mongolia's projected electricity demand up to 2050.
- ⇨ The planned expansion of renewable-based capacity of 1.4 GW, however, remains highly uncertain given the high dependence on large hydropower projects.
- ⇨ The implementation of the coal expansion plans (1.7 GW) will prolong the country's coal dependency for electricity generation or create costly stranded assets in case of early retirement before 2050.
- ⇨ The continuous dependence of Mongolia's electricity supply on coal-based generation will not allow for any significant emission reductions below today's levels until mid-century.

3.1 Defining the Current Development Scenario

The Current Development Scenario (CDS) presents the expected evolution of the electricity supply sector in Mongolia assuming the successful implementation of existing sectoral policies and the most recent capacity expansion plans that aim to supply electricity to the Mongolian grid. Power plants exclusively built for exports and not connected to the Mongolian grid are not included in the CDS.

The only electricity generating unit in Mongolia currently planned for exports only is the Shivee Ovoo coal-fired power plant (Government of Mongolia, 2018). The Shivee Ovoo project has been under consideration since 2005 and has subsequently been delayed several times. Current plans indicate a coal-fired power plant with 5.3 GW of installed capacity located 260 km from Ulaanbaatar. The plant would supply all of its generated electricity to the Chinese power grid (Global Energy Monitor, 2015).

Even though the project will have a significant impact on Mongolia's electricity sector emissions if implemented, our present analysis focuses on Mongolia's electricity sector capacity expansion to supply its own electricity demand. The emissions from such power plant would need to be accounted for in Mongolia's future emission inventories given that the plant is located within the Mongolian jurisdiction. This is regardless of the fact that all electricity would be exported.

Table 2 provides an overview of sectoral targets and electricity supply sector plans in the CDS developed in the PROSPECTS+ Mongolia scenario evaluation tool.

Table 2: Inclusion of sectoral policies and governmental plans in the Current Development Scenario (CDS) for the Mongolian electricity supply sector

Sectoral target / plan	Policy (see list of policies at end)	Operationalization in PROSPECTS+
Capacity extension of 1.7 GW in coal capacity, 0.9 GW in hydropower capacity, and 0.6 GW in other renewable capacity by 2030.	Mid-Term Development Plan of 2018 Draft NDC of 2019	Recalculation of installed capacity into share of electricity generation using the *Power Plant Stock Turnover Tool* for Mongolia (see Section 0).
Increase renewable electricity capacity from 7.62% in 2014 to 20% by 2023 and to 30% by 2030 as a share of total electricity generation capacity.	State Policy on Energy of 2015	Target for renewable energy capacity from State Energy Policy of 2015 are met considering current capacity expansion plans.
Reduce electricity transmission losses from 13.7% in 2014 to 10.8% by 2023 and to 7.8% by 2030.	State Policy on Energy of 2015	Direct inclusion from targets set in State Energy Policy (2015) for 2023 and 2030 in '*Losses as percentage of generation*' indicator.
Reduce internal energy use of Combined Heat and Power plants (improved plant efficiency) from 14.4% in 2014 to 11.2% by 2023 and 9.14% by 2030.	State Policy on Energy of 2015	Direct inclusion from targets set in State Energy Policy (2015) for 2023 and 2030 in '*Own use as percentage of generation*' indicator.
Implement advanced technology in energy production such as super critical pressure coal combustion technology by 2030.	State Policy on Energy of 2015	Not included in CDS given lack of information available on how target will affect '*Emission intensity'* indicator for coal combustion.

Energy sector policies considered in Current Development Scenario (CDS)

Draft NDC of 2019	Final technical report on scenario modelling for Mongolia's Draft NDC of 2019
Mid-Term Development Plan of 2018	Mid-Term National Programme to Develop the State Policy on Energy (2018-2023) of 2018 (Resolution No. 325 of Mongolian Parliament)
State Policy on Energy of 2015	State Policy on Energy of 2015 (Resolution No. 63 of Mongolian Parliament)
Green Development Policy of 2014	Green Development Policy of 2014 (Resolution No. 43 of Mongolian Parliament)

While we focus our scenario analysis on the emissions associated with electricity supply, the analysis is a result of a broader modelling exercise developed for all supply and demand sectors (excluding LULUCF) to ensure consistency between supply and demand using the PROSPECTS+ scenario evaluation tool. An overview of all data input for all supply and demand sectors is available upon request in an external documentation.

3.2 Electricity generation capacity

Mongolia's power plant stock is old and heavily dependent on coal-fired combined heat and power (CHP). According to the IEA, 89% of Mongolia's power generation in 2017 was based on coal (IEA, 2019). There is lack of detailed publicly available information about the historical installed capacity for electricity in Mongolia. Therefore, distinct data sources containing information about Mongolia's power plants were merged to create one extensive dataset.

The PLATTS database (S&P Global Platts, 2016) was used as the main dataset due to its comprehensiveness and level of detail. Its entries were crosschecked using the Global Coal Plant Tracker database for coal-fired power plants (Global Energy Monitor, 2019a), and IRENA's Renewable Capacity Statistics for renewables (IRENA, 2019b). Diesel plants could not be verified due to lack of other data sources.

The merged database covers the period between 1990 and 2017. For the period between 2018 and 2030, we use information provided by the Ministry of Energy in the context of the NDC modelling exercise conducted in 2019 (Dorjpurev, 2019). The development of installed capacity post-2030 is based on the decommission of power plants according to the expected average technical lifetimes. Figure 11 presents the results for the total installed capacity in the Current Development Scenario between 2010 and 2050.[5]

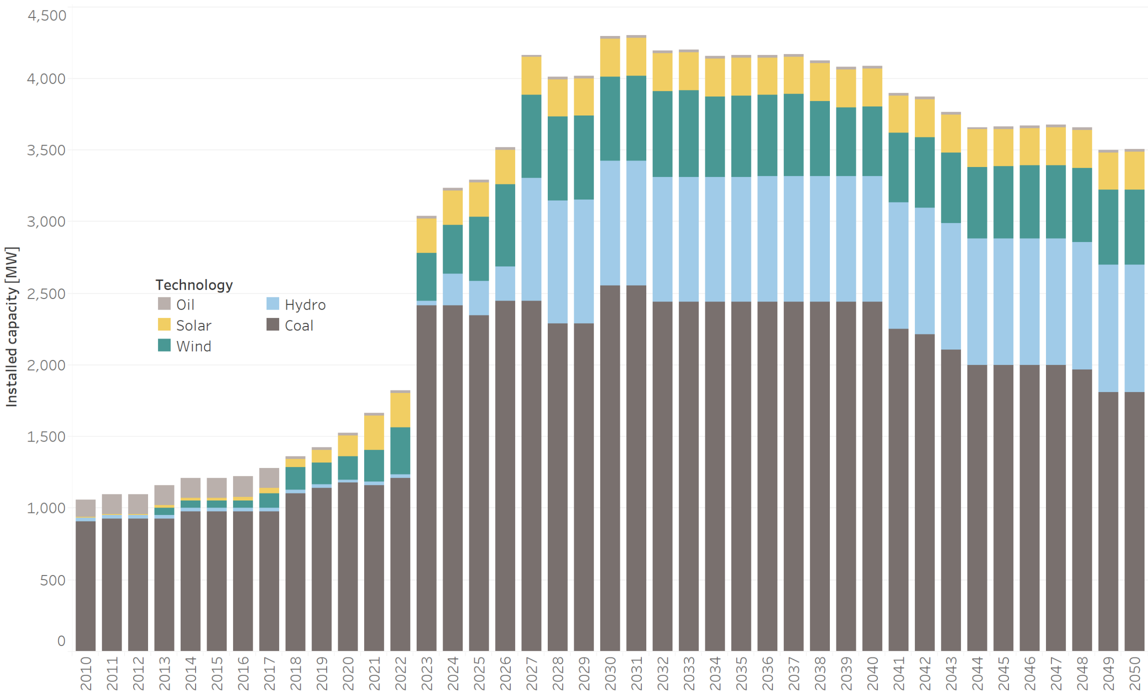

Figure 11: Overview of existing and planned Mongolian installed electricity generation capacity under the Current Development Scenario (CDS).

Steep increase of newly installed coal capacity and uncertain renewable expansion

Total installed coal capacity is projected to roughly double in the next years. Mongolia has relied mostly on coal- and oil-fired power plants in the past, but current plans show signs of decrease in installed capacity shares. Coal-fired installed capacity is expected to be reduced from 80% in 2019 to 60% in 2030 and 52% of the total installed capacity in 2050. This is to be achieved mostly via a capacity expansion of hydropower and onshore wind technologies.

Renewables are projected to represent 20% of total installed capacity by 2023 and 40% by 2030. This would result in the achievement of the renewable targets of 20% and 30% in the respective years presented in Mongolia's State Policy on Energy of 2015 and the Draft NDC of 2019 (Government of Mongolia, 2015, 2018; Dorjpurev, 2019), but there is high uncertainty if these planned capacity additions will be built.

In the past, Mongolia has issued power generation licenses that did not result in successful project construction, due to, *inter alia*, difficulties in access to finance and grid connectivity issues. The amendment to the renewable energy law in 2019 might provide a more reliable

[5] Installed capacity remained relatively stable between 1990 and 2010, ranging between 1,020 and 1,090 MW. We omit years before 2010 to focus on the period with more substantial capacity expansion.

environment for renewable development and investment in the country, but it remains to be seen whether all the planned projects will be implemented.

Besides that, around 60% of the renewable capacity planned for construction between 2020 and 2030 will be hydropower. From the total 830 MW of hydropower capacity planned, approximately 800 MW are large-scale projects (>30 MW). As of January 2020, Mongolia has not built one single large-scale hydro power project. These projects generally face high uncertainty due to their potential environmental impact and uncertain operation considering the effects of climate change. The project Egiin Gol, for example, has been postponed due to Russian concerns on cross-border upstream environmental impacts caused by its damn on the ecosystem of Lake Baikal (AIKPRESS.COM, 2019).

Forecasted electricity demand to almost double between 2020 and 2050

The forecasted electricity demand based on bottom-up calculations for all demand sectors in our analysis will almost double between 2020 and 2050, reaching around 11 TWh by mid-century as displayed in Figure 12. Other recent modelling exercises conducted for the Third National Communication of 2018 and Mongolia's Draft NDC of 2019 suggest that domestic demand might be significantly higher given accelerated economic activity, passing 12 TWh of annual demand already by 2030. The projected increase in future electricity demand emphasises the need to increase efforts to introduce sustainable, low-carbon technologies to provide reliable heating and electricity to meet the domestic demand in the future.

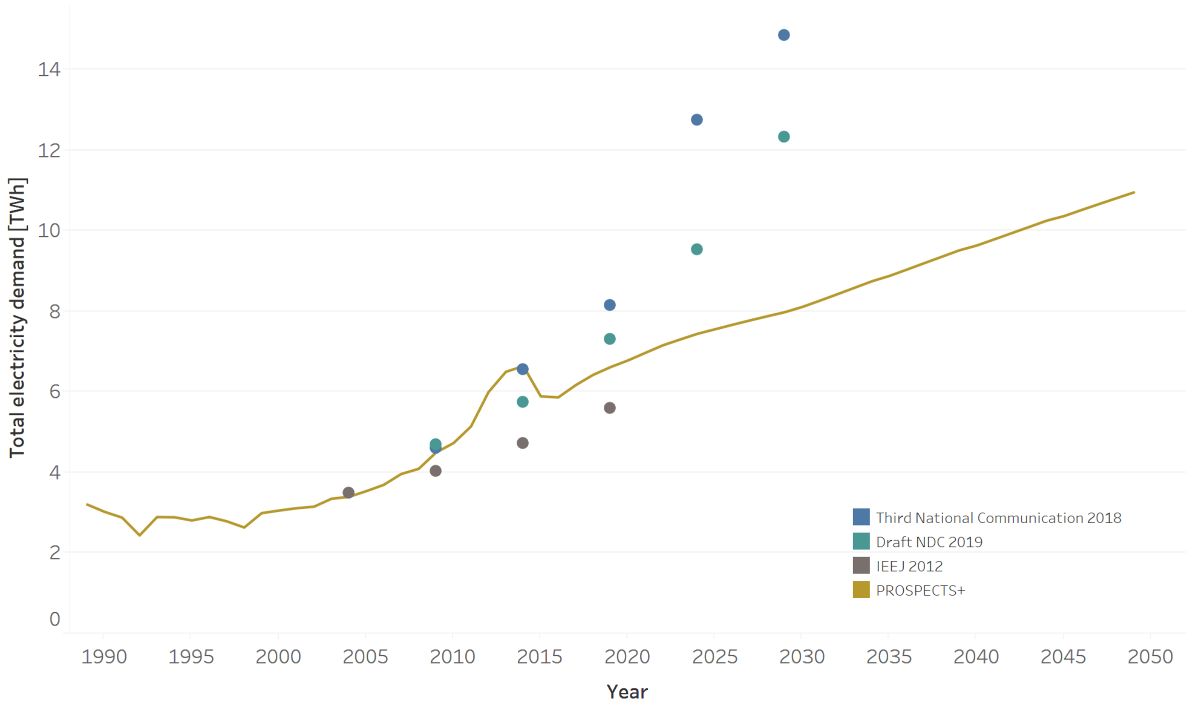

Figure 12: Electricity demand calculated in the PROSPECTS+ scenario evaluation tool under a Current Development Scenario for 1990-2050. Comparison with external data for validation.

Planned capacity expansion would lead to an oversupply of electricity up to 2050

Our analysis suggests that the available electricity generated by existing and planned power plants is enough to supply the electricity demand calculated using the PROSPECTS+ scenario evaluation tool up to 2050. The planned installed capacity would lead to considerable electricity oversupply from 2022 onwards, as shown in Figure 13.

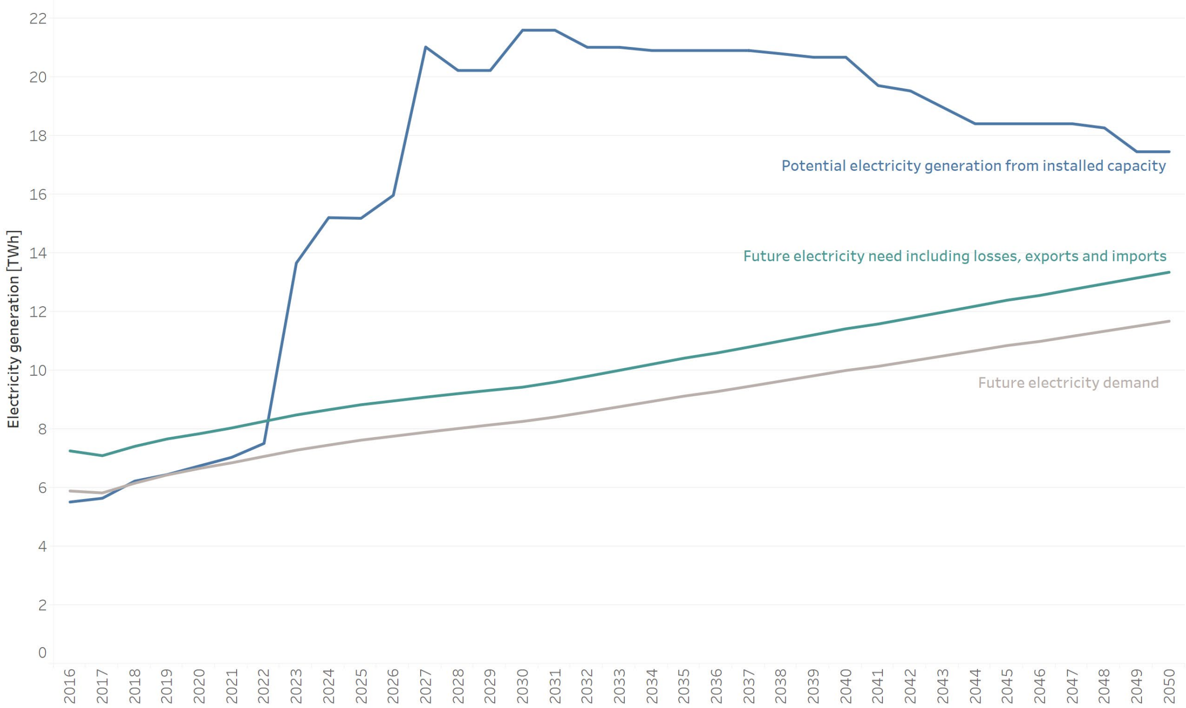

Figure 13: Mongolia's electricity power generation under the Current Development Scenario (CDS) modelled using the PROSPECTS+ scenario evaluation tool.

Although there is considerable expansion of renewable capacity planned for the next 10 years, mostly based on hydro and wind power expansion (see Figure 11), our findings indicate that the capacity mix will not change substantially between 2030 and 2050. Coal capacity and its respective electricity supply will remain a relevant part of total installed capacity (average of 61%) and the generation mix (average of 62%) between 2020 and 2050. The high dependence on coal-based electricity will prolong Mongolia's carbon lock into carbon-intense technologies. This lock-in will create more barriers for low carbon development or result in costly stranded coal assets if any further investment in renewables materialize post-2030.

3.3 Resulting GHG emission levels and their validation

High emissions projected until mid-century and uncertainty surrounding hydropower

The continuous dependence of Mongolia's electricity supply on coal-based generation under current governmental plans will not reduce GHG emissions beyond current levels as od 2020 by mid-century. Our analysis in Figure 14 shows that sector emissions will reach around 12 $MtCO_2e$ by 2020, decrease to 10 $MtCO_2e$ by 2030 due to large hydropower capacity coming online between 2026 and 2017, and increase back to 12 $MtCO_2e$ by 2050.[6] Also, emission levels from 2020 onwards might be significantly higher if part of the newly planned 830 MW hydropower capacity would not come online by 2027 or thereafter.

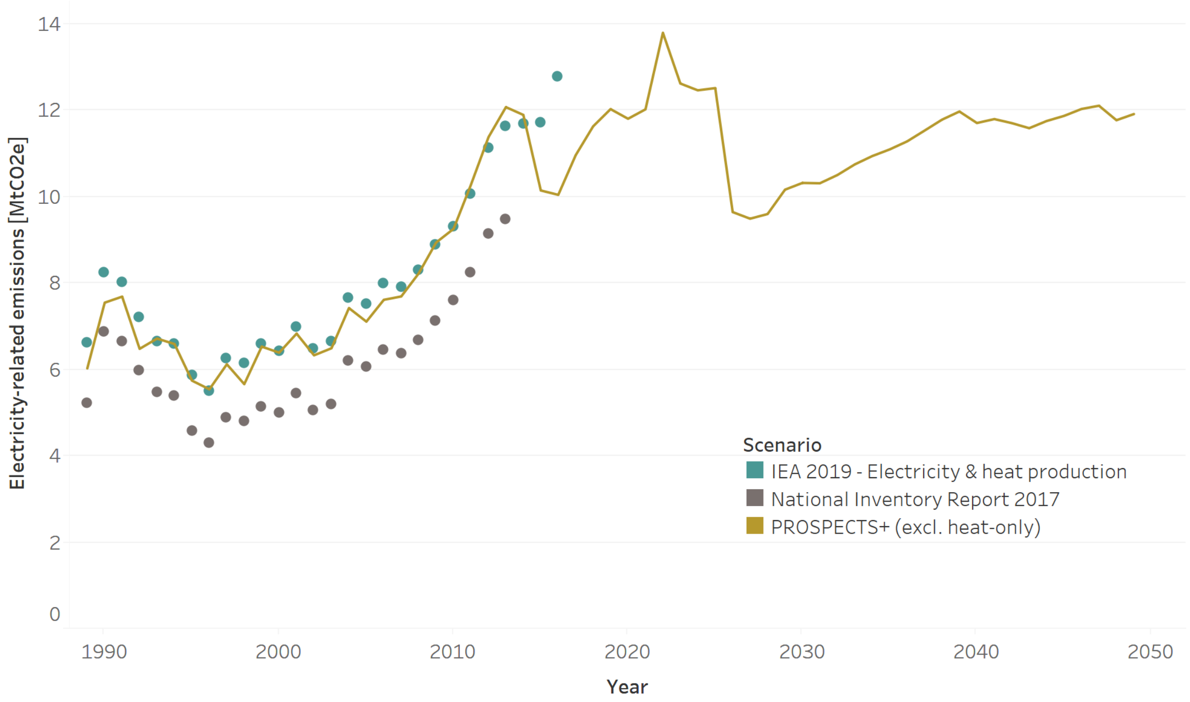

Figure 14: Electricity supply sector emissions calculated in the PROSPECTS+ scenario evaluation tool under a Current Development Scenario for 1990-2050. Comparison with external data for validation.

The high uncertainty surrounding several of Mongolia planned hydropower projects casts doubt on whether emissions between 2030 and 2050 will only grow marginally as shown in our analysis. The abrupt change in emission levels between 2026 and 2027 originate from the large uptake of hydropower and the respective assumed reduction in coal-based power generation as specified in the Mongolian government's most recent capacity extension plans, namely the *Mongolia's Mid-Term National Programme to develop the State Policy on Energy (2018-2023)* of 2018 and the draft version of the updated NDC of 2019.

These emission reductions would not materialise if planned hydropower capacity was not to come online, with coal capacity filling the generation gap instead.

An indicative analysis: comparing total CDS emission levels to the Draft NDC of 2019

Our projections indicate that economy wide GHG emissions (excl. LULUCF) in Mongolia will increase by 8% between 2015 and 2050, reaching 43 $MtCO_2e$ in 2050. The emission pathways in Mongolia's draft NDC of 2019 even forecast an increase of 53% until 2030 already compared to 2015 if all mitigation actions will be implemented (see *Draft NDC 2019 - Mitigation Scenario* in Figure 15). This substantial difference originates from the differences in electricity demand projections as well as the different levels of forecasted economic activity.

[6] Important to highlight, the Current Development Scenario presented here does not include any emission from the possible construction of the Shivee Ovoo coal-based power plant.

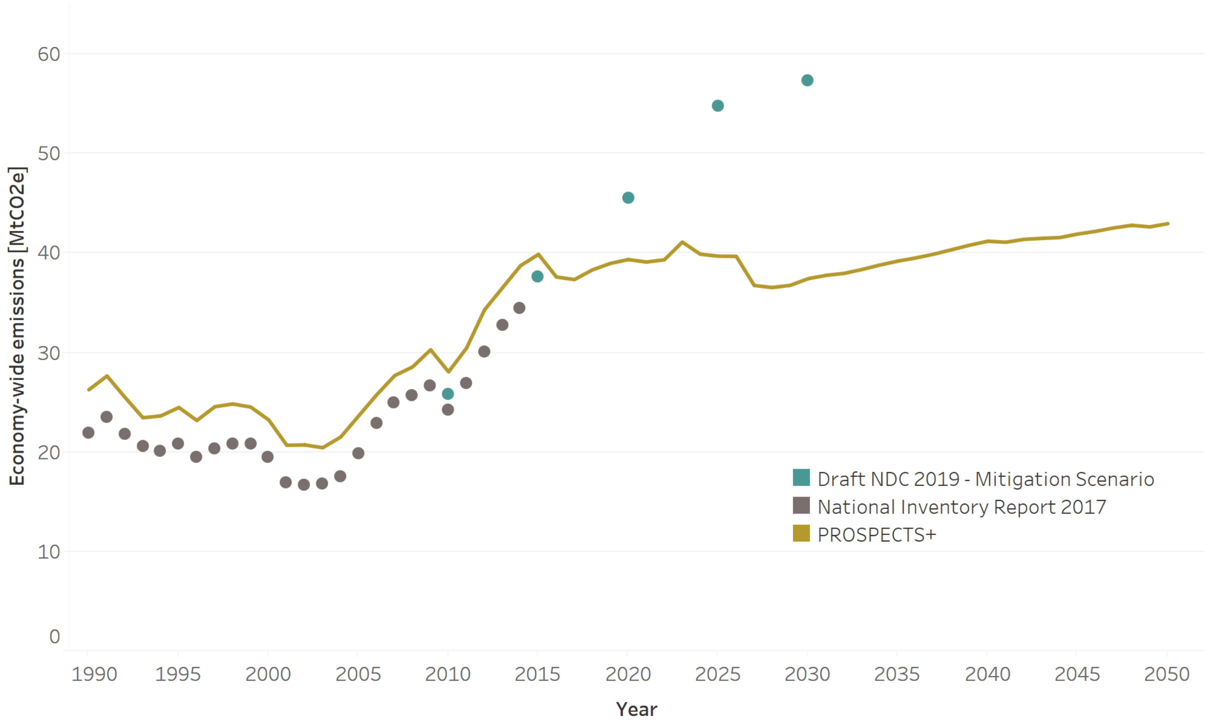

Figure 15: Economy-wide emissions (excl. LULUCF) calculated in the PROSPECTS+ scenario evaluation tool under a Current Development Scenario for 1990-2050. Comparison with external data for validation.

4 An alternative future: Paris compatible electricity supply

Paris Agreement Scenario: Key messages

- ⇨ The Paris Agreement Scenario (PAS) for the Mongolian electricity supply sector represents a first estimate of emission pathways compatible with the Paris Agreement's temperature limit.
- ⇨ An increasing body of recent academic literature on the implications of the Paris Agreement for the Mongolian electricity supply suggests that emissions need to decrease sharply by 60-100% up to 2050 compared to 2015 levels, a decrease driven by an accelerated uptake of renewable technologies.
- ⇨ Under the Mongolian government's current plans, emissions will remain inconsistent with the Paris Agreement temperature target in the long-run due to the expansion of coal-fired power plants and uncertainty around the development of new hydropower projects.
- ⇨ Mongolian policy makers can draw on such long-term scenario analysis to inform their sector planning and communicate financial and technical support needs from the international community.
- ⇨ Actionable next steps forward can include, among others, the implementation of pilot projects for renewable-based heating to decouple heat and electricity supply, the improvement of electricity transmission network and grid operation capacities for integration of (variable) renewables, as well as further development of national research, planning and training capacities for renewable energy development.

4.1 Defining the Paris Agreement Scenario range

The Paris Agreement Scenario (PAS) for the Mongolian electricity supply sector represents a first estimate of emission pathways compatible with the Paris Agreement's temperature limit. For this purpose, most recent literature and academic findings provide country-specific assumptions and renewable shares to inform the range of emission pathways towards 2050. It was assumed the remaining economic sectors follow the current development scenario trends.

The review comprises modelling results from governmental authorities, international organisations, and independent research organizations using different modelling environments. The studies can be classified in three broad groups:

1. **Global-level** modelling with Mongolia specific results: These studies are based on global models that investigate 100% renewables scenarios and their implication (Jacobson *et al.*, 2017; Teske *et al.*, 2019)
2. **City-level** modelling focused on Ulaanbaatar: a study that develops different scenarios for the capital's energy master plan, including 100% renewable electricity and heating (Stryi-Hipp *et al.*, 2018)

3 **Zero-emissions** scenarios: NewClimate Institute's own scenarios informed by emissions and technology trends from international modelling exercises (IEA, 2017; IPCC, 2018).

Table 3 presents the main assumptions for all scenarios used to determine the Paris Agreement-compatible emissions pathway range. None of these reviewed scenarios assume similar levels of installed coal capacity by mid-century as proposed in the current coal capacity expansion plans by the Mongolian Government. The proposed expansion by 1.7 GW is not compatible with decarbonisation of the power sector around mid-century without early decommissioning.

Table 3: Main assumptions Paris Agreement Scenario (PAS) range based on selected studies

Scenarios // Main Assumptions by 2050	Zero coal	RE generation share (variable)	RE generation share (dispatchable)
Teske et al. (2019) – 1.5°C scenario	No	94% (74%)	20% (hydropower)
Teske et al. (2019) – 2°C scenario	No	94% (71%)	22% (hydropower)
Jacobson et al. (2017) – 1.5°C scenario	Yes	100% (88%)	12% (CSP)
Stryi-Hipp et al. (2018) – Ulaanbaatar Base case	No	95% (68%)	-
Stryi-Hipp et al. (2018) – Ulaanbaatar Base case plus Regional Wind	Yes	100% (83%)	-
Zero emissions by 2050 assuming linear phase in of mitigation technologies	Yes	100% (-)	39% (hydropower)
Zero emissions by 2060 assuming linear phase in of mitigation technologies	No	78% (-)	30% (hydropower)

Some practical challenges exist of using the available literature. Most scenarios present the share of dispatchable and variable renewable generation separately, however, not all of them specify the technology breakdown further. In addition, the studies do not present a full time series neither for the power generation nor installed capacity shares.

In the CDS, the electricity generation capacity expansions are fully defined by national plans (refer to Section 3). These national plans can be translated/interpreted to determine power generation shares over time, requiring no further assumptions. In the case of the PAS, such detailed capacity expansion plans compatible with the Paris Agreement are not available.

For this reason, the Power Plant Stock Turnover Tool is used to identify capacity shares compatible with the generation shares in the studies presented in Table 3.

4.2 Electricity generation capacity

According to our analysis, all scenarios present alternatives able to fulfil electricity demand and reserve margin requirements in Mongolia. Each of these scenarios would lead to a distinct share of renewables in power generation. Figure 16 presents an overview of how installed capacities translate into technology-specific shares of electricity generation in the Mongolian electricity supply.

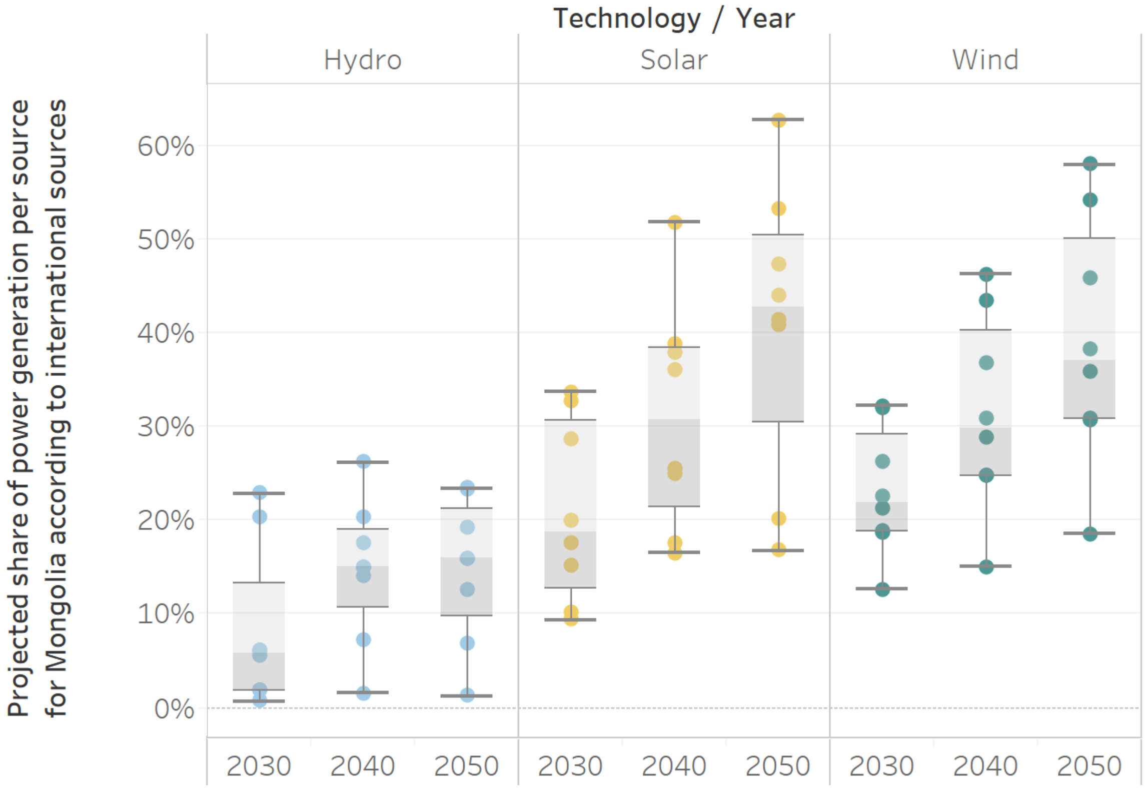

Figure 16: Box-and-whisker plot of renewable share in electricity generation for Mongolia based on existing scenarios from international research (Jacobson *et al.*, 2017; Stryi-Hipp *et al.*, 2018; Teske *et al.*, 2019). Each dot represents a distinct scenario.

The Power Plant Stock Turnover Tool allows for the user to set a merit order when matching electricity supply and demand. In the case of selected scenarios for which no technology granularity is available, we develop two main alternatives to meet the share of variable renewable generation: one with *high solar* PV uptake and another with *high wind* uptake. An overview of the resulting installed capacity shares per scenario is available in Figure 17.

None of the scenarios analysed expects the uptake of large hydropower capacities that Mongolia plans for in their current capacity expansion plans (refer to Section 0). If the Mongolian Government implements these expansion plans for hydropower, Mongolia could have an even higher share of dispatchable renewable electricity. This would in turn reduce the need for variable technologies with lower capacity credits, like solar PV and onshore wind.

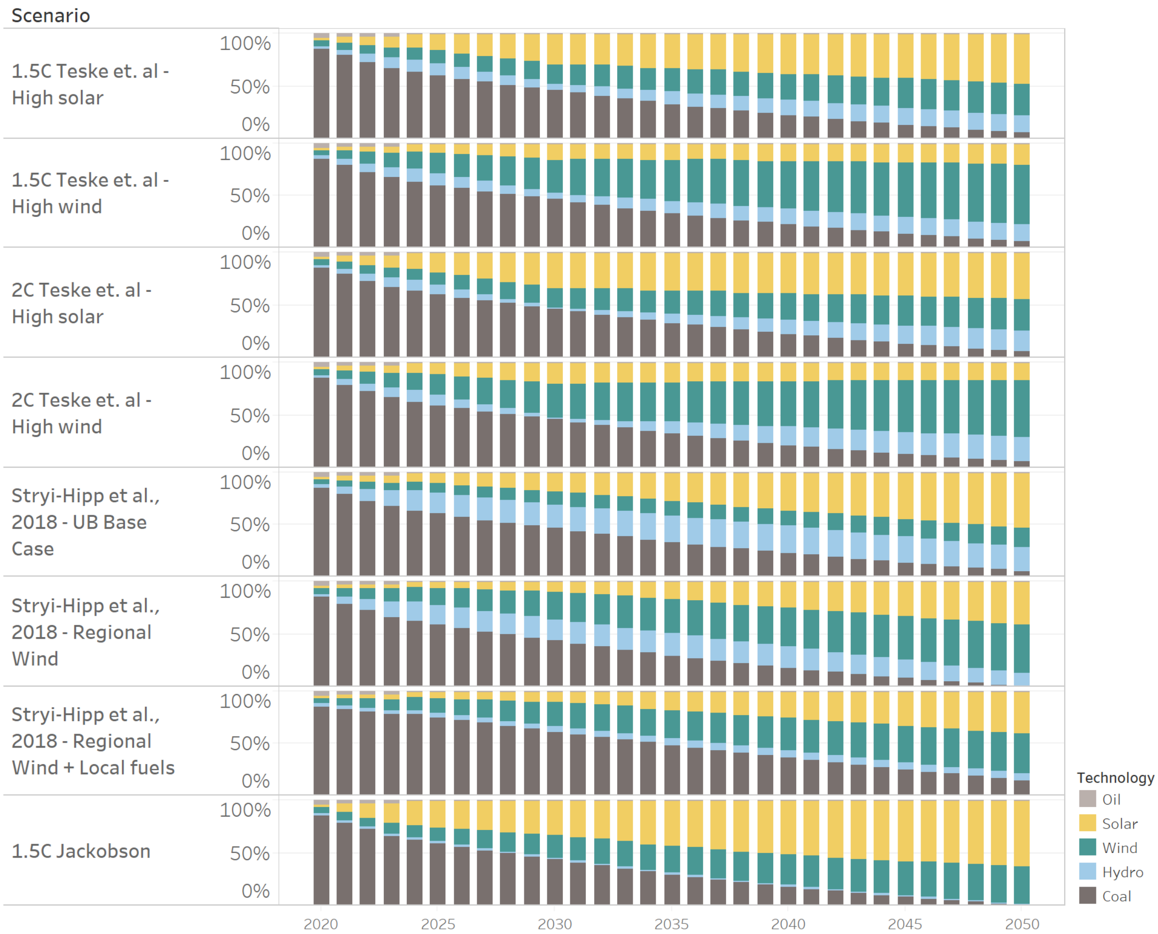

Figure 17: Installed capacity shares per technology under different scenarios that result in the decarbonisation of Mongolian electricity supply in line with the Paris Agreement's temperature limit

4.3 Resulting GHG emissions

A proposal for a non-binding, indicative long-term vision towards 2050

The Paris Agreement Scenario (PAS) range of this analysis can be used to define a non-binding, indicative long-term vision for Mongolian electricity supply towards 2050. The current version exclusively focuses on electricity supply for Mongolia. A long-term vision comprising heating supply would need to account for uncertainty of feasible low-carbon technological solutions to replace the current combined heat and power (CHP) based system to provide reliable heating in Ulaanbaatar and *aimag* centres given Mongolia's climatic circumstances.

Figure 18 displays the range of emissions related to electricity supply that could be considered Paris-compatible, building upon a range of scenarios presented in literature on decarbonisation of the electricity supply sector (IEA, 2017; Jacobson *et al.*, 2017; IPCC, 2018; Stryi-Hipp *et al.*, 2018; Teske *et al.*, 2019). The results are meant as a first estimate to illustrate the general trend the electricity supply sector emissions could follow under a scenario of accelerated decarbonisation efforts.

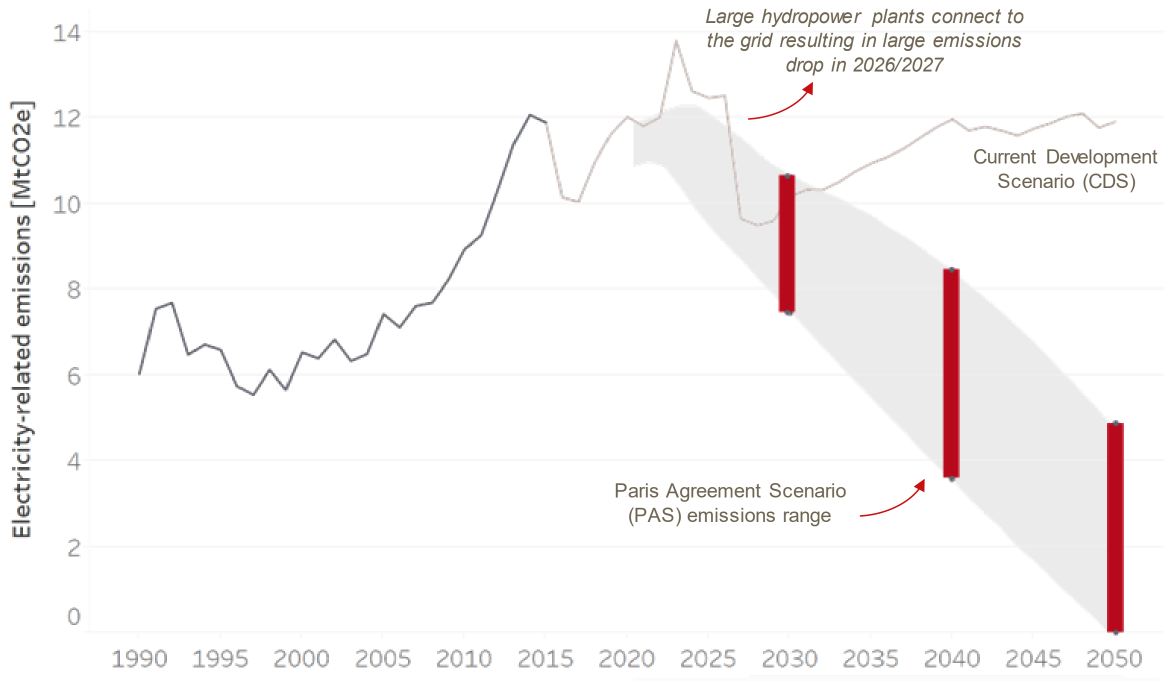

Figure 18: Emission pathways for the Mongolian electricity supply sector considered 'Paris Agreement-compatible' (first estimate) informing the selection of emission ranges in 2030, 2040 and 2050. The Current Development Scenario presents the expected evolution of the electricity supply sector in Mongolia assuming the successful implementation of existing sectoral policies and the most recent capacity expansion plans.

A sharp decrease in emissions by 60-100% up to 2050 compared to 2015

All scenarios in the PAS range foresee a relatively sharp decrease in emissions up to 2050, however, scenarios informing the upper bound still assume substantial remaining emissions in 2050. Considering Mongolia's high coal dependency, the Mongolian government might opt for operating some coal plants for a longer period beyond the 2050. In order to fulfil its commitments to the Paris Agreement, such prolonged operation should be restricted to special cases and a total coal phase out should not be delayed significantly after mid-century.

According to our analysis, Mongolia's emissions would still be in a Paris compatible range up to 2030 if the large-scale and highly uncertain hydropower plants are commissioned as planned in 2027. Nonetheless, considering the coal expansion happening in parallel and the economic growth after 2030, emissions will start to rise again towards 2050. Consequently, the Mongolian government would need to revisit its current expansion plans for coal-fired power plants to avoid constructing power plants that are not needed.

The Paris Agreement Scenario in the context of long-term sector planning

Sectoral long-term planning becomes imperative for the submissions of both Nationally Determined Contributions (NDCs) and Long-Term Strategies (LTS) in 2020 and the future revision cycles of these processes. The robust analysis of sectoral pathways enables policy makers to understand the implications of different levels of mitigation ambition in terms of technologies, emissions, and socio-economic impacts. This allows to identify technology, financial and capacity support needs for the international community to effectively increase mitigation action. Such forward-looking analysis therefore helps to determine appropriate sectoral mitigation targets for 2030 and 2050, and to update these targets over time.

In this context, the PAS represents a first input to understand the implications of international mitigation action mandated by the Paris Agreement on the Mongolian electricity supply sector. Building thereupon, Mongolian policy makers and respective line ministries can initiate integrated and iterative sectoral long-term planning processes to proactively shape the sector's transition towards low-carbon technologies.

4.4 Outlook and actionable next steps

Understanding the science behind climate change constitutes the starting point to develop technological solutions for an electricity supply sector transition

The unambiguous findings of the IPCC's special report on 'Global Warming of 1.5°C' and their implications for the electricity supply sector worldwide constitutes a starting point for sectoral planning processes. Policy makers in Mongolia can use analysis such as the Paris Agreement Scenario (PAS) range for the electricity supply sector to conceptualise the development of required technological solutions and respective needs in terms of finance, human capacity development, and technology transfer. Such planning should integrally be built on an in-depth understanding on different phases of power system transformation and related challenges in a country-specific context (De Vivero *et al.*, 2019). This approach enables policy makers to actively engage in a strategic discourse to develop and implement low-carbon alternatives over time.

Actionable next steps forward to accelerate mitigation ambition in the Mongolian electricity supply sector in the future

While the in-depth assessment of technological solutions is outside the scope of this analysis, we identify several actionable next steps in the medium-term to lay the foundations to accelerate mitigation ambition in the future. These next steps in key fields of action have been identified during the energy sector consultations for the development of the NDC between the Ministry of Energy (MoE), the Ministry of Environment and Tourism (MET), and other relevant stakeholders in the sector. The selection has been further informed by a review of the most recent planning documents of the Government of Mongolia and other available literature (IRENA, 2016; GCF Country Programme of Mongolia, 2018; Government of Mongolia, 2018; Stryi-Hipp *et al.*, 2018).

I. **Implementation of pilot projects for renewable-based heating in Ulaanbaatar and *aimag* centres**: Alternatives for renewable-based heating in Mongolia can reduce the ongoing need for coal-based CHP capacity in Ulaanbaatar to provide reliable heating supply, thus allowing to decouple heat and electricity production.

II. **Improvement of electricity transmission network for integration of (variable) renewables**: An improved and expanded transmission network can connect regional energy systems to the central energy system and facilitate the grid-connection and integration of (variable) renewables capacity.

III. **Improvement of grid operation capacities for integration of (variable) renewables**: The improvement of Mongolian grid operation capacities would ensure more reliable operation of electricity transmission and distribution network and facilitate grid-connection and integration of (variable) renewables capacity.

IV. **Further development of national research, planning and training capacities for renewable energy development**: Measures in this field of action improve the national capacity of human resources in the energy sector to obtain required know-how and skills for an accelerated uptake of renewables and other low-carbon technologies.

If addressed successfully in the medium-term, these actionable next steps could enable Mongolia to accelerate mitigation ambition in the electricity supply sector in line with the Paris Agreement. For this purpose, Mongolia will require continuous and reliable financial and technical support by the international community to successfully initiate and implement concrete measures in each of the four fields of action.

5 Quantification of air pollution impacts

Quantification of air pollution impacts: Key messages

- ⇨ Coal-fired power plants accounted for roughly 6% of national air pollution in 2016, providing the third-largest source of particulate matter in Mongolia.
- ⇨ Continued operation of coal-fired power plants could cause almost 1,600 premature deaths / 42,000 years of life lost in Mongolia between 2020 and 2050.
- ⇨ Around 70% of these premature deaths and years of life lost will be caused by power plants not yet in operation but included in coal capacity expansion plans of the Mongolian Ministry of Energy as of January 2020.
- ⇨ The proposed Shivee Ovoo power plant alone would cause more premature deaths (640) and years of life (17,380) lost by 2050 than all other proposed new coal plants together (470 and 12,640 respectively). Shivee Ovoo's pollution will directly affect the Mongolian population while exclusively producing electricity for use in neighbouring China.

5.1 Air pollution in Mongolia

Air pollutant emissions released through energy-related fuel combustion have negative impacts on human health and the environment. In 2017, air pollution was the fifth highest mortality risk factor globally (Health Effects Institute, 2019). The energy sector, including both production and use, is the largest source of anthropogenic air pollutant emissions, responsible for the emissions of 85% of primary particulate matter and almost all of the SO_2 and NO_x emitted worldwide (IEA, 2016; Watts *et al.*, 2017). Combustion of fossil fuels is the main source of both GHG emissions and air pollutants. Consequently, climate mitigation measures that reduce the use of fossil fuels typically have great potential to cut emissions of other air pollutants.

In Mongolia, overall ambient (outdoor) air pollution led to roughly 3,300 premature deaths in 2016 with associated costs of MNT 18.4 billion (USD 8.5 million) in Ulaanbaatar alone (National Center for Public Health and UNICEF, 2018). Most of the Mongolian population is exposed to ambient air concentrations of particulate matter which are well above the WHO guidelines and the National Standards of Mongolia (UNDP, 2019). In January 2018 the recommended maximum level of $PM_{2.5}$ was exceeded 133 times in Ulaanbaatar (Fuhrmann, 2019). Mongolia recognises this issue and in March 2017 set a target to decrease air pollutants by 80% between 2017 and 2025 (WHO, 2019). While most of the particulate matter comes from burning raw coal for heating and cooking, followed by vehicle emissions, coal-fired power generation is the third-largest contributor to air pollution in Mongolia, accounting for roughly six percent of the total (ADB, 2018).

5.2 Defining the scope of quantification

Our analysis uses the AIRPOLIM-ES to estimate the health impacts of the existing (1 GW) and proposed new (7 GW, including Shivee Ovoo plant of 5.3 GW) coal capacity in Mongolia, which is in line with the latest capacity expansion plans by the Ministry of Energy for the period to 2030. We include the planned 5.3 GW Shivee Ovoo power plant since it will have significant health impacts for the Mongolian population, despite exclusively exporting the electricity it generates to China.

The calculations assume an annual capacity factor of 65% for all power plants. Technical data used in the analysis, including heat rate or capacity factor, is based on data collected in the Global Coal Plant Tracker data base (Global Energy Monitor, 2019b). The Ministry of Energy provided data on each plant's capacity (MW) and lifetime (Dorjpurev, 2019). We calculate health impacts for the period from 2020 to 2050, though most power plants are currently expected to run beyond this point in time.

Figure 19 provides a geographical overview of all existing and planned coal-fired power plants included in the analysis and the affected distance bands around these plants, which reflect the exposed population for which we estimate health impacts.

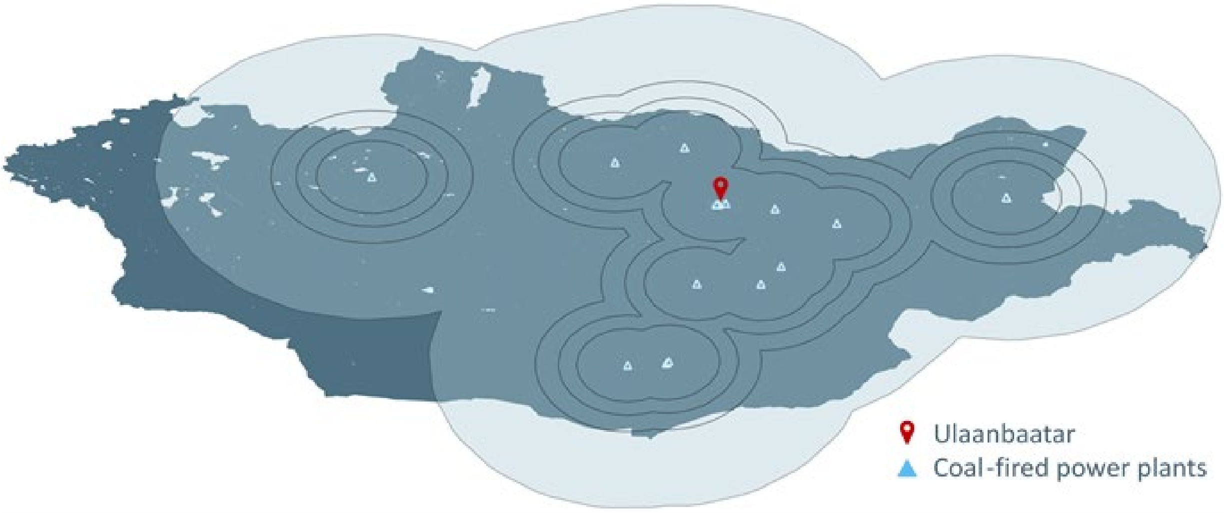

Figure 19: Existing and planned coal-fired power plants in Mongolia and distance bands affected by the air pollutants emitted by each coal-fired power plant within the country. Each triangle represents one coal-fired power plant.

5.3 Health impacts from air pollution

Air pollution from coal-fired power plants causes premature deaths until 2050

The operation of coal-fired power plants leads to the release of air pollutants that have negative impacts on human health throughout the plants' whole lifetime. Figure 20 provides an overview of the estimated number of premature deaths for 2020-2050 by year and cause of death. The leading cause of death in each year is heart disease (caused by a narrowing of the arteries), followed by stroke, lung cancer, and chronic obstructive pulmonary disease. The drop in premature deaths in 2044 is caused by the planned retirement of several older power plants.

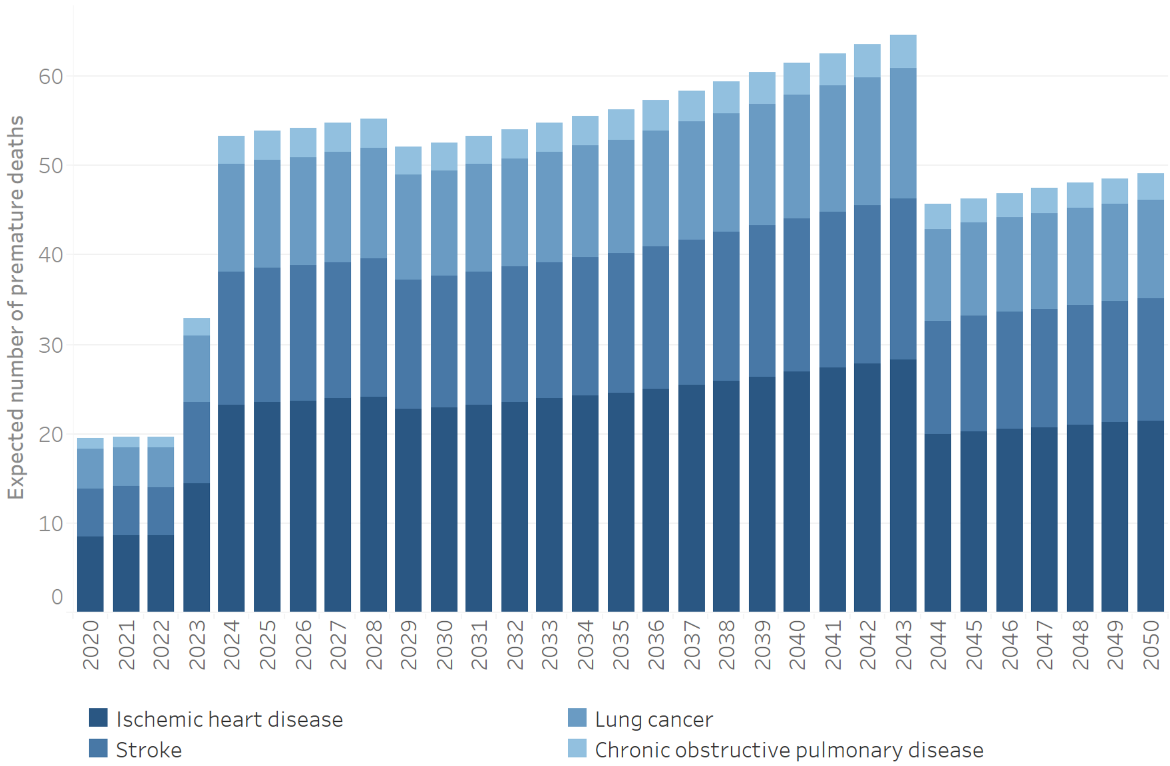

Figure 20: Annual premature deaths caused by coal-fired power plants in Mongolia between 2020 and 2050 per cause

The Shivee Ovoo power plant alone would cause more premature deaths than all other proposed new coal plants together

Aggregating the annual results in Figure 21, a total of 1,560 people would die prematurely in Mongolia until 2050 due to air pollution from coal-fired power generation if current capacity expansion plans are fully implemented. This corresponds to roughly 42,000 years of life lost during the same period (see Figure 22). Over 70% of these health impacts are caused by coal-fired power plants that are not yet in operation and could potentially be replaced by cleaner energy sources. While 788 MW of proposed new coal capacity are already under construction, the majority of the ~7 GW of new capacity is only announced.

The proposed Shivee Ovoo power plant alone would cause more premature deaths (640) and years of life lost (17,380) than all other proposed new coal plants together (470 and 12,640 respectively). The results of this analysis can be considered conservative estimates since a whole range of further impacts – including all morbidity-related factors, health impacts from other pollutants, impacts on children, and workdays lost – are not included in the quantification.

In addition, the topography of Ulaanbaatar further contributes to poor air quality. The city is surrounded by mountains and typically has very cold, dry air in the autumn and winter months. This combination traps the air near the surface in and around the city, preventing dispersion of the pollutants (ADB, 2018). As these features are not fully accounted for in our modelling, the number of premature deaths and years of life lost is potentially higher than those we estimate.

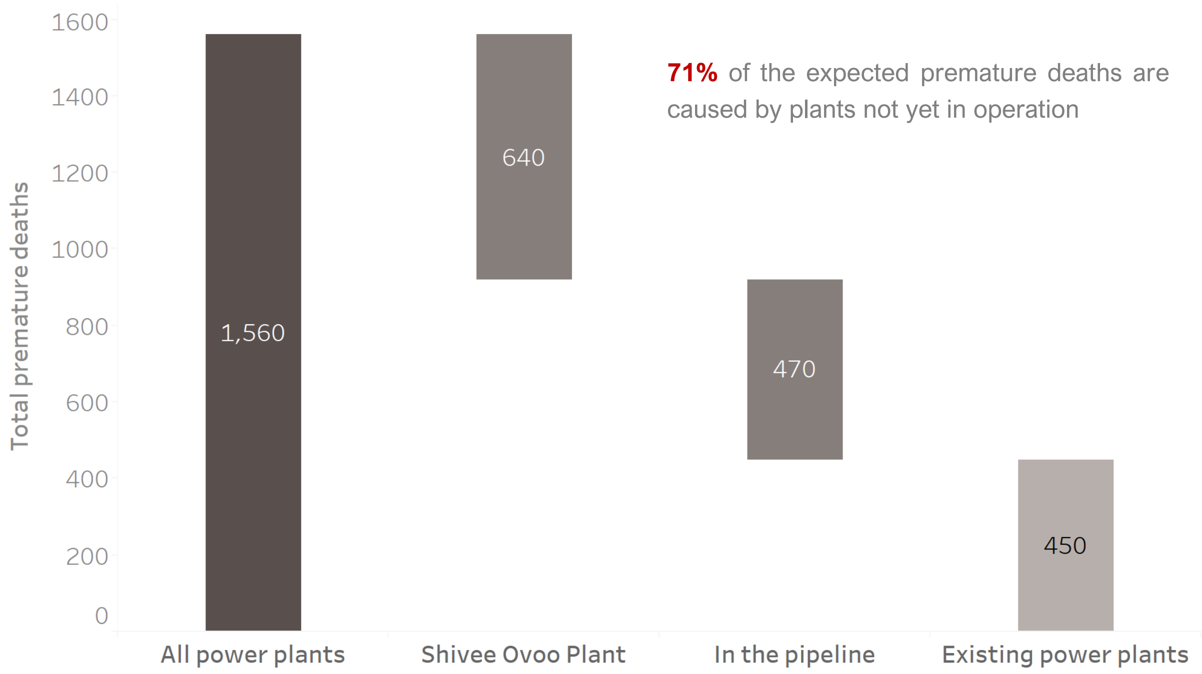

Figure 21: Total premature deaths caused by coal-fired power plants in Mongolia 2020-2050 by power plant group

Mongolia is rapidly urbanising: between 2000 and 2017 the share of its population living in urban areas grew from 57% to 68% (World Bank, 2018). Rural-to-urban migration is driven by both environmental and economic factors. The transition to a market-based economy after 1990 impacted support to nomadic herders. The central supply of fodder that helped herders feed their animals through harsh winters was discontinued and the livestock in specific areas close to markets increased, concentrating the animals in smaller grazing areas and reducing feedstock quality (Rao *et al.*, 2015). The intensification of summer droughts followed by severe winters (dzuds), killing over 11 million animals between 1999 and 2002, and 8 million in 2009 alone, also contributed to the growing urbanisation trend observed between 1999 and 2010, mostly to Ulaanbaatar (Faraz Shibli, 2017).

Most of the existing and planned coal-fired power plants are located close to urban centres. If the urbanisation trend continues, premature deaths could substantially increase as more people would live and work in closer proximity to the power plants. The health impact of Mongolia's coal-fired power plants will increase compared to the previous year with every additional year of operation, as long as the population – particularly in Ulaanbaatar – continues to grow.

Assessing air pollution impacts in Mongolia's future energy sector planning

Our analysis illustrates the importance of integrating health and other socio-economic impacts into Mongolia's energy sector planning. Analysis based on robust and credible methodologies can inform the potential implications of different future energy sector scenarios. The air pollution analysis in this study, using the AIRPOLIM-ES, is based on the most recently available capacity expansion plans by the Ministry of Energy, as of January 2020. Similar future analyses can enable Mongolian policy makers to better understand the synergies between accelerated climate action in the energy sector and achieving wider sustainable development objectives and to integrate such insights in their sector planning processes.

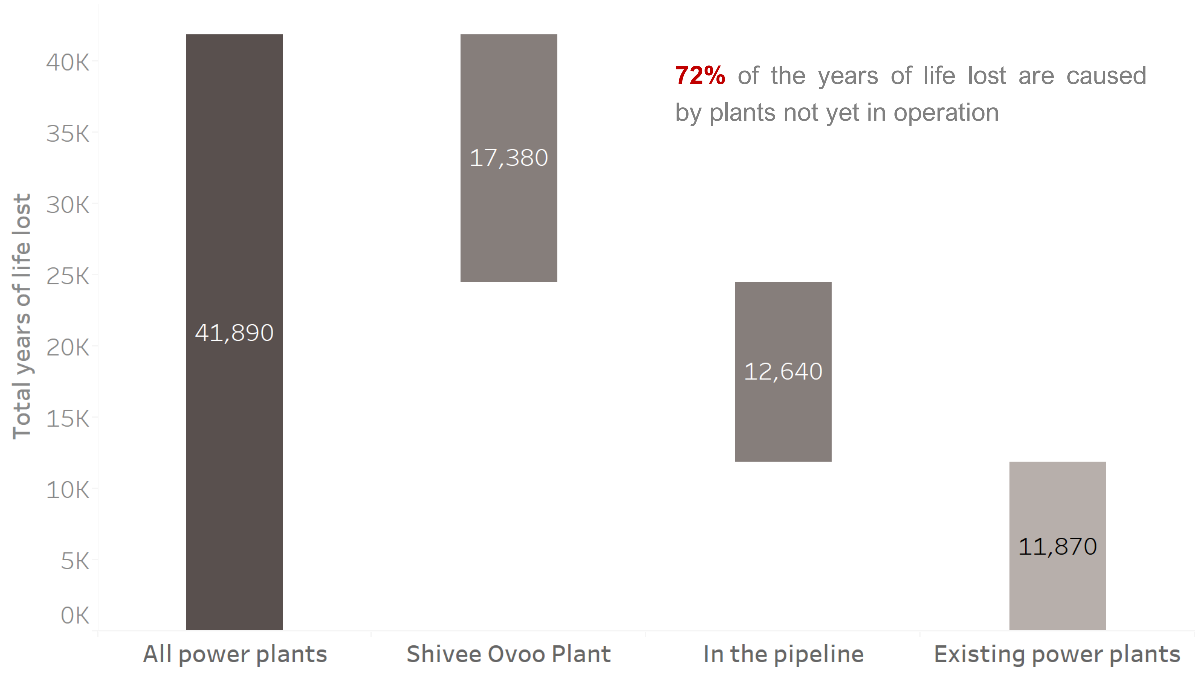

Figure 22: Total years of life lost due to coal combustion for electricity generation in Mongolia 2020-2050 by power plant group

The scope of the analysis of socio-economic impacts can be further extended in two ways going forward. First, the assessment of health impacts could be expanded to include air pollution deriving both from burning raw coal for heating as well as vehicle emissions. Both emission sources are the two major sources of air pollution in Mongolia to date. Second, other socio-economic impacts such as implications for employment levels and investment in the country could be assessed for different energy supply scenarios.[7] This can help policy makers to make well-informed decisions for the future of Mongolia's energy supply considering a range of technical, economic, social and environmental indicators.

[7] For example, NewClimate Institute developed the Economic Impact Model for Electricity Supply (EIM-ES) which estimates the domestic employment – and wider economic - impacts of investments in the electricity supply sector within a country. The open-source tool and further information is available under https://newclimate.org/2018/11/30/eim-es-economic-impact-model-for-electricity-supply/.

6 Concluding remarks

The present analysis focuses on the Mongolian electricity supply sector and presents an outlook for emissions pathways until 2050, in line with current developments in the sector as well as with the global warming limit set by the Paris Agreement. The analysis focuses on electricity supply but is based on an economy-wide bottom up modelling exercise to appropriately reflect projected growth in electricity demand in different sectors.

Further analysis is required to inform policy makers on low-carbon transition

Such indicative long-term scenario modelling provides first insights for policy makers to understand the implications of the Paris Agreement's temperature target. However, additional analyses will be fundamental to enable Mongolian policy makers to conceptualise and implement a successful transition from a heavily coal-based electricity supply to a low emission electricity mix by 2050.

The scope of the present analysis must be expanded to better understand effects on other relevant sectors, like coal mining or heating supply. It is necessary to investigate how Mongolia can replace revenues from coal mining to ensure future economic growth for example, but also to picture what a fossil-free heating sector could look like by mid-century. Another key aspect is the feasibility of decarbonisation scenarios, considering both technical limitations (e.g. electricity grid constraints) and financial aspects (e.g. incentive design or access to international finance).

Policy makers can proactively plan for a just transition away from coal for affected communities

Our analysis explores possible co-benefits of climate mitigation action in Mongolia. It shows that thousands of premature deaths can be prevented by cancelling current electricity capacity expansion plans heavily focusing on coal. Shifting investments from fossil fuels to renewable energy has the potential for domestic job creation in Mongolia and supports the development of domestic manufacturing industries, particularly in low-carbon-oriented fields.

Mongolian policy makers need to actively manage a just transition for those communities affected by the reduction of coal-related jobs, given the uncertain future for such jobs in Mongolia (and worldwide) as part of the global efforts to phase out coal combustion. The current analysis outlines an indicative long-term vision, which can provide an input to the indispensable discussion about the country's just transition towards decarbonisation. Mongolia can use this exercise to support the development of its LTS and overall long-term planning. It would provide a clear blueprint for investments and technology transfers, while ensuring the required support is provided to affected communities.

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Annex - Data

Chapter 3 - Current Development Scenario: A future locked into carbon

Table 4: Data outputs for *Figure 11: Overview of existing and planned Mongolian installed electricity generation capacity under the Current Development Scenario (CDS).*

Installed capacity [MW]					
Year	Solar	Wind	Hydro	Coal	Oil
2010	0	1	29	908	121
2011	0	1	29	926	141
2012	0	1	29	926	141
2013	15	51	29	926	141
2014	15	51	29	976	141
2015	15	51	29	976	141
2016	25	51	29	976	141
2017	35	101	29	976	141
2018	60	155	24	1107	18
2019	85	155	24	1142	18
2020	140	165	24	1177	18
2021	240	225	25	1159	18
2022	240	330	26	1209	18
2023	240	334	27	2419	18
2024	240	339	218	2419	18
2025	240	443	244	2345	18
2026	240	573	245	2445	18
2027	264	577	862	2445	18
2028	264	581	863	2288	18
2029	264	586	864	2288	18
2030	264	590	865	2558	18
2031	264	595	866	2558	18
2032	264	599	868	2443	18
2033	264	604	869	2443	18
2034	264	558	870	2443	18
2035	264	563	871	2443	18
2036	264	568	873	2443	18
2037	264	572	874	2443	18
2038	264	526	875	2443	18
2039	264	477	876	2443	18
2040	264	481	878	2443	18
2041	264	486	879	2253	18
2042	264	490	880	2217	18
2043	264	495	881	2107	18
2044	264	500	882	1997	18
2045	264	504	884	1997	18
2046	264	509	885	1997	18
2047	264	513	886	1997	18
2048	264	518	887	1969	18
2049	264	523	889	1809	18
2050	264	527	890	1809	18

Supplementary information on Table 4: Data compiled by merging PLATTS database (S&P Global Platts, 2016), Global Coal Plant Tracker database (Global Energy Monitor, 2019a), and IRENA's Renewable Capacity Statistics for renewables (IRENA, 2019b)*. The merged database covers the period between 1990 and 2017. For the period between 2018 and 2030, we use information provided by the Ministry of Energy in the context of the NDC modelling exercise conducted in 2019 (Dorjpurev, 2019). The development of installed capacity post-2030 is based on the decommission of power plants according to the expected average technical lifetimes.*

Table 5: Data outputs for *Figure 12: Electricity demand calculated in the PROSPECTS+ scenario evaluation tool under a Current Development Scenario for 1990-2050. Comparison with external data for validation.*

Electricity demand [TWh]									
Year	PROSPECTS+ (excl. heat-only)	Third National Communication	Draft NDC 2019	IEEJ 2012	Year	PROSPECTS+ (excl. heat-only)	Third National Communication	Draft NDC 2019	IEEJ 2012
1990	3.21				2021	6.79			
1991	3.02				2022	6.97			
1992	2.88				2023	7.16			
1993	2.44				2024	7.31			
1994	2.90				2025	7.45	12.76	9.53	
1995	2.89				2026	7.56			
1996	2.81				2027	7.67			
1997	2.90				2028	7.78			
1998	2.79				2029	7.88			
1999	2.64				2030	7.98	14.84	12.33	
2000	2.99				2031	8.11			
2001	3.06				2032	8.27			
2002	3.12				2033	8.43			
2003	3.15				2034	8.59			
2004	3.35				2035	8.75			
2005	3.40			3.48	2036	8.88			
2006	3.54				2037	9.04			
2007	3.70				2038	9.20			
2008	3.97				2039	9.36			
2009	4.09				2040	9.52			
2010	4.50	4.60	4.69	4.02	2041	9.64			
2011	4.73				2042	9.79			
2012	5.15				2043	9.95			
2013	6.00				2044	10.10			
2014	6.50				2045	10.26			
2015	6.64	6.56	5.74	4.73	2046	10.37			

Electricity demand [TWh]									
Year	PROSPECTS+ (excl. heat-only)	Third National Communication	Draft NDC 2019	IEEJ 2012	Year	PROSPECTS+ (excl. heat-only)	Third National Communication	Draft NDC 2019	IEEJ 2012
2016	5.89				2047	10.52			
2017	5.87				2048	10.67			
2018	6.17				2049	10.81			
2019	6.43				2050	10.96			
2020	6.62	8.16	7.29	5.59					

Supplementary information for Table 5: Forecasted electricity demand based on PROSPECTS+ bottom-up calculations for all demand sectors between 1990 and 2050. Other recent modelling exercises conducted for the Third National Communication of 2018 (Ministry of Environment and Tourism, 2018) and the modelling results for Draft NDC of 2019 (Dorjpurev, 2019).

Table 6: Data outputs for *Figure 13: Mongolia's electricity power generation under the Current Development Scenario (CDS) modelled using the PROSPECTS+ scenario evaluation tool.*

Electricity demand and generation [TWh]			
Year	Future electricity demand	Future electricity need including losses, exports and imports	Potential electricity generation from installed capacity
2016	5.89	7.26	5.51
2017	5.82	7.09	5.64
2018	6.16	7.41	6.23
2019	6.44	7.66	6.45
2020	6.66	7.84	6.74
2021	6.85	8.04	7.04
2022	7.07	8.26	7.51
2023	7.28	8.48	13.66
2024	7.45	8.66	15.20
2025	7.62	8.83	15.18
2026	7.76	8.96	15.96
2027	7.89	9.09	21.02
2028	8.02	9.21	20.22
2029	8.14	9.32	20.22
2030	8.26	9.43	21.59
2031	8.41	9.60	21.59
2032	8.58	9.80	21.01
2033	8.76	10.00	21.01
2034	8.94	10.21	20.90

Electricity demand and generation [TWh]			
Year	Future electricity demand	Future electricity need including losses, exports and imports	Potential electricity generation from installed capacity
2035	9.12	10.42	20.90
2036	9.28	10.59	20.90
2037	9.45	10.79	20.90
2038	9.64	11.00	20.79
2039	9.81	11.21	20.67
2040	10.00	11.42	20.67
2041	10.14	11.58	19.70
2042	10.31	11.78	19.52
2043	10.49	11.98	18.96
2044	10.67	12.19	18.40
2045	10.85	12.39	18.40
2046	10.99	12.55	18.40
2047	11.16	12.75	18.40
2048	11.33	12.95	18.26
2049	11.50	13.15	17.45
2050	11.67	13.34	17.45
2045	264.00	504.07	883.67
2046	264.00	508.62	884.89
2047	264.00	513.16	886.12
2048	264.00	517.71	887.35
2049	264.00	522.75	888.58
2050	264.00	527.30	889.80

Supplementary information for Table 6: Forecasted electricity demand based on PROSPECTS+ bottom-up calculations for all demand sectors between 1990 and 2050. The power need is calculated by assuming continuation of current trends for exports, losses (assuming achievement of the NDC targets) and imports. The potential electricity generation from existing capacity is calculated using average capacity factors.

Table 7: Data inputs for *Figure 14: Electricity supply sector emissions calculated in the PROSPECTS+ scenario evaluation tool under a Current Development Scenario for 1990-2050. Comparison with external data for validation.*

Electricity-related emissions [MtCO2e]					
Year	PROSPECTS+ (excl. heat-only)	National Inventory Report 2017	Year	PROSPECTS+ (excl. heat-only)	National Inventory Report 2017
1990	6.03	5.21	2021	11.80	
1991	7.55	6.86	2022	12.02	
1992	7.69	6.64	2023	13.79	
1993	6.48	5.97	2024	12.62	
1994	6.71	5.47	2025	12.46	
1995	6.59	5.37	2026	12.51	
1996	5.74	4.58	2027	9.64	
1997	5.54	4.30	2028	9.49	
1998	6.12	4.88	2029	9.60	
1999	5.66	4.79	2030	10.16	
2000	6.53	5.13	2031	10.32	
2001	6.39	5.00	2032	10.31	
2002	6.83	5.43	2033	10.50	
2003	6.33	5.06	2034	10.74	
2004	6.49	5.18	2035	10.94	
2005	7.42	6.20	2036	11.09	
2006	7.11	6.06	2037	11.28	
2007	7.61	6.45	2038	11.53	
2008	7.69	6.36	2039	11.78	
2009	8.22	6.67	2040	11.97	
2010	8.94	7.11	2041	11.70	
2011	9.25	7.60	2042	11.79	
2012	10.28	8.24	2043	11.70	
2013	11.37	9.12	2044	11.58	
2014	12.07	9.47	2045	11.75	
2015	11.89		2046	11.87	
2016	10.14		2047	12.03	
2017	10.04		2048	12.10	
2018	10.96		2049	11.77	
2019	11.62		2050	11.91	
2020	12.02				

Supplementary information for

Table 7*: Forecasted electricity-related emissions based on PROSPECTS+ bottom-up calculations for all demand sectors between 1990 and 2050. Historical data presented for validation based on IEA CO_2 emissions database (IEA, 2019) and Mongolia's latest national GHG inventory (Government of Mongolia, 2017).*

Table 8: Data inputs for *Figure 15: Economy-wide emissions (excl. LULUCF) calculated in the PROSPECTS+ scenario evaluation tool under a Current Development Scenario for 1990-2050. Comparison with external data for validation.*

Economy-wide emissions [MtCO2e]							
Year	PROSPECTS+	National Inventory Report 2017	Draft NDC 2019 - Mitigation scenario	Year	PROSPECTS+	National Inventory Report 2017	Draft NDC 2019 - mitigation scenario
1990	26.29	21.95		2021	39.12		
1991	27.66	23.49		2022	39.34		
1992	25.52	21.74		2023	41.12		
1993	23.47	20.55		2024	39.91		
1994	23.65	20.04		2025	39.71		54.80
1995	24.50	20.78		2026	39.69		
1996	23.19	19.50		2027	36.77		
1997	24.58	20.33		2028	36.56		
1998	24.85	20.77		2029	36.77		
1999	24.54	20.84		2030	37.45		57.36
2000	23.24	19.45		2031	37.78		
2001	20.70	16.89		2032	37.98		
2002	20.73	16.72		2033	38.37		
2003	20.45	16.79		2034	38.82		
2004	21.53	17.55		2035	39.22		
2005	23.65	19.84		2036	39.54		
2006	25.77	22.86		2037	39.91		
2007	27.70	24.91		2038	40.37		
2008	28.58	25.65		2039	40.82		
2009	30.29	26.66		2040	41.21		
2010	28.08	24.22	25.82	2041	41.11		
2011	30.47	26.92		2042	41.40		
2012	34.31	30.11		2043	41.50		
2013	36.54	32.69		2044	41.58		
2014	38.75	34.48		2045	41.94		
2015	39.89		37.61	2046	42.21		
2016	37.61			2047	42.55		
2017	37.36			2048	42.81		
2018	38.33			2049	42.66		
2019	38.98			2050	42.98		
2020	39.37		45.57				

Supplementary information for Table 8*: Forecasted economy-wide emissions based on PROSPECTS+ bottom-up calculations for all demand sectors between 1990 and 2050. Mongolia's latest national GHG inventory (Government of Mongolia, 2017) and draft NDC results (Dorjpurev, 2019) presented for comparison.*

Chapter 4 - An alternative future: Paris compatible electricity supply

Table 9: Data inputs for *Figure 16: Box-and-whisker plot of renewable share in electricity generation for Mongolia based on existing scenarios from international research (Jacobson et al., 2017; Stryi-Hipp et al., 2018; Teske et al., 2019). Each dot represents a distinct scenario.*

Electricity generation shares				
Scenario	Technology	2030	2040	2050
1.5C Jackobson	Hydro	2%	2%	1%
1.5C Jackobson	Solar	33%	52%	63%
1.5C Jackobson	Wind	21%	29%	36%
1.5C Teske et. al - High solar	Hydro	6%	15%	16%
1.5C Teske et. al - High solar	Solar	29%	38%	47%
1.5C Teske et. al - High solar	Wind	19%	25%	31%
1.5C Teske et. al - High wind	Hydro	6%	15%	16%
1.5C Teske et. al - High wind	Solar	15%	16%	20%
1.5C Teske et. al - High wind	Wind	32%	46%	58%
2C Teske et. al - High solar	Hydro	1%	14%	19%
2C Teske et. al - High solar	Solar	34%	39%	44%
2C Teske et. al - High solar	Wind	19%	25%	31%
2C Teske et. al - High wind	Hydro	2%	18%	23%
2C Teske et. al - High wind	Solar	20%	18%	17%
2C Teske et. al - High wind	Wind	32%	43%	54%
Stryi-Hipp et al., 2018 - Regional Wind	Hydro	20%	20%	13%
Stryi-Hipp et al., 2018 - Regional Wind	Solar	9%	25%	41%
Stryi-Hipp et al., 2018 - Regional Wind	Wind	26%	37%	46%
Stryi-Hipp et al., 2018 - Regional Wind + Local fuels	Hydro	6%	7%	7%
Stryi-Hipp et al., 2018 - Regional Wind + Local fuels	Solar	10%	26%	41%
Stryi-Hipp et al., 2018 - Regional Wind + Local fuels	Wind	23%	31%	38%
Stryi-Hipp et al., 2018 - UB Base Case	Hydro	23%	26%	23%
Stryi-Hipp et al., 2018 - UB Base Case	Solar	18%	36%	53%
Stryi-Hipp et al., 2018 - UB Base Case	Wind	13%	15%	18%

Supplementary information for Table 9*: Renewable share in electricity generation for Mongolia based on existing scenarios from international research (Jacobson et al., 2017; Stryi-Hipp et al., 2018; Teske et al., 2019). Data gaps were calculated using the Power Plant Stock Turnover Tool.*

Table 10: Data inputs for *Figure 18:*

Electricity-related emissions [MtCO2e]			
Year	Paris Compatible (min)	Paris Compatible (max)	Current Development Scenario
1990			6.03
1991			7.55
1992			7.69
1993			6.48
1994			6.71
1995			6.59
1996			5.74
1997			5.54
1998			6.12
1999			5.66
2000			6.53
2001			6.39
2002			6.83
2003			6.33
2004			6.49
2005			7.42
2006			7.11
2007			7.61
2008			7.69
2009			8.22
2010			8.94
2011			9.25
2012			10.28
2013			11.37
2014			12.07
2015			11.89
2016			10.14
2017			10.04
2018			10.96
2019			11.62
2020	10.85	11.81	12.02
2021	10.94	11.96	11.80
2022	10.83	12.12	12.02
2023	10.36	12.23	13.79
2024	9.81	12.25	12.62
2025	9.40	12.02	12.46
2026	8.99	11.72	12.51
2027	8.60	11.43	9.64
2028	8.21	11.12	9.49
2029	7.83	10.84	9.60

Electricity-related emissions [MtCO2e]			
Year	Paris Compatible (min)	Paris Compatible (max)	Current Development Scenario
2030	7.45	10.61	10.16
2031	7.04	10.43	10.32
2032	6.65	10.26	10.31
2033	6.25	10.09	10.50
2034	5.86	9.90	10.74
2035	5.47	9.70	10.94
2036	5.09	9.45	11.09
2037	4.71	9.22	11.28
2038	4.34	8.98	11.53
2039	3.96	8.72	11.78
2040	3.59	8.44	11.97
2041	3.22	8.12	11.70
2042	2.85	7.82	11.79
2043	2.49	7.50	11.70
2044	2.13	7.17	11.58
2045	1.77	6.83	11.75
2046	1.42	6.45	11.87
2047	1.07	6.07	12.03
2048	0.72	5.69	12.10
2049	0.37	5.29	11.77
2050	0.03	4.87	11.91

***Supplementary information for Table 10**: Own estimation using PROSPECTS+ informed by literature (Jacobson et al., 2017; Stryi-Hipp et al., 2018; Dorjpurev, 2019; IEA, 2019; Teske et al., 2019)*

Chapter 5 - Quantification of air pollution impacts

Table 11: Data inputs for *Figure 20: Annual premature deaths caused by coal-fired power plants in Mongolia between 2020 and 2050 per cause*

Year	Lung cancer	Stroke	Ischemic heart disease	Chronic obstructive pulmonary disease
2020	4	5	8	1
2021	4	5	9	1
2022	4	5	9	1
2023	7	9	14	2
2024	12	15	23	3
2025	12	15	24	3
2026	12	15	24	3
2027	12	15	24	3
2028	12	15	24	3
2029	12	15	23	3
2030	12	15	23	3
2031	12	15	23	3
2032	12	15	24	3
2033	12	15	24	3
2034	12	15	24	3
2035	13	16	25	3
2036	13	16	25	3
2037	13	16	25	3
2038	13	17	26	3
2039	14	17	26	4
2040	14	17	27	4
2041	14	17	27	4
2042	14	18	28	4
2043	15	18	28	4
2044	10	13	20	3
2045	10	13	20	3
2046	11	13	21	3
2047	11	13	21	3
2048	11	13	21	3
2049	11	14	21	3
2050	11	14	21	3

***Supplementary information for Table 11**: Own results based on the application of AIRPOLIM-ES.*

NewClimate Institute

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On behalf of:

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Capacity Development for climate policy in the countries of South East, Eastern Europe, the South Caucasus and Central Asia, Phase III

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