G20 CLIMATE RISK ATLAS

Impacts, policy, economics

METHODOLOGICAL NOTES

AND REFERENCES

01 . CLIMATE

The Climate section of G20 Atlas provides a comprehensive picture for temperature and precipitation patterns experienced in the recent past and projected for future conditions under different hypotheses of concentration scenarios and for different hypothesis of average temperature increases (i.e., +1.5°, +2°, and +4°C). Such a picture relies on the use of basic climate variables (i.e., temperature and precipitation), derived from climate data properly selected for current and future climate, and turned into a set of key climate indicators to illustrate how climate change can affect humans, ecology, and environment as well as have impacts on sectors such as agriculture, health, energy, and water. In the following, further details are reported for each component of this processing chain.

1) Sources of input climate variables

For recent climate, the fifth global reanalysis released by the European Centre for Medium-Range Weather Forecasts (ECMWF), recognised as the ERA5 reanalysis (Hersbach et al., 2020[1]), was used. This reanalysis, which is freely available on the Copernicus Climate Data Store (CDS) platform, is currently recognised as the most plausible and authoritative description for the current climate. In general terms, a reanalysis is a powerful tool that provides a picture of the current climate by combining numerical modelling with observations into a comprehensive global dataset that is consistent with the laws of physics (data assimilation). As for the ERA5 reanalysis, it has global coverage with a native spatial resolution of 0.28° (31 km) and provides hourly scale outputs from 1950 to the present (with a latency of five days). These features make ERA5 suitable for a wide range of applications: climate change monitoring, research, education, policy-making and business, and in sectors such as renewable energy and agriculture (Buontempo et al., 2020[2]).

For future projections, we used an ensemble of Global Circulation Model (GCM) data as those included in the fifth Climate Model Intercomparison Project (CMIP5, Taylor et al., 2012[3]) and in the sixth Climate Model Intercomparison Project (CMIP6, Eyring et al., 2016[4]) in the frame of the World Climate Research Programme's (WCRP). CMIP5 and CMIP6 were developed through a common protocol for generating global climate projections under different greenhouse gas concentration trajectories (i.e., Representative Concentration Pathway, RCP) up to 2100 for CMIP5, and different scenarios of projected socioeconomic global changes (i.e., Shared Socioeconomic Pathways, SSPs) up to 2100 for CMIP6. Furthermore, CMIP5 and CMIP6 respectively represent the basis to produce the Fifth Assessment Report (AR5) and of the Sixth Assessment Report (AR6) by the Intergovernmental Panel on Climate Change (IPCC). The use of a large ensemble of runs represents a shared strategy to assess the potential uncertainty in climate projections to adopt a large ensemble of runs with the aim of quantifying the so-called "inter-model variability". Indeed, despite each model's run (driven by the same

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[1] Hersbach, H.; Bell, B.; Berrisford, P.; Hirahara, S.; Horanyi, A.; Muñoz-Sabater, J.; Nicolas, J.; Peubey, C.; Radu, R.; Schepers, D.; et al. (2020). The ERA5 global reanalysis. Q. J. R. Meteorol. Soc., 146, 1999–2049, doi: 10.1002/qj.3803.

[2] Buontempo, C.; Hutjes, R.; Beavis, P.; Berckmans, J.; Cagnazzo, C.; Vamborg, F.; Thépaut, J.-N.; Bergeron, C.; Almond, S.; Amici, A.; et al. (2020). Fostering the development of climate services through Copernicus Climate Change Service (C3S) for agriculture applications. Weather. Clim. Extremes, 27, 100226, doi: 10.1016/j.wace.2019.100226.

[3] Taylor, K. E., Stouffer, R. J., & Meehl, G. A. (2012). An Overview of CMIP5 and the Experiment Design, Bulletin of the American Meteorological Society, 93(4), 485-498, doi: 10.1175/BAMS-D-11-00094.1.

[4] Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J., and Taylor, K. E. (2016). Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. Geosci. Model Dev., 9, 1937-1958, doi: 10.5194/gmd-9-1937-2016.

concentration scenario) represents an equally plausible projection of the future evolution of the climate, the projected climate change signals may show significant differences, precisely due to differences in the models' formulation and physical parameterization.

2) Climate indicators

A set of bioclimatic indicators (see Table 1), based on basic climate variables such as monthly temperature and monthly precipitation, has been computed to characterize current and future climate conditions according to ERA5 re-analysis and CMIP6 data, respectively. In addition, a fixed number of key climate-indicators (see Table 2), computed in Arnell et al. (2019)[5] for CMIP5 data, has been considered to illustrate how climate change beyond three authoritative average temperature increases (i.e., +1.5°, +2°, and +4°C) could impact on sectors such as agriculture, health, energy, and water. These key climate-indicators were originally computed on specific macro-areas including different countries. For this reason, some countries will show the same values. Such a similarity will be only retrieved in the VARIATION OF SPECIFIC CLIMATE INDICATORS section. Table 3 lists the macro-areas associated with each G20 country.

Table 1: Selected bioclimatic indicators description.

Indicator	**Description**	**Unit**
Annual mean temperature	Annual mean of the daily mean temperature at 2 m above the surface	°C
Maximum temperature of warmest month	Maximum daily temperature of the month with the highest monthly mean of daily mean temperature	°C
Minimum temperature of coldest month	Minimum daily temperature of the month with the lowest monthly mean of daily mean temperature	°C
Annual precipitation	Annual sum of daily (or monthly) precipitation (both liquid and solid phases)	mm
Precipitation of wettest month	Maximum of the monthly precipitation	mm
Precipitation in warmest quarter	The mean of monthly precipitation during the warmest quarter, defined as the quarter with the highest monthly mean temperature using a moving average of 3 consecutive months	mm

Table 2: G20 countries identification based on Arnell et al. (2019).

	Macro-areas as defined in Arnell et al. (2019)	**G20 Countries**
Africa	Southern Africa	South Africa

[5] Arnell, N.W., Lowe, J.A., Challinor, A.J. et al. (2019). Global and regional impacts of climate change at different levels of global temperature increase. Climatic Change 155, 377–391, doi: 10.1007/s10584-019-02464-z.

Asia	Middle East	Saudi Arabia, Turkey
	South Asia	India
	South-East Asia	Indonesia
	East Asia	China, South Korea, Japan
Australasia	Australasia	Australia
Europe	Western Europe	French, Germany, Italy, UK
	Eastern Europe	Russia
	Western Europe, Central Europe, Eastern Europe	EU27
North America	Canada	Canada
	USA	USA
South America	Brazil	Brazil
	Central America	Mexico
	Rest of South America	Argentina

Table 3: Description of indicators based on Arnell et al. (2019).

Indicator	Description
Agricultural drought proportion of time	Proportion of time spent in agricultural drought (defined by Standardised Precipitation Evaporation Index). Weighted by cropland area
Agricultural drought frequency	Likelihood (%) that a year will contain an agricultural drought, lasting for at least three consecutive months. Weighted by cropland area
Hydrological drought proportion of time	Proportion of time spent in hydrological drought (Standardised Runoff Index). Averaged over cells with more than 1000 people in 2010
Hydrological drought frequency	Likelihood (%) that a year will contain a hydrological drought, lasting for at least six consecutive months. Averaged over cells with more than 1000 people in 2010

Heatwave duration	Average annual number of days in a heatwave (i.e., maximum temperature greater than the 98th percentile of the warm season temperatures for at least two days.). Averaged over cells with more than 1000 people in 2010
(Major) Heatwave frequency	Likelihood (%) that a year will contain a heatwave, with maximum temperature greater than the 99th percentile of the warm season temperatures for at least 4 days. Averaged over cells with more than 1000 people in 2010
Runoff increase	% of region with an increase in average annual runoff more than twice the standard deviation of 30-year average runoff
Runoff decrease	% of region with a decrease in average annual runoff more than twice the standard deviation of 30-year average runoff

3) Section Description

This last part provides a short description about contents and methodology for each section constituting a country sheet (see Table 4).

Table 4: Description of sections constituting each country sheet.

Section	**Description**
OVERVIEW	Short comment on general climate features
TEMPERATURE	Short comment on temperature regime for the recent period
TEMPERATURE MEAN	Map reporting the spatial distribution of annual mean temperature averaged over 1991-2020 derived from ERA5 re-analysis
TEMPERATURE TREND	Time series of temperature anomalies for the recent period derived from ERA5 re-analysis with respect to 1961-1990. Operatively, annual temperature is first calculated over country and then averaged to obtain a single country value.
TEMPERATURE PROJECTIONS	Time series of temperature anomalies for future projections derived from CMIP6 with respect to 1985-2014 according to SSP126, SSP245 and SSP585 scenarios. Operatively, annual temperature is first calculated over country and then averaged to obtain a single country value.

EXPECTED VARIATION FOR TEMPERATURE AT 2050	Variations of temperature bioclimatic indicators with respect to the reference period 1985-2014 for a thirty-year period centred on 2050 (2036-2065). Data are based on CMIP6 projections for SSP126, SSP245 and SSP585 scenarios
PRECIPITATION	Short comment on precipitation regime for the recent period
PRECIPITATION MEAN	Map reporting the spatial distribution of annual precipitation averaged over 1991-2020 derived from ERA5 re-analysis
PRECIPITATION TREND	Time series of precipitation anomalies for the recent period derived from ERA5 re-analysis with respect to 1961-1990. Operatively, annual precipitation is first calculated over country and then averaged to obtain a single country value
PRECIPITATION PROJECTIONS	Time series of precipitation anomalies for future projections derived from CMIP6 with respect to 1985-2014 according to SSP126, SSP245 and SSP585 scenarios. Operatively, annual precipitation is first calculated over country and then averaged to obtain a single country value
EXPECTED VARIATION FOR PRECIPITATION AT 2050	Variations of precipitation bioclimatic indicators with respect to the reference period 1985-2014 for a thirty-year period centred on 2050 (2036-2065). Data are based on CMIP6 projections for SSP126, SSP245 and SSP585 scenarios
VARIATION OF SPECIFIC CLIMATE INDICATORS	Anomaly of climate indicators derived from Arnell et al. (2019) for expected temperature increase of +1.5°, +2°, +4°C. These indicators are computed according to CMIP5 data. Further details are reported in Arnell et al. (2019)

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02. OCEAN

The data and information on current climate conditions and trend of sea surface temperature for each member of the G20 was extracted from the ESA-CCI SST satellite product (Good et al., 2019). All other data and information on the physical and biogeochemical marine environment were extracted from the Coupled Model Intercomparison Project phase 6 (CMIP6) public archive (see references 4 to 33). The statistics reported are based on an ensemble of 15 different Earth System Model realisations from which the data for each of the G20 member states were extracted. Inland seas were excluded from the analysis as they are not sufficiently resolved in the models included in CMIP6.

The data and information on potential fish catch for each of the members are based on the averages of the two datasets reported in chapter 4 of the technical paper no. 627 of the Food and Agriculture Organisation of the United Nations (Barange et al., 2018). As these datasets are based on the previous generation of Earth System Models (CMIP5) with significantly lower spatial resolution, in this case also semi-enclosed basins are excluded from the analysis including Mediterranean Sea, Black Sea, Red Sea, the Baltic Sea and the Persian Gulf. Consequently, no specific data was available for Italy, Saudi Arabia and Turkey. The data and information for these countries were approximated by the data of the Large Marine Ecosystem that contains their marine areas as reported in Cheung et al. (2016).

The representation of geographical areas applied for each member is based on the Exclusive Economic Zone (EEZ) definition for their mainlands obtained from Marine Regions (https://marineregions.org), excluding any disputed areas and joint regimes.

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03. COASTS

The sheets are based on a review of existing data and information on the coastal zone of each of the G20 countries, focusing on the characteristics of the coastal system of the country and on the implications of climate change, with a focus on the impacts and exposure to risks by the year 2050 under a RCP4.5 scenario. The literature review covered scientific literature, technical reports, data portals and grey literature. The coastal zone and the impacts of climate change have been described covering coastal hazards, including sea level rise and the impacts of future extreme water levels, and the risk on coastal settlements, infrastructure and communities. Data includes observational databases of global sea level rise from NOAA, the latest IPCC projections of sea level rise, combined with regional studies on past and future sea level rise. A literature review of current storms and wave climate and the impact of climate change on future events was informed by additional data on future global extreme sea level carried out by the European JRC. Information and data on risk has been derived by the review of existing studies at the national level, with specific data extracted from the global Digital Elevation Model CoastalDEM. Infographics are also provided to illustrate the combined effects of sea level rise, storm surges, tides and wave set up.

The projected erosion values per country for the moderate emissions scenario RCP4.5 at 2050 are quite similar to those of the high emission scenario RCP8.5 at 2050. While most values for the RCP4.5 at 2050 are lower than the RCP8.5 values at 2050, there are also cases of slightly higher erosion values under the moderate emission scenario. This result can be related to a range of factors driving erosion in addition to sea-level rise, including atmospheric drivers influencing the frequency and intensity of storms. As a consequence, only the erosion values under the RCP4.5 scenario at 2050 are reported, which is consistent with most scenarios considered in the G20 Climate Risk Atlas.

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04. WATER

The sheets are based on a review of existing data and information on water resources for each of the G20 countries, focusing on the characteristics of the water resource system of the country and on the implications of climate change, with a focus on the impacts and exposure to risks by the year 2050 under RCP2.6, 4.5 and 8.5 scenarios. The literature review covered scientific literature, technical reports, data portals and grey literature. The water resource system has been described covering the water cycle and extreme events, with information and sections on rainfall, surface water and runoff, groundwater, droughts and floods. Specific data and indicators have been derived by public institutional databases and using the analysis of the outputs of numerical and hydrological models. Information and data on risk has been derived by the review of existing studies at the national level. Specific data on water stress has been derived from an institutional database.

Data

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05. AGRICULTURE

The data and information for the agriculture sector representing **historical trends** over the last two decades were extracted from FAO data services for each member of the G20:

- "Agricultural land", "Area equipped for irrigation", "Share of agriculture value added in total," and "Value added of agriculture, forestry and fishing" were retrieved from the FAO Statistical yearbook 2020 (FAO, 2020)

- Production statistics (production quantity and yield) of main crops for year 2018-2019 have been defined from the FAOSTAT database (FAO, 2021a) and define both annual production quantity (Megatons per year) and baseline crop productivity (tons per hectare per year) of main representative crops

- Water withdrawal share from the agricultural sector and water stress indicators are instead derived for year 2017-2018 from the AQUASTAT database (FAO, 2021b). The water stress (SDG indicator 6.4.2) identifies the freshwater withdrawal as a proportion of available freshwater resources.

Future trends and impact of climate change on agricultural productivity for each G20 member were extracted from the ISIMIP (The Inter-Sectoral Impact Model Intercomparison Project, https://www.isimip.org/) database hosted by the Potsdam Institute for Climate Impact.

We selected the ISIMIP dataset to have a single dataset for all G20 Countries that was comparable, i.e., obtained with the same simulation protocol, climate models, scenarios, and crop models. Moreover, this dataset allowed us to have simulations with an ensemble of different climate and crop models (which is essential in impact studies but extremely complex and time consuming, and therefore not always present in studies available in the literature), simulations with constant and increasing values of CO_2 concentration and under irrigated and rainfed conditions.

The ISIMIP objective is to establish and provide a tailored community-driven process of cross-sectoral climate-impact model intercomparison and evaluation. The consistent impact projections for different sectors are shared from a broad modelling community, using standardized protocols for modelling setting up and parameterization, to consolidate and harmonize scientific basis for comparison to higher levels of global mean temperature change (based on the low-emissions Representative Concentration Pathway RCP2.6 and a no-mitigation pathway RCP6.0). The Agricultural Model Intercomparison and Improvement Project (AgMIP) coordinates agricultural modelling activities within the ISIMIP. AgMIP is a major international Intercomparison network effort to produce improved climate impact projections for the agricultural sector.

The statistics reported for the agricultural sector include future trends of productivity of main crops from the ISIMIP archive (ISIMIP v2b), from which the data for each of the G20 member states were extracted, based on an ensemble of 3 different Crop models X 4 global climate models realisations (12 projections ensemble per crop):

- bias-corrected climate data from the global climate models GFDL-ESM2M, IPSL-CM5A-LR, HadGEM2-ES, and MIROC5 (https://www.isimip.org/gettingstarted/isimip2b-bias-correction/)

- crop modelling data projections are available from GEPIC (Liu J et al. 2007, Folberth et al., 2012, https://www.isimip.org/impactmodels/details/48/), PEPIC (Liu W et al., 2016, https://www.isimip.org/impactmodels/details/107/), LPJmL (Bondeau et al., 2007, Müller et al., 2016, https://www.isimip.org/impactmodels/details/83/).

The models provide a rich and comprehensive simulation of key model processes for crop growth, crop phenology, light use and leaf development, yield formation, biogeochemical cycles, water dynamics, etc. Among other processes, these models account for CO_2 enrichment effects through different simulated mechanisms: Radiation use efficiency, Transpiration efficiency, Leaf-level photosynthesis-rubisco.

Several modelling exercises in the past have limited the implementation of CO_2 effects due to related uncertainties. Uncertainty still remains for the effects of elevated CO_2 concentrations. Nevertheless, recent literature has advocated using results that fully include CO_2 effects (as well as N limitation) for policy purposes (Toreti et al., 2020). Accordingly, were used those ISIMIP crop productivity projections, which include the effect of enriched CO_2 values related to the different RCPs.

Effects of elevated CO_2 under climate change may significantly increase crop yields, especially for C3 species (e.g., wheat, rice, barley) under optimum water and nutrient conditions (by 10% to 30%). While crop yields of C4 species (e.g., maize, sorghum, millet, sugarcane, etc.) do not change significantly when grown under full water supply conditions (Toreti et al., 2020). Moreover, elevated CO_2 concentrations cause a reduction in stomatal conductance and consequently in crop transpiration, improving crop water productivity (yield/ET) up to 40% (Deryng et al., 2016), especially for C4 species under water-limited conditions (e.g., +41% for maize and +15% for sorghum) (Toreti et al., 2020). These two combined effects may, to various extents, limit or overcome the negative effects of warming temperatures. However, nutrient deficiencies can minimize the CO_2 effect on crop productivity.

Crop modelling projections are defined distinctly for both a low and a high emissions scenario (RCP2.6 and RCP6.0). Future reference is identified as a 30-years period around 2050 (2036-2065), while baseline is represented for a 30-years historical period (1976-2005). The average baseline/future productivity is calculated as the ensemble mean of the 12 projections (3 crop models x 4 climate models) averaged over the 30 years for main representative crops. The Multi-projection ensemble mean represents the most conservative estimate despite modelling uncertainties (Herger, 2018). The change or anomaly in productivity is then estimated as the difference between average future and baseline productivity over baseline productivity as reference, as a percentage.

Crop models still present different levels of uncertainties, which are only limited by considering multi-model ensembles:

- Crop simulation methodology (parameterization, ET equation, nitrogen stress, extreme heat sensitivity, phenology & planting date decision/cultivar choice…)
- CO_2 sensitivity methodology (simple Radiation Use Efficiency vs detailed Photosynthesis-Respiration representation).

ISIMIP dataset covers the following crops: maize, wheat, rice, sugarcane, cassava, sugar beet, soybean, rapeseed, and sunflower.

For the crops not covered by ISIMIP (e.g., tree crops, vegetables, etc.), the information was derived from the most recent literature (see reference section) from peer-review papers, technical reports, and open access material from governmental platforms and research projects.

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06. FORESTS AND FIRES

To assess historical trends forest area, forest carbon stocks, fire activity, burned area data for the last two decades were extracted from the FAO Global Forest Resources Assessment (https://fra-data.fao.org/). Fire emission data come from the Global Fire Emissions Database (https://www.globalfiredata.org/). The only exception is the burnt area data for Europe, Italy, France and Germany. In this case, in fact, the European Forest Fire Information System (EFFIS) data from 1990 to 2019 was used.

Climate change is expected to influence future forest productivity, burned areas and, in turn, fire emissions. In this work, these future impacts are estimated through two global vegetation models (i.e., LPJmL and ORCHIDEE) drive by four climate models (IPSL-CM5A-LR, HadGEM2-ES, GFDL-ESM2M, and MIROC5) based on low and medium emission scenarios (RCP2.6 and RCP6.0, respectively) and one socioeconomic pathway (SPP2) from ISI-MIP dataset (simulation round 2b). Finally, future forest productivity, burned area, and fire emission are reported as anomalies for the period 2036-2065 compared to the historical period. Biomes and ecoregions definitions mentioned in the text follow those suggested by Dinerstein et al. (2017).

As can be deduced from the infographics, impacts models predict a generalized increase in primary forest productivity. This effect shown by models, is primarily linked to the fertilization effect of carbon dioxide, still much debated in the scientific community.

In several cases, it is possible to observe contrasting patterns between burned area and C emissions. This is due to a number of uncertainties related to the dynamic vegetation models and the embedded fire spread and emission modelling (including uncertainties in e.g. fire emission factors, combustion completeness), as well as the spatiotemporal dynamics of fires in different biomes. Thus, some model's members project higher estimates of fire emission for specific biomes due to these differences and this could flatten, or even inverts, the sign of the multimodel mean.

Furthermore, a wide literature review under both search engines i.e., Scopus (the largest abstract and citation database of peer-reviewed literature) and Google Scholar were carried out to identify expected impacts of climate change on forest species (or more generally forest ecosystems) and variation of specific fire indicators for each G20 country.

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07. URBAN

The information reported derive from a survey of the most recent literature (see reference section) on the assessment of climate change impacts, focussing in particular on reports specific for the urban contexts of the G20 Members. The search yielded peer review papers as well as country reports responding to international reporting obligations (UNFCC as well as EU related reporting) and technical reports.

Quantitative information from such sources related to urban areas was mostly related to single case studies, projections for single countries. With regards to elements driving specific aspects of vulnerability of urban population, globally available data was used from different sources as World Bank and UN indicators, and the Copernicus Land Monitoring Service, while Climate Data refers to the data produced for the sections "coast" and "climate", so the references are reported in the respective bibliographies.

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08. HEALTH

The information reported in the health chapter has been extracted through a thorough survey of the existing literature on the impacts of climate change on human health. While the focus has been on peer-reviewed articles, we also had to use technical reports from WHO and public health impact assessment reports. The methodologies used by these studies are varied in nature, including epidemiological modelling, mathematical, and statistical modelling, and econometric analysis. These models consider climate and socio-economic scenarios, time frames, and different climate-sensitive diseases and labour impacts. We have made an attempt to harmonize these findings and present them in a consistent framework.

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09. ENERGY

The information presented in this section has been collected from a variety of sources. For some indicators, specific methodologies have been consistently applied, and are described more in detail in the paragraphs below.

For all the remaining content of the section not explicitly mentioned in the next paragraphs, the information reported derives from a survey of the most recent literature on the assessment of climate change impacts on the energy sector. The literature reviewed includes published peer review papers, technical reports, and open access material from Horizon 2020 projects; for current impacts of climate change, it has been integrated, when relevant, with newspaper articles in the international and national press reporting on specific events. The methodologies used by different studies are highly heterogeneous and vary with the energy vector, energy sub-sector, and sector of energy use considered and range, from technical modelling to econometric and statistical studies. They also refer to different climate scenarios, time frames and impact types.

Current energy supply and demand

The shares of specific energy use sectors in total final consumption as well as the shares of energy vectors in total primary energy supply have been computed as direct ratios of each component to the country overall aggregate, for the latest available year (2018 or 2019) using the International Energy Agency Energy Statistics Database, which has been also used for the Import Dependence Ratio (net imports over available energy). Analogously, the shares of air conditioning on residential electricity demand have been computed using the ENERDATA database for the latest available year (2015-2017). ENERDATA also directly provides the energy intensity indicator as thousand tons of oil equivalent divided by GDP at constant 2015 prices and purchasing power parity. In 2020, it ranged between 0.25 and 0.054 ktoe/$2015p, and world average was 0.114 ktoe/$2015p.

Heating Degree Days and Cooling Degree Days

Near-surface air temperature data used for the computation of the thermal discomfort indices derives from the simulations of the NASA Earth Exchange Global Daily Downscaled Climate Projections (NEX-GDDP) dataset (NASA). NEX-GDDP is a large ensemble of downscaled and biased-corrected 0.25 gridded daily meteorological fields from 21 Global Climate Models (GCMs) that simulate moderate (RCP 4.5) warming under the Coupled Model Intercomparison, Phase V (CMIP5) climate model exercise. Mid-21st century future climates are drawn from the models' output for 2041-2060, under the RCP 4.5 scenario. Using the projected meteorological variables, we assemble CDDs and HDDs at annual scales by employing the commonly used method defined by (A. S. H. R. A. E. ,2009):

$$CDD = \sum_{i=1}^{n} \quad (Td - Tb) \quad + \qquad (1)$$

$$HDD = \sum_{i=1}^{n} \quad (Tb - Td) \quad + \qquad (2)$$

where '+' signifies only positive values accumulate over n days in each year in our study, and *Td* and *Tb* represent the daily mean outdoor, and base (threshold) temperatures measured in degree Celsius (°C). The threshold *Tb* is set to 18°C for both CDDs and HDDs.

Changes in Hydropower Generation

Changes in hydropower generation induced by climate change are taken from Schleypen et al. (2019). The study computes the ratio of future to current hydroelectricity generation by combining the annual mean of the climatic variables under warming scenarios RCP4.5 and RCP8.5 (simulated by means of five climate models: CCSM4, GFDL-CM3, INM-CM4, IPSLCM5A-MR, and MIROC5) with the results of an econometric panel regression model. The latter "estimates the parameters characterizing a reduced-form relationship to investigate the impact of both gradual and extreme climatic stressors on hydropower generation at the country-level" (Schleypen et al. 2019, p.77). It controls "for a set of climatic variables and number of other covariates controlling for time-invariant country-specific heterogeneity (country fixed-effects), unspecified exogenous influences affecting all countries and units (year fixed-effects), and confounding factors such as installed power generation capacity, total electricity consumption, and electricity generation mix." (*Ibidem*)

Net change in energy demand due to changes in HDD/CDD

Net changes in energy demand are taken from van Ruijven et al. (2019). The study first combines "the income elasticities for energy consumption from De Cian and Sue Wing (2018) with GDP per-capita projections from the Shared Socioeconomic Pathway to construct five scenarios of baseline energy demand in 2050 without climate-change impacts, based on projections of future spatially disaggregated population and GDP growth for 183 countries" (van Ruijven et al., 2019). Then the study uses "the historical evidence on energy use over a period of about 30 years […] as an analog of how we might use energy in the future over the next 30 years to generate a set of counterfactual scenarios aimed at exploring climate and socioeconomic uncertainty" (*Ibidem*). Last, mid-century climate change relative to the baseline are again taken from NEX-GDDP: ensemble impact projections are computed as the difference between each grid cell's NEX-GDDP projected annual exposure and its baseline exposure over the period 2040–2060, and the results are combined with the study's long-run elasticities of energy demand to temperature to generate annual changes in energy demand.

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10. ECONOMIC IMPACTS

The information reported derive from a survey of the most recent literature (see reference section) on the economic assessment of climate change impacts. The literature is mixed referring to published peer review papers, technical reports and open access material from Horizon 2020 projects. The methodologies used by different studies are highly heterogeneous ranging from modelling exercises, econometric and statistical analyses. They also refer to different climate scenarios, time frames and impact types. An effort has been made to harmonize these findings and present them within an internally consistent framework.

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11. POLICY

The information in the "Policy" sections has been collected from a variety of sources, as detailed below:

Overview

UNFCCC inventory of greenhouse gases (GHG) is the source of data for Annex I countries' yearly emissions from 1990 to 2018. GHG emissions of non-Annex I countries have been retrieved from Climate Watch (https://www.climatewatchdata.org/) and in particular from its CAIT dataset, for the sake of comparability.

International commitments

International policy commitments for the Kyoto Protocol are taken from UNFCCC Annex B of the Kyoto Protocol (FCCC/CP/1997/L.7/Add.1). The collective target for the 15 countries of the European Union was shared among the different Member States. The target levels are taken from the European Council Decision of 25 April 2002 (2002/358/CE).

Concerning the Paris Agreement, the source of information about the specific National Determined Contribution (NDC) is the UNFCCC's NDC Interim Registry.

International climate finance assistance

The data on climate finance assistance are taken from the latest available Annex I countries' 4th Biennial Reports to the UNFCCC (with the exclusion of Turkey and USA). Data refer to the years 2017 and 2018 and to the financial amounts labelled as "Climate-specific".

For non-Annex I countries, Turkey and USA, the financial data are taken from OECD Development Assistance Committee 's (DAC) 2017 and 2018 dataset on climate-related development finance. Both datasets use OECD DAC's Official Development Assistance (ODA) standard as main reference and are therefore comparable. Data were elaborated in order to provide and facilitate the graphical representation of financial flows. In some cases, small financial flows have been aggregated to be properly visualized.

Sustainable Recovery Policy

The data on sustainable recovery derive from the Global Recovery Observatory (https://recovery.smithschool.ox.ac.uk/tracking/), an initiative of the Oxford University Economic Recovery Project (OUERP) and supported by UNEP, the International Monetary Fund and GIZ through the Green Fiscal Policy Network (GFPN). Data refer to 2020. The full methodological paper is available at this link: https://recovery.smithschool.ox.ac.uk/wp-content/uploads/2021/03/20210201-Global-Recovery-Observatory-Draft-Methodology-Document-.pdf

Domestic Adaptation Policy and Adaptation Policy Highlights

Domestic adaptation policies and the relative highlights derive from a widespread desk review that encompasses a variety of sources such as the official national documents made available through governmental websites, the National Determined Contributions from the UNFCCC NDC Interim Registry, the National Communications and the Biennial Reports to the UNFCCC, Climate-ADAPT platform (for the European Union Member States), the websites of UN bodies and agencies and Multilateral Development Banks (e.g., UNDP, World Bank, etc.).

Energy Transition

The Energy Transition composite indicator is aimed at evaluating the current positioning of selected countries vis-à-vis energy transition. We considered Energy Transition as a multi-dimensional concept aggregating some indicators related to five essential energy domains: Fossil Fuels, Renewables, Efficiency, Electrification and Emissions.

The indicator related to Fossil Fuels is calculated taking into account the share of fossil fuels in final energy consumption (with a weight of 60%), the national reserves of oil and coal (with a weight of 15%) and the reserves of gas (with a weight of 10%), and the level of subsidies to fossil fuels as a share of GDP (with a weight of 15%). The Renewables indicator is calculated considering the share of renewable energy sources in the national electricity mix (weighted 55%) and the contribution of RES in the country's final energy consumption (weighted 45%). The Efficiency indicator is calculated taking into account the value of transmission and distribution losses of the electricity grid (with a weight of 30%), the level of energy intensity of the economy (weighted 40%) and the availability of clean cooking services (weighted 30%). The Electrification indicator is calculated considering the share of electricity in final energy consumption (with a weight of 40%), the share of the population with access to electricity modern electricity services (with a weight of 30%), and the quality of electricity supplies in terms of readiness, costs, reliability, transparency (weighted 30%). Finally, the Emissions indicator is calculated considering the levels of CO_2 emissions per capita (with a weight of 40%), the CO_2 intensity of the energy sector (with a weight of 30%) and the level of air pollution in urban contexts, expressed in terms of mean annual exposure to PM2.5 (with a weight of 30%).

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