Asessing China's Climate Responsibility

Final Paper

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List of Abbreviations

AFOLU	Agriculture, Forestry, Land Use
CAT	Climate Action Tracker
CBRD	Common but differentiated responsibilities and respective capabilities
COP	Conference of the Parties
EDGAR	Emissions Database for Global Atmospheric Research
GDP	Gross domestic product
GHG	Greenhouse gas
GNI	Gross national income
GW	Gigawatt
NDC	Nationally determined contributions
REDD+	Reducing Emissions from Deforestation and Forest Degradation
UNFCCC	United Nations Framework Convention on Climate Change

Contents

1 Introduction

The development that the People's Republic of China has taken in recent decades is nothing short of remarkable. While the country, under the dictatorial leadership of Mao Zedong, was plagued by poverty and famine during the first three decades after its founding in 1949, Deng Xiaoping's policy of reform and opening started the country's economic boom in the late 1970s. Millions of Chinese have made the leap out of poverty since, and the country, which at the beginning of the 21st century was still considered the "workbench of the world", has now developed into an economic and technological superpower that is readying itself to overturn the global supremacy of the U.S..

During the same period, China's emissions have risen rapidly. In 2004, the country surpassed the U.S. as the world's largest greenhouse gas emitter and is likely to retain that title for some time. In 2019, more than 25% of all global greenhouse gas emissions came from China, more than the U.S. and (at the time still) EU-28 combined (see Figure 1). As a consequence of this development, China's emissions profile changed dramatically: While the agricultural sector still accounted for a large share of emissions in the early 1970s, its contribution has been only marginal in recent years. Figure 2 shows the large-scale industrialization of the country starting in the mid-1990s and the corresponding increase in emissions from the energy sector. More recently, transport sector emissions have picked up speed, likely reflecting the wealthy share of China's citizens spending more money on individual (fossil-fuel based) modes of transport.

China's energy mix is still largely dominated by coal. In 2020, more than 60% of the country's total energy supply stemmed from this fossil fuel. Renewables on the other hand only contributed 6.2% to total energy supply (excluding biofuel and waste). Looking at just the electricity production, the numbers are a bit different: Here the renewable sources' share was approx. 28% (**?**). However, China remains the country with the world's largest coal fleet and also the highest planned coal capacity additions. In 2021, the country started building 33 GW of additional coal-based power generation and consumed about five times as much coal as India, and nearly six times as much as the U.S. (**?**).

Chinese carbon emissions growth was predominantly driven by its rapid economic development, which in turn caused the energy sector to grow too. Since the year 2000, China's GDP per capita has more than quadrupled, while carbon emissions have more than tripled in the same period (see Figure 3). However, the growth of emissions has slowed in recent years, as energy intensity of GDP had started decreasing after the year 2005 and also carbon intensity of energy peaked in 2010 and has been slowly decreasing since. While for the first two decades of the 21st century carbon emissions growth rates were closely resembling the growth rates of

GDP per capita, since 2010 the two numbers have decoupled. China's immense expansion of renewable energy sources over the last years is likely an underlying driver of this trend, however, as we have seen, Chinese annual emissions remain very high at 14.2 GtCO2e in 2019.

The question arises, how China plans to curb its emissions. At the United Nations General Assembly in 2020, Chinese President Xi Jinping announced the goal of Chinese carbon neutrality before 2060 (?). This was the first time China officially committed to a long-term emissions reductions goal (?). One year later, in November 2021, ahead of COP26, China submitted its updated NDC to the UNFCCC. Accordingly, the country plans to peak its carbon emissions before 2030, decrease the carbon intensity of GDP by over 65% (relative to 2005), have around 25% of non-fossil fuels in primary energy consumption by 2030, increase the forest stock volume by six billion cubic meters until 2030 and have 1,200 GW of wind and solar power capacity installed by the same year (?). Although some of these objectives are vague to some degree, and the emissions reduction target is only a relative goal, the ambitions China has set for itself are a marked improvement over the targets set out in the previous 2016 NDC. Additionally, it is important to note that these goals are unconditional and hence not relying on external climate finance. China has adopted numerous policies to support its international targets, such as the "Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality" and the "Action Plan for Carbon Dioxide Peaking Before 2030". The former spells out a set of principles and sectoral goals to achieve carbon dioxide peaking and carbon neutrality, among them the need to exercise nationwide planning and the prioritization of conversing energy (Department of Resource Conservation and Environmental Protection, 2021a). The latter defines key tasks for driving the low-carbon energy transition or saving energy, carbon emission mitigation and efficiency improvement (?). With its "14th Five-Year Plan on Renewable Energy", the country aims to further accelerate its renewable energy expansion. By 2025, 33% of electricity ought to be supplied by renewable sources (18% non-hydro), which could decrease annual carbon emissions by 2.6 gigatons (?).

Nonetheless, China's goals and policies are widely viewed as inadequate by various parties. The CAT for example projects that China is likely to comfortably overachieve its NDC targets without substantially increasing its current mitigation efforts. Hence, their overall rating of the country's goals and policies is "insufficient". If all countries were to pursue the same level of ambition as China, global warming would reach approx. 3°C. Therefore, China's current goals and policies leave significant room for further target-raising ambition. The CAT additionally concludes that China's contributions are also not sufficient to do its "fair-share" in fighting climate change and limiting global warming under the Paris Agreement (?).

China itself assesses its responsibility for climate change mitigation measures very differently though. In its 2021 NDC update, China assigns responsibility for global warming to developed countries. It were their emissions that had caused the dramatic increase of GHGs in the atmosphere. China, on the other hand, was a developing country, thereby having the right to develop (**?**).

This line of argument is as old as the UNFCCC itself. In 1992, at the first COP in Rio de Janeiro, where the parties agreed on the UNFCCC, they classified countries into two groups of "Annex-I" and "non-Annex I" countries, consisting of mostly developed and (at the time) developing countries respectively. At the same time the principle of common but differentiated responsibilities and respective capabilities (CBRD) was introduced. According to this principle, the industrialized nations would need to bear the main responsibility when it comes to emission reductions, while the "non-Annex I" countries would initially have no obligations to avoid emissions. This principle was also enshrined in the 1997 Kyoto Protocol. The 2015 Paris Agreement reaffirmed the CBRD principle, but, for the first time, brought all signatory countries together to undertake ambitious efforts to tackle climate change and adapt to its impacts (**?**). However, it has caused long-standing debates, whether China should continue to be classified as a developing country, given its economic and emissions growth since the UNFCCC was adopted, or whether it has a greater responsibility in addressing climate change.

With these developments in mind and following up on China's claim to be a developing country, we set out in this paper to discuss equity considerations for China, focusing on two research questions. First, we will investigate whether China, from an emissions perspective, can still be characterized as a developing nation. For this we compare China's Kaya identity with other developing and developed nations. Furthermore, we consider China's sectoral emissions trends and contrast them with those of (other) developing and developed nations, controlling for differences in population size and GDP. Secondly, we investigate China's claim of developed countries' being the driver of climate change, by calculating different measures of (historic) responsibility and assess the level of responsibility China bears in combatting climate change. We discuss these findings with regards to a projection of China's cumulative emissions.

The remainder of this paper is structured as follows: In section 2 we provide an overview of our data and main assumptions, before analyzing China's self-characterization as a developing country in section 3. Section 4 compares different equity metrics for China and other big emitters and discusses China's role in addressing climate change against different scenarios of future Chinese cumulative emissions. In section 5 we discuss our findings in light of other available assessments of China's role and conclude.

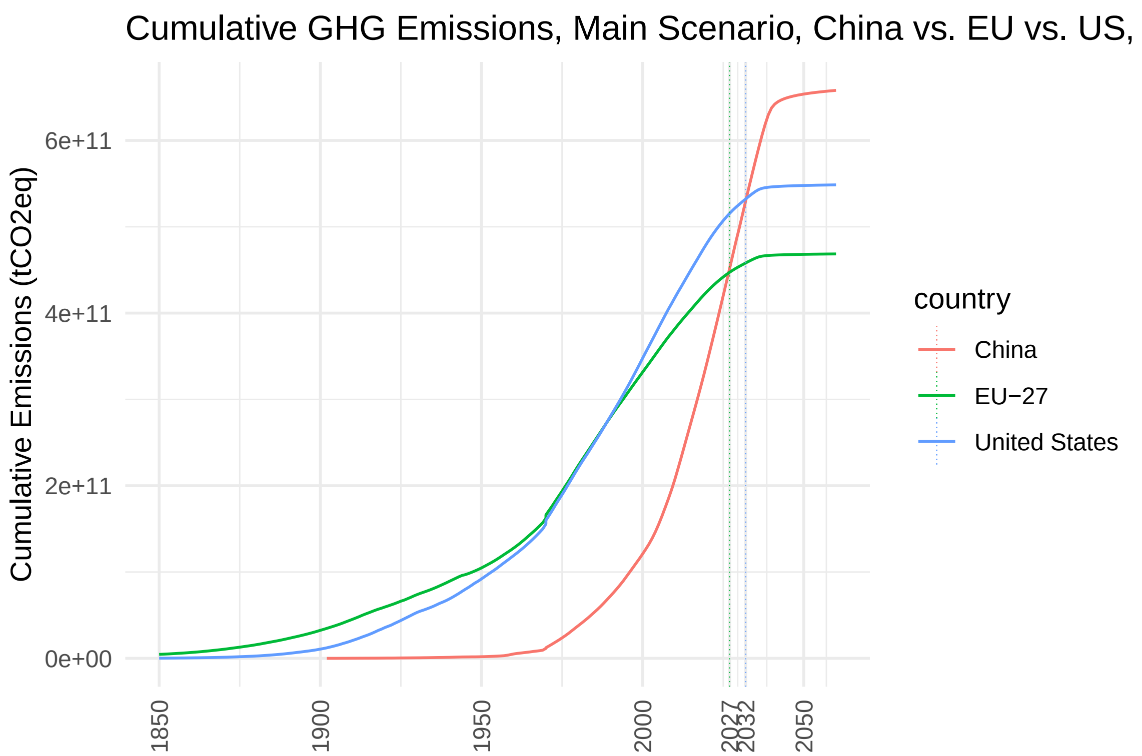

Figure 1.1: Figure 1

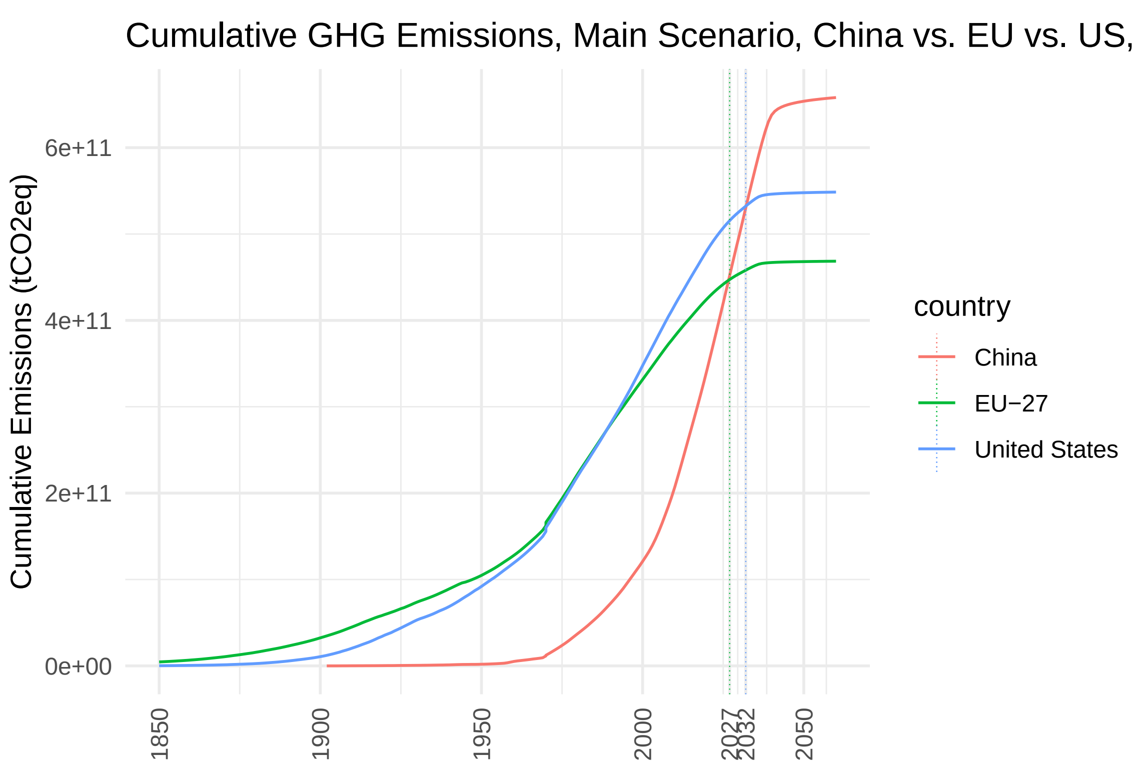

Figure 1.2: Figure 2

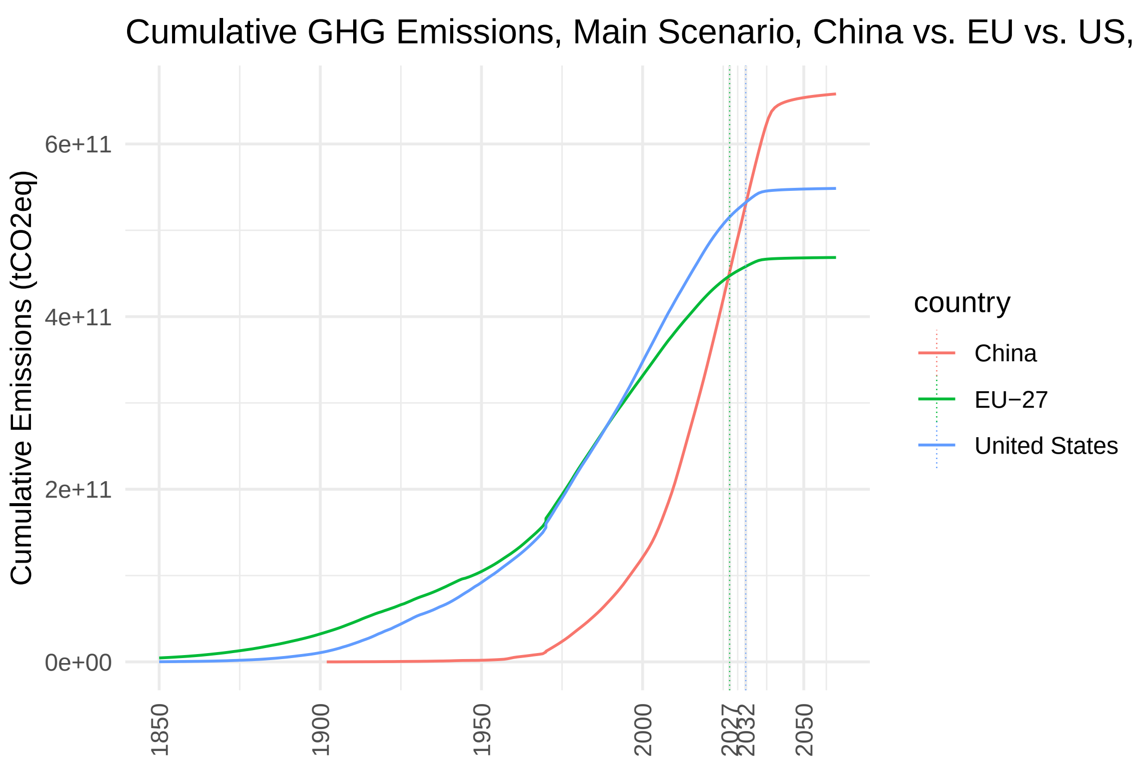

Figure 1.3: Figure 3

2 Data & Assumptions

Our project is data-driven in nature and relies heavily on the availability of various metrics on both greenhouse gas emissions and measures of (economic) development. Furthermore, there are key assumptions connected to our analysis that impact our findings. This section provides an overview of the data-sets we use, and makes our underlying assumptions about the data explicit.

2.1 Used Data

In terms of data on GHG emissions we make use of the EDGAR database as the core of our analysis. It contains yearly emissions data on the major greenhouse gases by country and sector and makes them commensurable based on global warming potentials on a 100-year scale. The database and its development are a joint project of the European Commission Joint Research Center and the Netherlands Environmental Assessment Agency (**?**).

We supplemented this data set with data on LULUCF emissions from the national GHG inventory database and add them to the total GHG emissions. The data itself was sourced from annual GHG inventories for Annex I countries and gathered from recent communications, biennial update reports, REDD+ submissions and NDCs for Non-annex I countries (**?**).

For consumption-based emissions of selected countries since 1990 we make use of an updated dataset from Peters et. al (updated from **?**). Additionally, we rely on world bank data for GDP, GNI and population (**?**). We further hand code variables for countries, specifically their membership to the EU 27 & 28 respectively, as well as their income classification according to the 2019-word-bank-classification for gross national income per capita (**?**). Lastly two datasets were made available to us a) an inventory of CO2 emissions since 1750 and b) IEA data for energy consumption.

2.2 General Assumptions

Regarding our main assumptions we limit our analysis to years until 2019 as we believe that the pandemic heavily distorted prior trends and hit countries and their economies to varying extents, making any meaningful interpretation and comparison difficult. Our main assumption here is that the trends and developments up to 2019 are more meaningful indicators for developments in the years and decades to come, compared to the pandemic years.

To make information accessible and to allow for comparisons across gases we choose to provide all information on multiple GHGs based on 100-year global warming potentials, as provided in our core database EDGAR.

3 Analysis

TO BE DONE: Intro statement.

3.1 China's Self-Characterization as a Developing Country

In the following, China's self-characterization as a developing country will be critically reviewed from an emissions perspective. For this, a definition of developed and developing countries will be developed. This is followed by a comparison of China's emissions development with the emissions development of other developed and developing nations by using a Kaya decomposition. As the distribution of emissions by sector is another way to distinguish between developing and developed countries, China's sectoral emissions are also compared to other countries. With this, we strive to find an answer to our first research question.

Categorization of Developed and Developing Countries

To distinguish between developed and developing countries, different indicators can be considered for instance GDP per capita, the gross national income GNI per capita or the human development index (HDI). Furthermore, other indicators such as the level of education or democracy can be taken into account when determining whether a country is developed, developing or underdeveloped (**?**).

Our main data set, the EDGAR dataset, already provides a classification of countries in two groups – developed and developing – which we will use as a starting point. According to this, China is categorized as a developing country. However, we realized that a more granular categorization of countries might be helpful to answer our first research question. Especially since any type of self-categorization might be biased as countries stand to gain from underestimating their development in order to receive more aid and have less responsibilities in the UNFCCC process.

Thus, we decided to use a second country classification scheme for comparison. Although a financial indicator might not completely summarize a country's level of development, we decided to use the GNI cut-offs as our main indicator of development. This is mainly because research finds that the GNI correlates with a number of accepted indicators of development outcomes (**?**). Furthermore, the income classification is the standard classification in discussions on development. The World Bank, but also other international organizations and aid agencies, use this for analytical and operational purposes. The GNI is calculated in the following way:

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Thus, going forward we will also use the World Bank's Classification of Countries by income, which assigns countries into four different groups: high income, upper-middle income, lower-middle income, low income. Income is measured using the GNI per capita of the previous year in U.S. dollars using a three-year average exchange rate. The classification is updated each year. For our analysis, we are using the threshold valid as of July 2019, as our emissions analysis considers this year as the last year. The thresholds are as follows:

Group	**Thresholds July 2019 in USD**
Low income	$< 1,026$
Lower-middle income	$1,026 - 3,955$
Upper-middle income	$3,966 - 12,375$
High income	$> 12,375$

According to the World Bank's classification, China is classified as an upper-middle income country since 2010 (**?**).

To make use of the more granular look at country groups in relation to our research question, we assume low- and lower-middle income countries to be more likely resembling developing nations and middle-upper- and high-income countries to be more likely resembling developed nations.

Comparison of Kaya Identities

With a Kaya identity, one can identify the main driving forces of CO2 emissions in a certain period. The Kaya identity expresses CO2 emissions (F) as a function of GDP (G), population (P) and energy (E):

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The term highlights the different components of the identity: G/P is GDP per capita, E/G is the energy intensity of GDP and F/E is the carbon intensity of energy (**?**). By comparing Kaya identities of different regions, we can also discuss regional differences. Hence, we use the Kaya identity to discuss if the driving forces of emissions show similarities with developing or developed nations.

Figure 4 displays China's and developing and developed countries' Kaya identities according to the IPCC classification in the Sixth Assessment Report from 2000 to 2019. In those years, China's GDP per capita was growing with a factor close to five, thereby being the strongest upward driver of emissions. GDP per capita increased almost in tandem with carbon emissions until 2010, in which a decoupling took place. Ever since, Chinese emission's growth rates have been much slower than those of GDP per capita. This decoupling is likely due to the decreasing energy intensity of GDP and carbon intensity of energy at the same time.

The energy intensity is the main counteracting factor on Chinese emissions and decreased constantly since 2005. The decreasing trend seemed to have already started in 2000 but had rebounded before 2005, which can be traced back to 2001, when China joined the WTO (**?**). However, since 2010 the decrease has been significant, hence driving the reduction of overall emissions growth rate. Furthermore, one can see that carbon intensity of energy decreased since 2010 meaning that the amount of CO2 per unit of energy is decreasing. Nevertheless, the relationship remains a positive one. The decline of both the energy intensity and carbon intensity is likely due to economic efficiency improvements. Additionally, carbon intensity further declined because of increasing capacity additions of renewable energies (changes in the fossil share) and the reduced emission intensity of fossil fuels (changes in the fossil intensity, fuel switch) (**??**). Population changes only played a minor role but can be considered as a persistent upward driver of emissions.

Comparing China's Kaya identity to the decomposition of the development of CO2 emissions of developing and developed countries does not provide a clear result on whether China can be considered a developing or developed nation. In general, economic growth is the main driver of CO2 emissions, both in developed and developing nations. However, GDP per capita growth is much larger and hence closer to China's figures in developing nations as they show a greater growth potential. Overall carbon emissions are decreasing in developed nations while they are increasing in developing nations and China. This supports the notion of China being a developing country relying on emissions driven growth. On the other hand, China's energy and carbon intensity are decreasing as it is the case for developed countries. The population's development of China also more closely resembles the trend of developed countries than those of developing countries. To sum up, this classification does not clearly indicate whether China is a developing or developed country. As mentioned above, comparing China to a more granular classification of countries might be worthwhile, as the EDGAR dataset for example considers Saudi-Arabia, a country with one of the highest GDP per capita as a developing nation.

Thus, in the next steps, the World Bank's Income Classification Scheme will be used for comparison (Figure 5). In high-income countries, GDP per capita and population are increasing only at low levels (by roughly the factor 0.5 and 0.2 respectively). Carbon intensity and energy intensity are decreasing, keeping carbon emissions down. The carbon intensity is decreasing because of two factors: the fossil intensity and the fossil share. In contrast, in low-income countries, the growth of CO2 emissions is exceeding the growth of GDP per capita, both rising by a factor of 2.8 and 5 respectively over the observed time span. This is driven by a high and increasing carbon intensity. Furthermore, population growth plays an important role in this group, and can be considered a further driving factor of CO2 emissions. The only contrasting factor is the decreasing energy intensity. Comparing both groups of

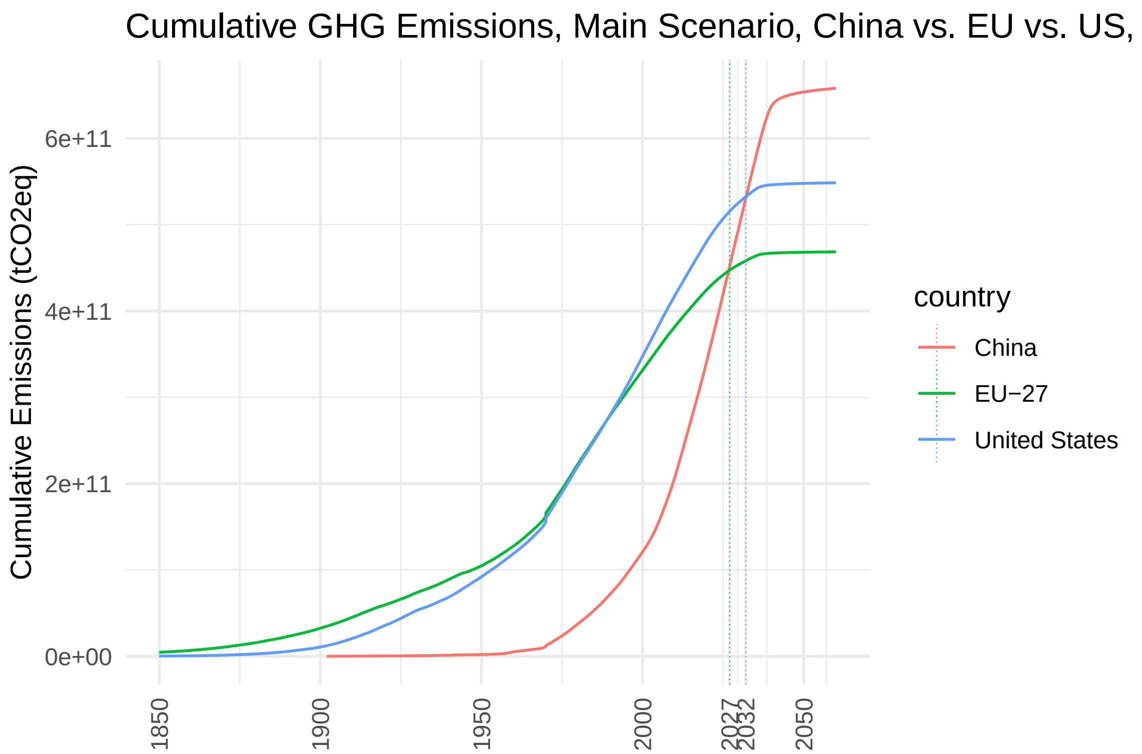

Figure 3.1: Figure 4

countries to China, one can resume that China's development does not fit in either of the groups perfectly. Like before China's Kaya decomposition shares similar characteristics as both groups: The small population growth resembles the trend of high-income countries, the dramatically decreasing energy resembles the trend of low-income countries. Considering lower-middle income countries, they seem to show upwards trends in any of the indicators except for energy intensity. In comparison, in upper-middle income countries carbon emissions and GDP per capita develop in tandem, while carbon intensity and energy intensity only fluctuate around zero in the years from 2000 to 2019.

To conclude, China seems to be an exception considering the driving forces of emissions and thus cannot be assigned uniquely to any of the studied group of countries. This is especially due to the exceptionally high GDP growth which only recently decoupled from carbon emissions. In terms of GDP growth rates and carbon emission growth, China can be considered a developing nation as they base their GDP growth on growing carbon emissions. However, the carbon and energy intensity that keep CO2 emissions down, show that China is already getting more efficient in its production and that it has the capacity to invest in renewable energy source. Considering only those two indicators, China can be better compared to developed countries. Thus, it seems that China has a responsibility to put forward this trend of efficiency gains in order to decouple economic growth and emissions even more. To examine the status of China in more depth, China's sectoral trends will be compared to the

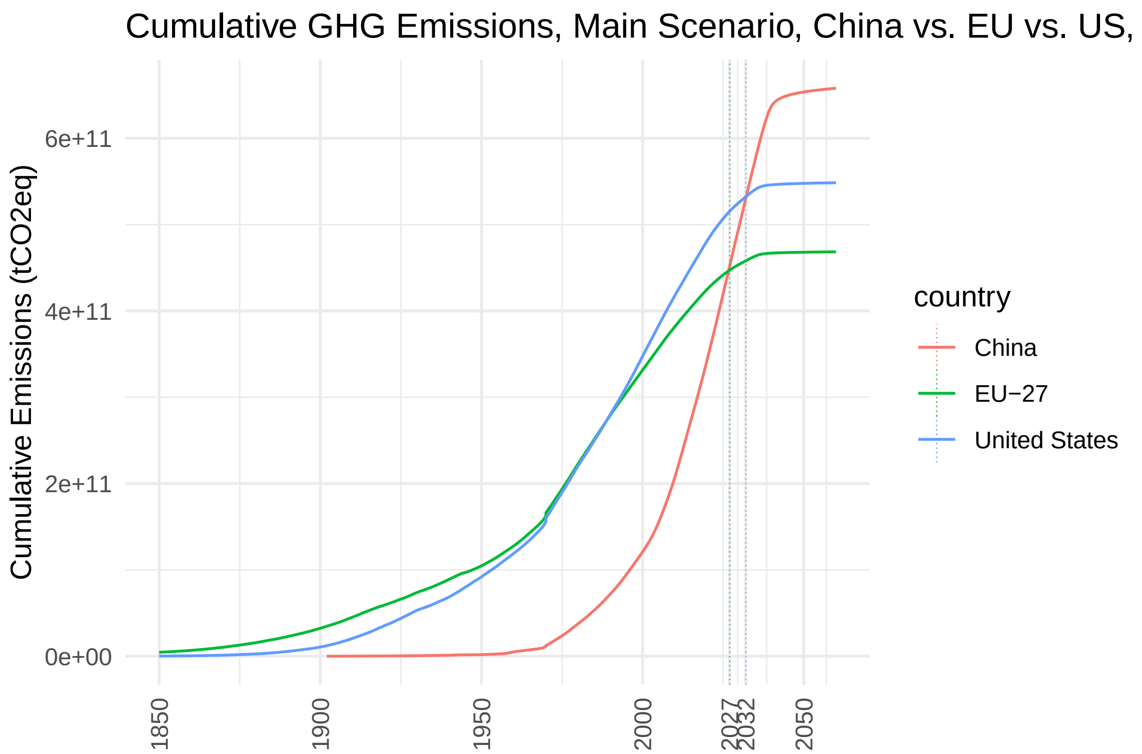

Figure 3.2: Figure 5

two discussed classification schemes in the following. This can provide further information on China's classification, since developing and developed nations usually generate wealth in different economic sectors.

Comparison of China's Sector Trends

In this part, sector trends of different groups of countries will be considered using the same two categories of country groups as before. We take into account five sectors: energy, industry, transport, AFOLU (which in the EDGAR database only includes agricultural emissions), and buildings. China's relative GHG emissions by sector are presented in a stacked bar plot in Figure 6 & 7. Most of China's emissions in 2019 came from the energy and industry sector with 44% and 38% respectively. Only smaller shares are attributable to transport (6%), buildings (5%) and AFOLU (6%).

In developed countries (according to the EDGAR classification), energy and industry still account for the majority of emissions (58% in total), but transport emissions play a much larger role (21%) of the GHG emissions than in China. This high share of transport emissions can be accounted to the high use of private cars in developed economies. For instance, the EU road transport accounts for 77% of GHG emissions in the transport sector in 2020 (**?**). AFOLU emissions and emissions from buildings each account for roughly 10% of the total

GHG emissions.

In contrast, in developing nations, the share of AFOLU emissions is much larger (21%). The high share is typically associated with the expansion of agriculture into carbon-dense tropical forests, but also the lack of economic development of other sectors. The share of transport, however, is much lower than in developed countries as individual transport is not that widely spread. The relative emissions in energy and industry are comparable to those in developed countries as developing countries are rapidly growing to fulfil their own and the developed countries' consumption needs. However, absolute emissions levels are much lower.

Again, China's split of emissions does not fit in either of the two categories. On the one hand, China's share of emissions coming from the AFOLU sector is relatively small resembling developed country characteristics. On the other hand, their emissions from transport sector are small as well. This is due to the immense share of emissions stemming from industry and energy, which reduces the share of emissions in the other sectors.

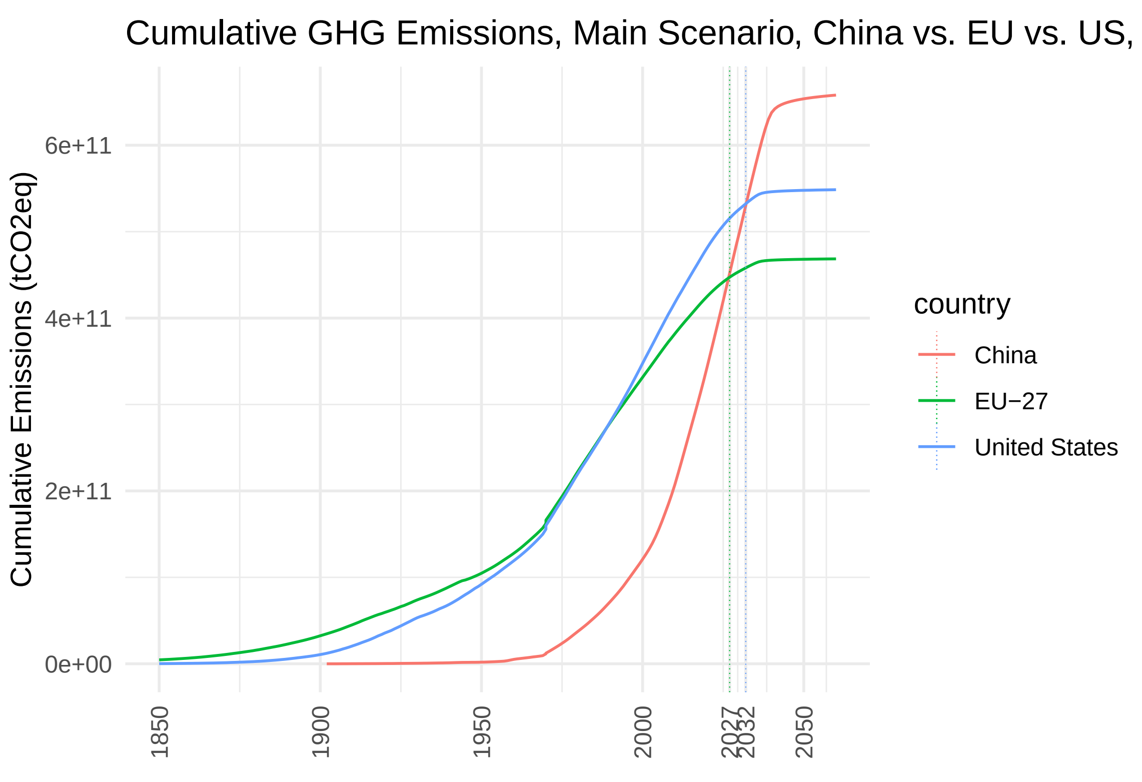

Figure 3.3: Figure 6

As before, to get a more granular view on the split of emissions by sector, the World Bank's classification will be consulted (Figure 7).

In this classification, differences between high-income and low-income countries are very pronounced. While in high-income countries a major share of emissions resulted from energy systems (37%) in 2019, the share of emissions from energy only accounts for 9% of all GHG emissions in low-income countries. This highlights an energy system largely depending on fossil fuels in high-income countries on the one hand, and the lack thereof in low-income countries on the other hand. The differences are also immense considering the transport sector. In high-income nations, 20% of the GHG emissions stem from transport, while in low-income countries, the share is only 7%. However, the biggest differences are the AFOLU emissions. High-income countries have a share of 9% for AFOLU emissions while in low-income countries this sector accounts for 57% of emissions. The reasons for these differences were discussed above.

The emissions by sector for lower-middle and upper-middle income countries are more similar, the only difference is that the share of AFOLU is larger in lower-middle income countries and the share of transport is larger for upper-middle income countries, indicating further progress on the typical developing path of the latter country group.

Again, China does not really fit into either of the categories due to its very high share of emissions stemming from the energy and industry sector. China's relative emissions from these two sectors are much larger than in any of the other groups studied.

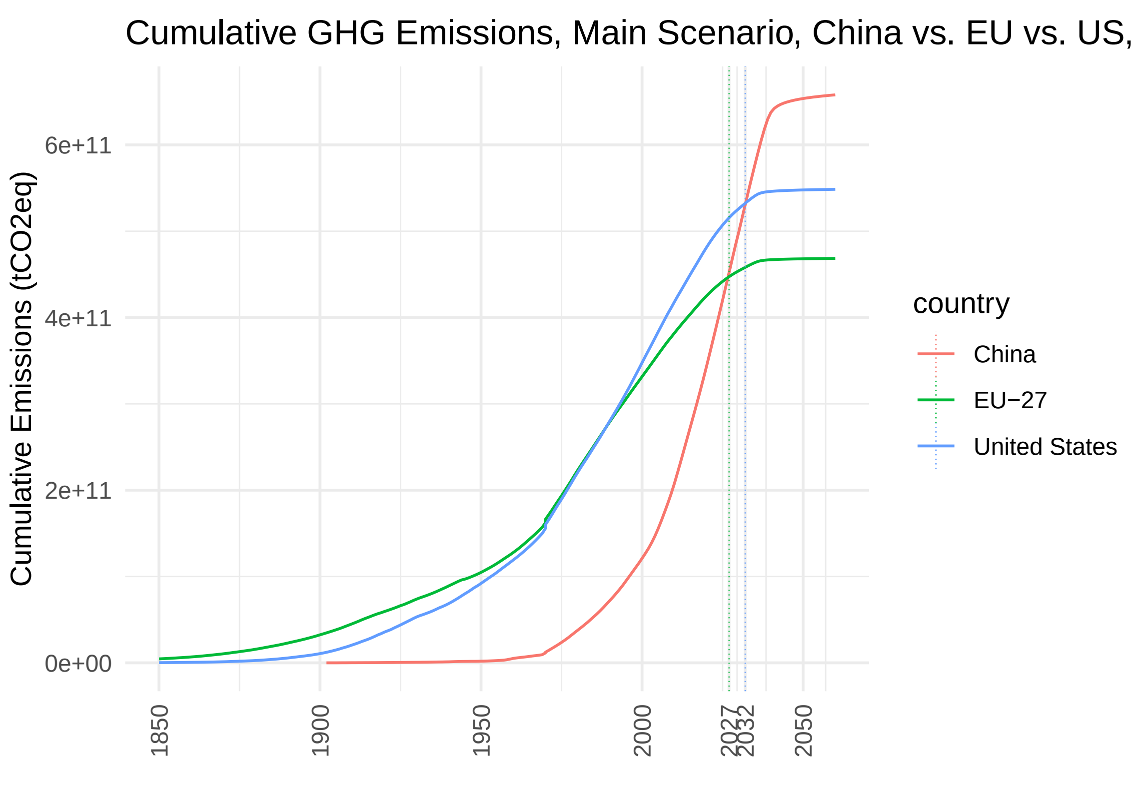

Figure 3.4: Figure 7

As the stacked bar plot can only provide a snapshot in time and relative emissions only tell a limited story, we will in a next step compare China's per capita emissions by sector over time from 1970 to 2019 to those of our four income determined country groups (Figure 8).

Comparing trends is particularly helpful, as emissions from the energy and industry sector in China are so large, that it makes any comparison of the remaining sectors with the potential peers very difficult.

China's AFOLU emissions per capita are relatively low and decreasing over time, similar to the emissions in lower-middle income countries in this sector. The AFOLU emissions per capita of high income and upper-middle income countries are large because a relatively high agricultural output spread over relatively small populations. In the building sector, Chinese emissions per capita are relatively low compared to high-income countries and rather on the same level as upper-middle income countries. The per-capita emissions of the building sector are high in richer countries as people require more floor space per capita compared to lower-income countries. For transport, China's emissions stayed on a low level until 2000 and then increased at high speed. Now, they are comparable to per capita emissions of upper-middle-income countries.

Considering the three sectors mentioned above, China seems to resemble more the emissions per capita characteristics of lower-middle or upper-middle income countries, however this is different for the energy and industry sectors. In the energy sector, China's emissions per capita increased up to roughly 4 tCO2eq in 2019. This is much higher than for upper-middle income countries, in which per capita emissions stayed relatively constant at 3 tCO2eq in 2019. In high-income countries, the per capita emissions from energy are still higher (5 tCO2eq) in 2019 than in China, however, one can see a downward trend there. Thus, one could argue that China can soon be compared to a high-income country regarding its per capita energy system emissions. The same holds for the industry sector, where this development is even more pronounced. Emissions per capita in the industry sector in China increased massively in the 2000s and are now at a plateau of 4 tCO2eq annually. The per capita emissions of high-income countries in the industry sector in contrast have decreased since the 1970s and are now at 3 tCO2eq. In the industry China has thus already surpassed per capita emissions levels of high-income countries and has the highest value among the five studied panels in this sector.

Discussion

The prior analysis has shown that clearly classifying China as either a developed or a developing from an emissions perspective remains difficult.

However, what this analysis has clearly shown, is that the simple self-characterization of China as a developing country, that is mirrored by Sixth assessment report of the IPCC, does not do justice to the drastic economic and emissions development China has witnessed in the last decades. As the analysis has shown, China clearly exhibits certain emission characteristics

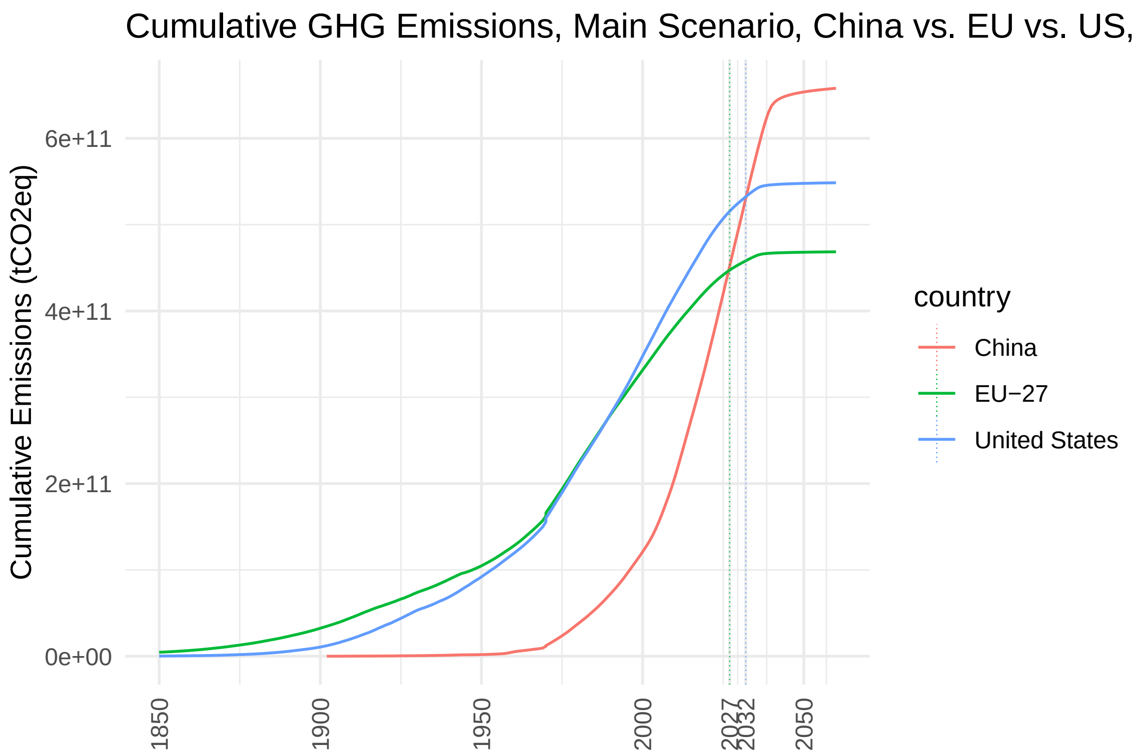

Figure 3.5: Figure 8

of developed countries in some sectors like industry and energy systems. When it comes to agricultural per capita emissions trends it is comparable to lower-income countries. Maybe most importantly, in the industry sector it has the highest per capita emissions of any of the candidates that were up for comparison.

What this analysis has undoubtedly confirmed is the realization that China is a special case in every respect. China's unique economic development, which has led to a five-fold increase in GDP per capita over the past two decades, saw the country develop an energy and industrial system that together accounts for 82% of the country's total emissions, a share 20% higher than that of high-income countries.

Nevertheless, one needs to consider that development is not equally distributed in China. The rural population has benefited significantly less from the economic development than the urban population (East-West divide) (**?**). However, the argument that one still has the right to predominantly emissions-based development (as in 1992) is no longer in line with China's current status as the world's biggest emitter. Hence, China's NDC's storyline, which seeks the main responsibility for climate change in developed nations, is too undercomplex and does not do justice to the evolved realities.

To further investigate this issue, in the next we will predict the future development of emissions of China and other countries and further consider different equity metrics.

3.2 China's Equitable Share in Climate Change Mitigation

The following chapter discusses China's equitable share in climate change mitigation. In order to answer the research question, we will first discuss the future development of China's emissions, to determine when China will become the biggest cumulative emitter. For this, we consider multiple development pathways of China in terms of emissions and discuss China's cumulative emissions in comparison to other countries. Moreover, we will present different rankings of absolute emissions, per capita emissions, GDP and GDP per capita, cumulative emissions and consumption-based CO2 emissions to discuss China's responsibility from different perspectives.

Future Development of China's Emissions

The first equity metric we consider is cumulative emissions, as China claims historic developed countries' emissions being the main driver of climate change. Looking at cumulative emissions from 1750 until 2019, China is on 3 rd position, only behind the U.S. and the EU-27. According to this, in 2019 China would already have the 3rd-largest responsibility to reduce emissions, since it has historically emitted a total of 12.4% of all greenhouse gases. This is in direct contrast to the country's claim to be less responsible for the warming climate.

Importantly, if China continues its emissions pathway, it will become the largest cumulative emitter at some point. In order to estimate when China will move into first place, we have modeled expected emission trends for China as well as for the EU and the U.S. Our modelling is based on the following assumptions:

First, for simplicity, we assume that China will reduce not only CO2 emissions, as communicated internationally, but all GHG emissions to zero. As we have seen in section 3, Chinese emissions trends vary strongly across sectors. Therefore, we have modelled each sector's future emissions pathway following different assumptions. In general, we assume a constantly declining growth rate of emissions in each sector until a peak year starting with the 2018 to 2019 growth factor. After the peak we consider an s-curve emissions reduction for the following years until zero emissions are reached, as China might first use the simple levers to reduce emissions fast and then needs to work on emissions which are difficult to bring down.

As emissions in the AFOLU sector have already been decreasing in China, we expect a relative flat emissions level until 2025, followed by a decrease until zero emissions are reached in 2060. Buildings are assumed to peak emissions in 2030 and are at zero in 2060. The energy systems sector is expected to peak the earliest, in 2028, due to the continued heavy roll-out of renewable energy sources in China and the experiences from other countries decarbonization journeys. Complete decarbonization is then assumed to be reached by 2055. We assume the industry sector to peak by 2030 and reach complete decarbonization by 2065. As transport is the fastest growing sector of Chinese emissions, we assume this trend to continue (but slowed down) until 2040, and complete decarbonization in 2065.

In modeling the development of emissions for the EU-27 and the U.S., we are guided by data from the PBL Netherlands Environmental Agency (**?**). For simplicity we do not differentiate by sector but assume a linear decrease in annual emissions up to the projected emissions value for 2030 in both the U.S. and the EU-27. Thereafter, we also use an s-shaped reduction curve to achieve zero emissions by 2050.

The resulting sectoral emissions pathways for each country/region are depicted in figure xx. The resulting cumulative emissions forecasts for the three countries/blocks are shown in figure xx. Accordingly, China will pass the EU-27 in cumulative GHG emissions in 2027 and is projected to pass the U.S. in 2032 . Afterwards it will be the largest cumulative emitter.

These projections hold even when modelling each sector according to the Chinese NDC (assuming peak years of 2030 and zero emissions by 2060). In the NDC-scenario China will surpass the EU and US respectively in the same years as modeled in our main scenarios, but at different emission levels – 452.4 GtCO2eq (main scenario) 451.8 GtCO2eq (NDC-scenario). When projecting only CO2 emission developments1 China will surpass the EU in 2031 and the US in 2038 according to both scenarios.

This analysis shows that maintaining targets that are ambitious in absolute terms but relatively easy to achieve compared to China's size and economic power, have already put China at the forefront of global responsibility for climate change. From a cumulative emissions perspective, China definitely has the same if not larger GHG reduction obligations as many developed countries, especially when considering that a majority of China's emissions were emitted after the problem of climate change has made it on top of the global policy agenda. Moreover, the statement of the Chinese NDC that climate change is mainly caused by others is not tenable.

However, cumulative emissions, while easily understood, are not the only conceivable equity metric to consider when attempting to assess a country's fair share in responding to climate change. Therefore, in the following sub-section we investigate other equity metrics.

Equity Metrics

This chapter presents different rankings which can shed light on the question of China's responsibility to mitigate climate change from different angles. The following rankings always display the top 10 countries (or in case of the EU regions) in the respective category. Furthermore, other important countries are added for comparison as well as a category named "Other" which summarizes the share of all remaining countries. The EU-27 is mentioned as

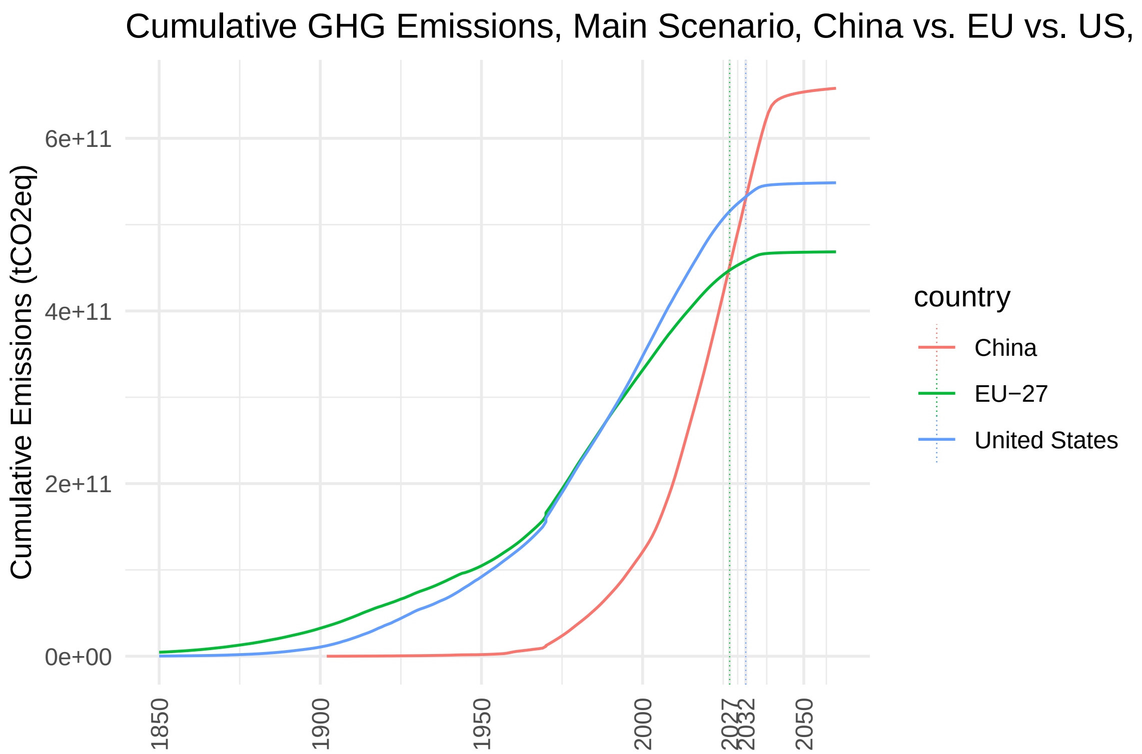

Figure 3.6: Figure 9

a point of reference, but emissions of the separate countries are displayed in the ranking or summarized in the "Other" category. Every graph also provides reference points for the rank position where cumulative 50 % of global GDP, population and emissions are surpassed.

First, we consider China's responsibility based on absolute emissions in the year 2019 (Figure X). In the ranking, China ranks on first place with absolute emissions of 14,219.37 Mt CO2 eq. This is more than double of the U.S. emissions (6,266.8 Mt CO2 eq) and also close to the emissions of all other countries that do not belong to the group of the top 10 emitters combined (14,075.12 Mt CO2 eq). Together with the U.S., India and Russia, China makes up for 50% of global emissions, but these four countries do not produce half of the global GDP, nor do they represent half of the world's population. This highlights that the responsibility of these four countries to drastically reduce emissions is high. Considering that China is producing more than double the emissions of the U.S., China has by far the highest responsibility to mitigate climate change from a current absolute emissions perspective.

Next, we consider emissions per capita (Figure x). This is important as China is the country with the biggest population worldwide of approx. 1.4 billion people (**?**). Looking at this ranking, it is important to consider that the top emitters according to per capita emissions are relatively small countries with low absolute emissions but also small populations. Thus, when it comes to reducing absolute emissions and fighting climate change, they can only play

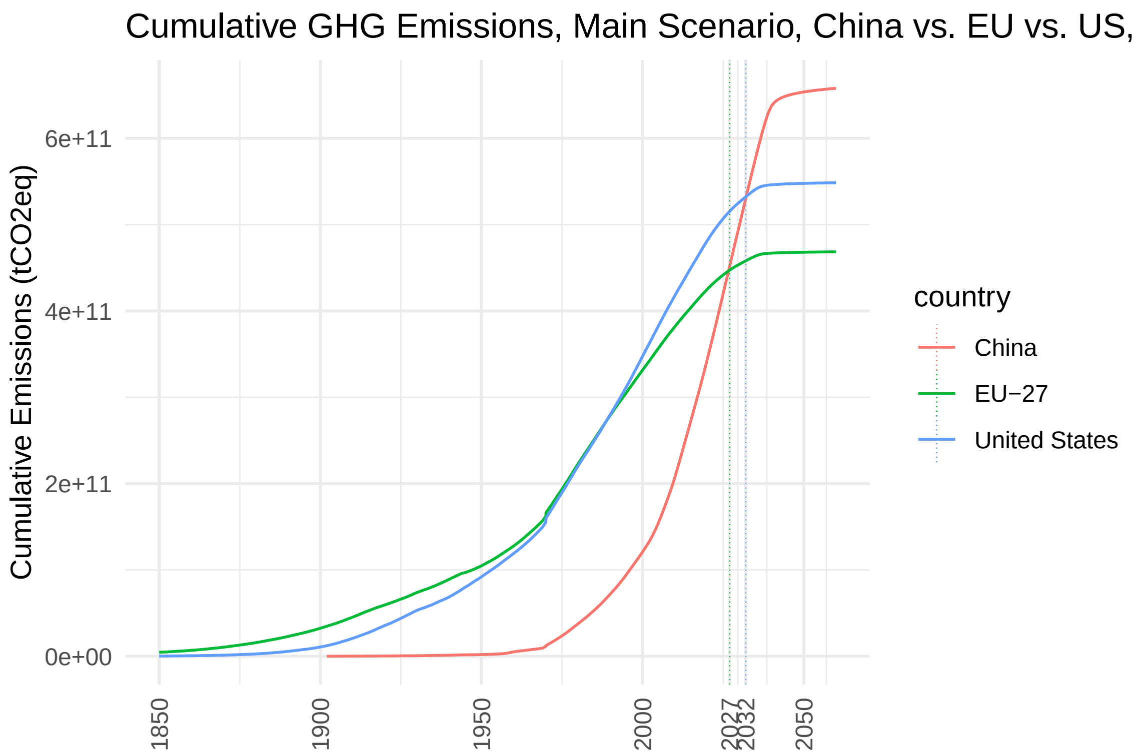

Figure 3.7: Figure 10

a minor role. China interestingly ranks on place 43 with roughly 10t CO2 eq / capita, before EU-27 but behind the U.S. (Ranking: 17). According to this equity metric, China's fair share to mitigate climate change from this perspective should be located between the share of these two countries/groups of countries.

Considering GDP and GDP per capita refers to the capacity of acting on climate change, following the assumption that richer countries have more resources available to fight climate change. As Figure XX shows, China had the highest GDP of all countries in 2019, with USD 22.49 trillion. Based on this, China would theoretically have to make the greatest conribution to reduce emissions. Absolute GDP, however, is limited in telling us about a country's actual capacity because it ignores population size. Therefore, considering GDP per capita might be more worthwhile. Here China only ranks 81st place in the world. Therefore, China's responsibility is relatively low from the GDP per capita perspective. In comparison, the U.S. rank on place 11. Countries that are in the top 10 emitters are often relatively small countries deriving their wealth from natural resources. Hence, they have a high responsibility to mitigate climate change as they have the ability to pay for climate change mitigation measures. However, their absolute emissions are relatively small and thus an ambitious reduction might not make a huge difference for achieving climate targets. Thus, one should consider that these countries should specifically contribute by providing financial aid to mitigate emissions elsewhere.

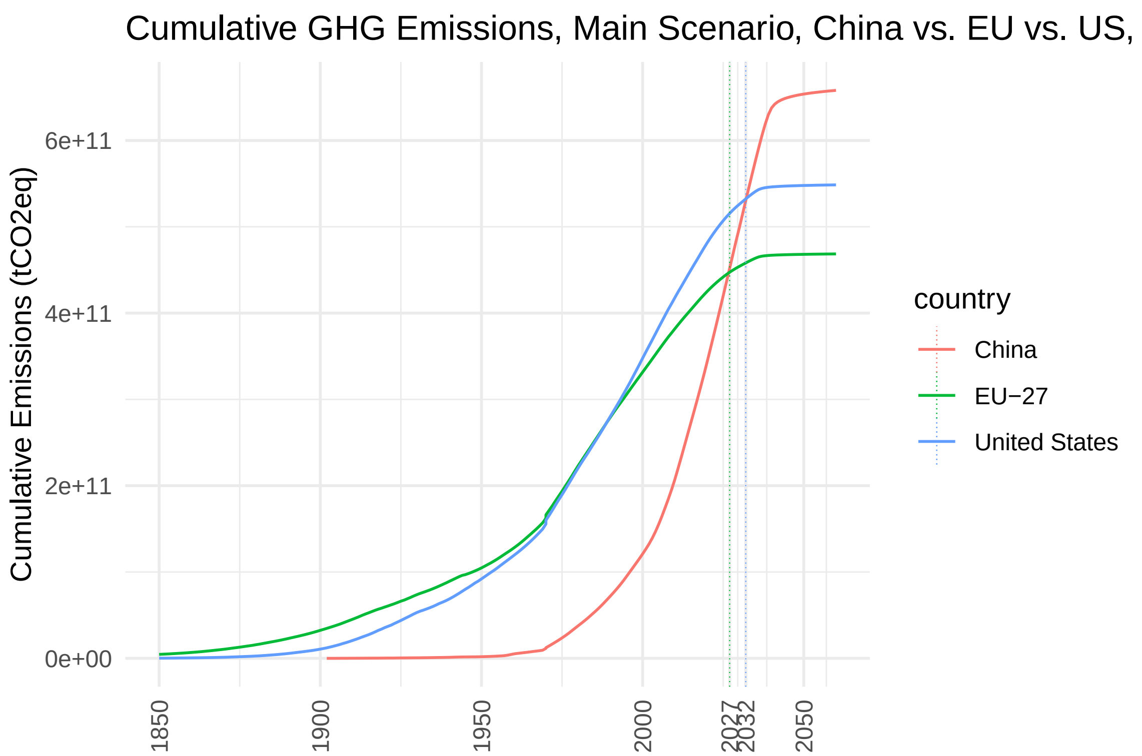

Figure 3.8: Figure 11

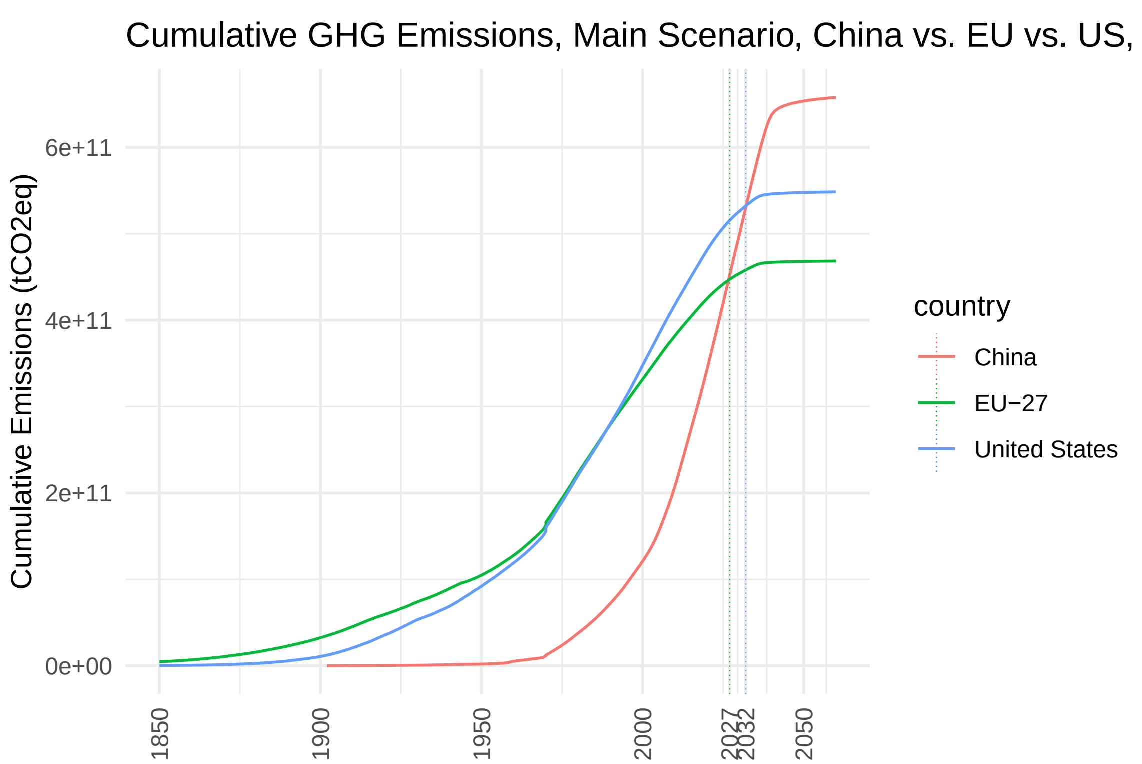

Figure 3.9: Figure 12

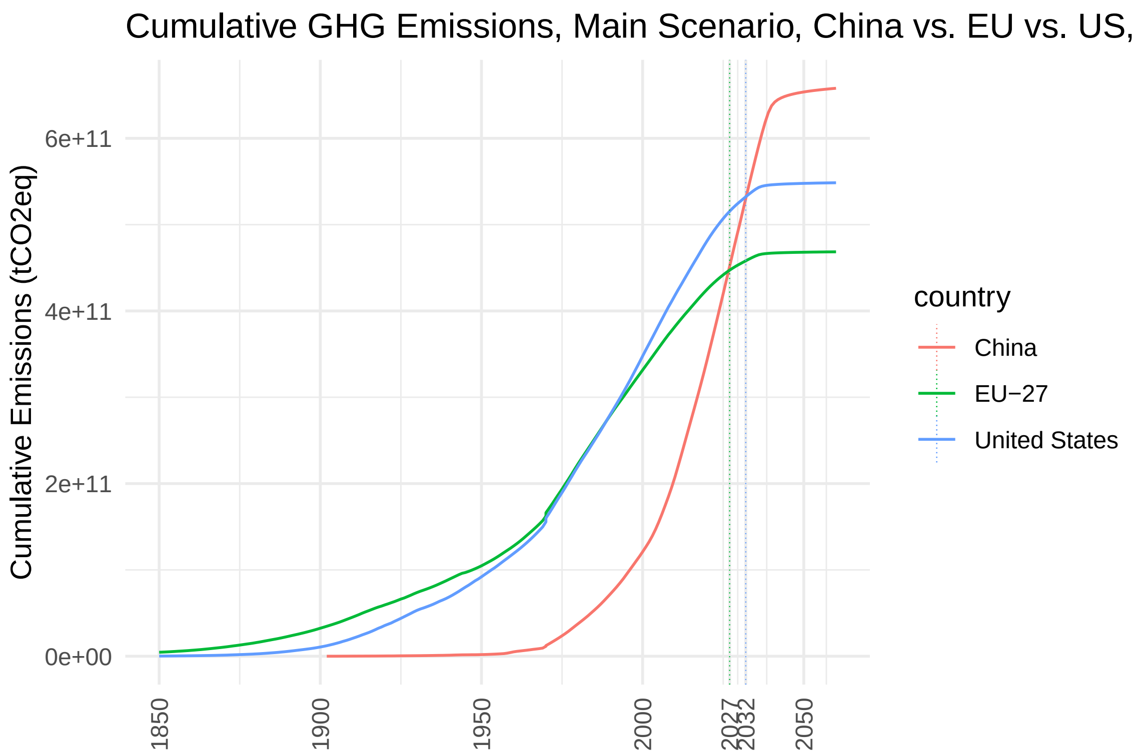

Figure 3.10: Figure 13

Discussion TBD

To sum up, China has a very high responsibility to mitigate climate change, even the highest responsibility of all countries when considering some of the discussed equity metrics. Based on our calculations, China is likely surpass the EU well before 2030 and the US shortly after in 2032 in terms of cumulative emissions over all GHGs from 1850 to 2019 and a modeling of emissions thereafter. The difference in emissions from all GHGs to CO2 emissions highlights the importance to extend the frame of historic respon

Therefore, China now has a major responsibility to reduce emissions which is reinforced when considering that the country's massive emissions growth only started after the adoption of the Kyoto Protocol in 1997, at a time when the consequences of climate change were already being heavily discussed.

However, we also need to consider that China only ranks on 81st. and 43rd place considering their GDP per capita and their emissions per capita, respectively. This diminishes China's responsibility to some extent, showing that the global community needs to grant space for economic development to be fair. However, this economic development should ideally be decoupled from a growth in emissions. If we look at the per capita emissions of the countries that rank first, we see that these are mostly very small and, from the perspective of absolute emissions, less important countries. Although these countries might have a high ability to pay from a per capita perspective, their overall economic power is not high. The opposite is true for China. China ranks first place in absolute emissions and GDP in 2019 with a great distance to the following places.

Thus, China has one of the greatest responsibilities to reduce emissions from a historic emissions, current emissions and economic capacity perspective.

4 Discussion and Conclusion TBD

In our analysis, we were striving to answer two research questions, namely if China can be considered a developing country and what China's fair share in climate change mitigation should be.

Regarding out first research question, we find that China cannot be easily classified as a developed or developing country. This is due to the unique economic growth (China's GDP per capita quintupled in the last 20 years), which went hand in hand with very high energy and industrial sectors' emissions. Comparing these to other developed countries, one can see that China clearly exhibits these countries' characteristics in term of sectoral emissions. However, China's agricultural per capita emissions trends are more comparable to lower-income countries.

Our analysis of different equity metrics for the second research question has shown that China not only has a huge responsibility to curb emissions, but also the financial capability to do so. The country is the world's largest emitter in annual and cumulative terms (based on our data) and has the highest GDP of all countries. While it is important to acknowledge further room for development, one cannot disregard the fact that without significant emission reductions from China, any attempt to stay within the temperature limits of the Paris Agreement is sure to fail.

Hence, we believe that China's fair share is much higher than what they currently plan to do. Together with the EU-27 and the U.S., China should bear the highest responsibility for climate change mitigation. Its self-classification as a developing country is clearly politically motivated, to not give in to the demands of having to do more. At the same time, the political leadership in Beijing can present itself as a top student in the international community by effortlessly surpassing its own goals, as it is expected by different observers (**?**).

In the following, our analysis will be contrasted with two other assessments of China's fair share – the assessment by the Climate Action Tracker and by the Climate Equity Monitor.

The CAT evaluates the fair share of a country based on assessments in the literature. The results of the literature are categorized using seven equity indicators ranging around considerations of responsibility, capability, cost-effectiveness and equality, which are weighted equally in the analysis. All results of the evaluated studies are then depicted on a scale for each category and a 90% confidence interval is built. Based on this, the CAT develops a range of what would be a fair share and where to categorize the different countries. The CAT values China's share in mitigation efforts as highly insufficient. In comparison, the U.S.'s, India's and the EU's planned policies and targets are only considered insufficient for achieving a fair share target under the Paris Agreement (?).

Another equity metric is developed by the Climate Equity Monitor. The Climate Equity Monitor is the first initiative from the Global South that tracks equity in climate action for Annex 1 and Non-Annex 1 countries. The initiative calculates the fair share of the carbon budget by using the share of cumulative emissions based on the share in the global population for a contemporary base year (2019). The cumulative annual emissions of a country are calculated for the period from 1850 to 2019. Based on this, the Climate Equity Monitor calculates if a country has a carbon debt or carbon credit. This measure is calculated as the difference between cumulative emissions of a country and the country's fair share of the global carbon budget already consumed. For China as a Non-Annex 1 country, they conclude that the country has a carbon credit of 122.4 Gt CO2eq. In comparison, India has a carbon credit of 337.6 Gt CO2eq while the US has a carbon debt of 445 Gt CO2eq, and Russia has a carbon debt of 125.44 Gt CO2eq (?). Accordingly, if China kept emitting at its current rate, it would have used up its remaining carbon credit until 2031.

It is interesting that the Climate Action Tracker and the Climate Equity Monitor come to conclusions that can be interpreted differently. While the latter initiative only considers cumulative emissions allowances in relation to population size, the former's assessment benchmarks climate targets and policies against a larger variety of equity metrics. The remaining carbon credit derived from the Climate Equity Monitor might be misleading to a certain degree, as it might suggest little urgency to act, especially when comparing the credit numbers to the debt numbers of other countries. The CAT's assessment, while being methodically more sophisticated, better communicates the implications of current emission reduction targets and respective policies from an equity perspective.

Our analysis has the following limitations: We only consider cumulative emissions from 1850-2019, but the consideration of other time periods could also be conceivable. The problem of climate change caused by anthropogenic greenhouse gas emissions has only been known since the 1970s, and since the 1990s there has been a dedicated international process to address the problem. Against this background, an additional consideration of cumulative emissions in these time periods might be worthwhile. For a comprehensive assessment of China's fair share, it would have also been interesting to discuss further equity metrics such as a ranking of consumption-based emissions. However, this was not possible for us, as our data only included consumption-based data for approx. 100 countries and crucially missing the US, making a comparison less meaningful.

Appendix

A Session Info (RStudio)

- R version 4.2.1 (2022-06-23 ucrt), `x86_64-w64-mingw32`
- Running under: `Windows 10 x64 (build 22621)`
- Matrix products: default
- Base packages: base, datasets, graphics, grDevices, methods, stats, utils
- Other packages: dplyr 1.0.10, eurostat 3.7.10, forcats 0.5.2, ggplot2 3.3.6, ggridges 0.5.4, imputeTS 3.3, kableExtra 1.3.4, magrittr 2.0.3, openxlsx 4.2.5, pacman 0.5.1, plotly 4.10.1, purrr 0.3.4, readr 2.1.2, readxl 1.4.1, stringr 1.4.1, tibble 3.1.8, tidyr 1.2.1, tidyverse 1.3.2, WDI 2.7.8
- Loaded via a namespace (and not attached): assertthat 0.2.1, backports 1.4.1, bibtex 0.5.0, broom 1.0.1, cellranger 1.1.0, class 7.3-20, classInt 0.4-8, cli 3.4.0, colorspace 2.0-3, compiler 4.2.1, countrycode 1.4.0, crayon 1.5.1, curl 4.3.2, data.table 1.14.2, DBI 1.1.3, dbplyr 2.2.1, digest 0.6.29, e1071 1.7-11, ellipsis 0.3.2, evaluate 0.16, fansi 1.0.3, farver 2.1.1, fastmap 1.1.0, forecast 8.18, fracdiff 1.5-2, fs 1.5.2, gargle 1.2.1, generics 0.1.3, ggtext 0.1.2, glue 1.6.2, googledrive 2.0.0, googlesheets4 1.0.1, grid 4.2.1, gridtext 0.1.5, gtable 0.3.1, haven 2.5.1, here 1.0.1, highr 0.9, hms 1.1.2, htmltools 0.5.3, htmlwidgets 1.5.4, httr 1.4.4, jsonlite 1.8.0, KernSmooth 2.23-20, knitr 1.40, labeling 0.4.2, lattice 0.20-45, lazyeval 0.2.2, lifecycle 1.0.2, lmtest 0.9-40, lubridate 1.8.0, modelr 0.1.9, munsell 0.5.0, nlme 3.1-157, nnet 7.3-17, parallel 4.2.1, pillar 1.8.1, pkgconfig 2.0.3, plyr 1.8.7, proxy 0.4-27, quadprog 1.5-8, quantmod 0.4.20, R6 2.5.1, Rcpp 1.0.9, RefManageR 1.4.0, regions 0.1.8, reprex 2.0.2, rlang 1.0.5, rmarkdown 2.16, rprojroot 2.0.3, rstudioapi 0.14, rvest 1.0.3, scales 1.2.1, stinepack 1.4, stringi 1.7.8, svglite 2.1.0, systemfonts 1.0.4, tidyselect 1.1.2, timeDate 4021.104, tools 4.2.1, tseries 0.10-52, TTR 0.24.3, tzdb 0.3.0, urca 1.3-3, utf8 1.2.2, vctrs 0.4.1, viridisLite 0.4.1, webshot 0.5.3, withr 2.5.0, xfun 0.33, xml2 1.3.3, xts 0.12.2, yaml 2.3.5, zip 2.2.1, zoo 1.8-11

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