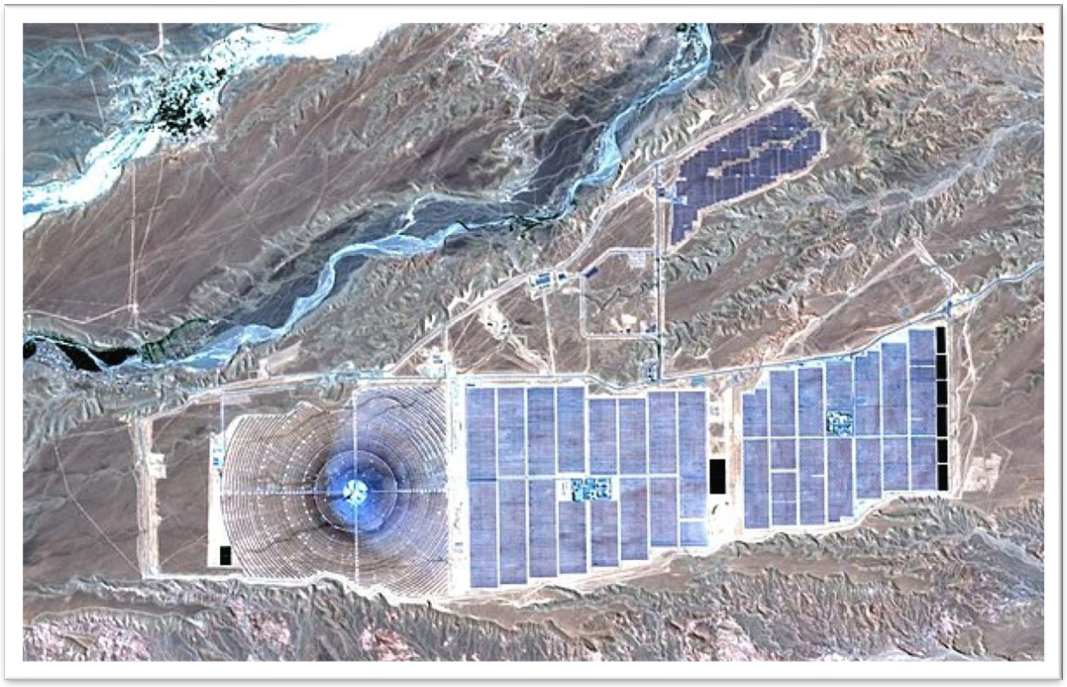
Breaking the Carbon Budget:

Accounting for Natural Capital



Noor Ouarzazate complex in Morocco

Noah Portman

Final Paper

SUSCPS5001

Abstract

This paper will explore how disproportionate levels in both human and natural capital have led to global disparities and how redefining these stocks can generate equitable and long-term sustainable growth to help the world meet its climate goals. To better understand these systems and their interconnectedness, research from several reports are cited in this paper, including the World Bank's Report *The Changing Wealth of Nations 2018: Building a Sustainable Future*, McKinsey Global Institute's (MGI) *Reduced Dividends On Natural Capital* (2020), and the Nationally Determined Contributions (NDCs) of several countries, such as Morocco, Costa Rice, and The Gambia, all three of whom are on track to meet their Paris Climate Agreement targets. Unfortunately, out of the 195 countries that have signed the Paris Agreement, only a handful are meeting their reduction goals that limit an increase of global temperatures to below 2 degrees Celsius above preindustrial levels.

A study helpful in examining the relationship between human and natural capital analyzes the status of decoupling between economic development and the sustainable use of natural capital using a three-dimensional footprint ecological model in the hinterland of Three Gorges Reservoir.[1] A paper authored by the chairman of the U.K.'s Natural Capital Committee (NCC) sets out a case for preserving the aggregate level of natural capital by considering the role of asset registers, and shows how a broader national plan could contribute to the policy objective of leaving the next generation with a richer endowment of natural capital.[2] The U.K. has enlisted this group of scientists to reassess if British targets are being met and, if not, update the country's policy every five years.

[1] Zhang et al., "Exploring the Dynamic, Forecast and Decoupling Effect of Land Natural Capital Utilization in the Hinterland of the Three Gorges Reservoir Area, China."
[2] Helm, "Taking Natural Capital Seriously."

Furthermore, to better prepare more developed economies to the shifting landscape due to new climate policies, The Natural Capital Coalition instituted a framework called *The Natural Capital Protocol* to help larger corporations meet emission goals without compromising on development.[3] The coalition is currently made up of 300 partnering organizations across a wide spectrum of disciplines. The importance of natural capital for business is increasingly being recognized by the popularity of sustainability indices. Also, the ongoing pandemic is causing governments to make drastic legislative changes and teaching them the value of sustainable assets. According to Niklas Hohne, the founding partner of the NewClimate Institute and creator of the Climate Action Tracker, "advances in policy and technology among small players tend to feed the energy transitions in larger nations".[4] Low-income countries could grow by embracing renewable resources, which often make up a larger share of their assets, while developed countries can look to developing ones as role models of resilience that comes from embracing natural capital as a source of wealth. However, strong institutions and sound policies must be in place to manage resource revenues and to turn these riches into sustainable development.

[3] "Natural Capital Coalition | Natural Capital Protocol."
[4] "Home | Climate Action Tracker."

Introduction

This past decade has not seemingly brought us any closer to achieving our carbon reduction goals as laid out in the Paris Climate Agreement, and governments and individual companies are facing critical decisions in how they move forward with the intensifying threat of climate change. Once the carbon budget, estimated to be between 850-1550 GtCO2 (gigatons of carbon dioxide),[5] is broken, according to climate scientists, we will have destroyed our chance of limiting warming to 2 degrees Celsius. Our global effort should be towards decoupling economic growth from carbon emissions. Ironically, developed nations, which have developed from centuries of industrialization, are now asking developing countries to abandon highly polluting technology. High-emitting countries argue charting a course of lower emissions would create economic stress, while low-emitting countries maintain the high emitters have already used more than their share of the budget. Countries are likely to find it difficult to agree on how stringent the budget should be, some arguing less than the current 66% probability of meeting the target, while others who perceive themselves as more vulnerable to climate change, such as island states, are seeking upwards of 80%. Some experts argue that rather than consider budget allocation by country, we should consider it by company, as only a short list of global corporations is responsible for the majority of greenhouse gas pollution. This report will attempt at answering how the remaining carbon budget can be allocated across time and space, and how understanding human and natural capital play a critical role.

Stocks and Flows

To better contextualize the carbon budget and understand how various stocks of capital in the planetary system interact, let us define two capital stocks: human and natural capital. Natural capital is defined as the stock of resources and environmental conditions provided by the Earth system, used to

[5] "Visualizing the Global Carbon Budget."

meet the basic needs of all people.[6] These include plants, animals, air, water, soils, and minerals, all of which yield a flow of benefits to people. Human capital is defined as healthy, well educated, skilled, innovative, and creative people, and according to Matson, a key task of sustainable development is figuring out how to foster these characteristics. Natural capital is the foundational support of human and financial capital (see Figures 1 and 2). However, natural capital has long been considered "free," which causes the benefits that nature provides to be taken for granted and used at a rate that the Earth cannot replenish (read Hardin's *Tragedy of the Commons (1968)* for more on this).[7]

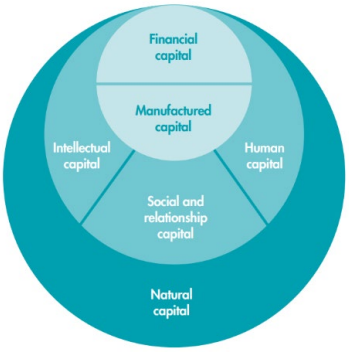


Figure 1: *Natural capital provides the environment in which the other capitals sit. This figure is an adaptation of the Forum for the Future's diagram of its Five Capitals Model at https://www.forumforthefuture.org/the-five-capitals/overview.*

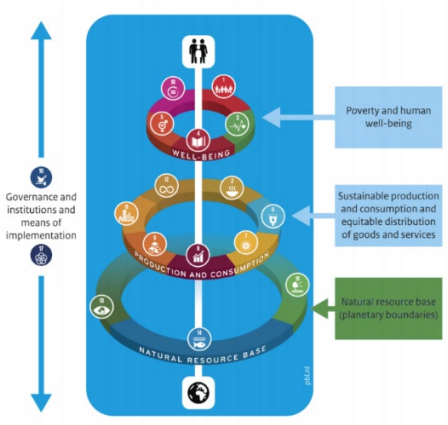


Figure 2: *This figure is adapted from "Towards a safe operating space for the Netherlands" (PBL, 2018). It goes back to the 'SDG wedding cake', developed by Pavan Suhkdev and Johan Rockstrom. It was adapted by PBL to strengthen the message that human wellbeing depends on sustainable production and consumption, which in turn depends on a natural resource base. Or, in terms of multi-capitals: Social and human capital depend on financial/physical capital that in turn depends on natural capital.*

[6] Matson, Clark, and Andersson, *Pursuing Sustainability; A Guide to the Science and Practice*.
[7] "Valuing and Accounting for Natural Capital."

Natural capital accounting helps policymakers understand the dependence of economic development on natural resources, both for supplying materials and services as well as for absorbing waste and pollution. Conservation International's Ecosystem Values and Accounting (EVA) system helps place a price tag on an ecosystem's goods.[8] EVA provides a framework to quantify a region's individual resources and how each resource flows, or works to provide services, within a community or country. For example, in the San Martin region of Peru, an EVA pilot project calculated the value of some environmental goods, including timber, firewood, water, and others, to the region's economy, conservatively, to be $58 million USD.

There also exists the System of Environmental Economic Accounting (SEEA), which is the agreed statistical framework for natural capital accounting. The SEEA uses the same accounting principles and structure of the System of National Accounts, which is the basis for gross domestic product (GDP) as well as other macro-economic indicators including produced assets. This enables countries to better understand how the environment underpins wealth and economic activity and to monitor environmental degradation and its costs.[9]

The World Bank published *The Changing Wealth of Nations* in 2018, which covers 141 countries over 20 years (from 1995 to 2014), to evaluate how we measure comprehensive wealth, a concept introduced as a complementary indicator to GDP.[10] The authors of the report hoped that it would be used by policy makers and others to improve measures of economic progress and lead to policies that improve lives for generations. According to the World Bank report, wealth grew 66% from $690 trillion to $1,143 trillion in constant 2014 U.S. dollars at market prices. Human capital was found to be the largest component of global wealth, accounting for two thirds of total wealth globally. While natural

[8] "Valuing and Accounting for Natural Capital."
[9] "Natural Capital Coalition | Natural Capital for Governments."
[10] "The Changing Wealth of Nations."

capital accounts for 9% of wealth globally, it makes up nearly half (47%) of the wealth in low-income countries, as seen in Table 1. More efficient, long-term management of natural resources is essential to sustainable development while these countries build their infrastructure and human capital.[11]

Table 1: *Wealth, by Type of Asset and Region, 2014*

Type of asset	Low-income countries (%)	Lower-middle-income countries (%)	Upper-middle-income countries (%)	High-income Non-OECD countries (%)	High-income OECD countries (%)	World (%)
Produced capital	14	25	25	22	28	27
Natural capital	47	27	17	30	3	9
Human capital	41	51	58	42	70	64
Net foreign assets	–2	–3	0	5	–1	0
Total wealth	100	100	100	100	100	100
Total wealth, US$ billion	$7,161	$70,718	$247,793	$76,179	$741,398	$1,143,249
Total wealth per capita	$13,629	$25,948	$112,798	$264,998	$708,389	$168,580

Source: World Bank calculations.
Note: Figures for wealth are in constant 2014 US dollars at market exchange rates.

A key takeaway from *The Changing Wealth of Nations* is that the value of natural capital assets doubled between 1995 and 2014. Most of that growth was in non-renewables (308%), largely because of changes in both the volume and prices of minerals and fossil fuels. The renewables – forests, protected areas, and agricultural land – did not decline in value overall but increased far more slowly than total wealth (44% compared to 66%). The top 20 countries with the fastest growing wealth per capita were dominated by developing countries, including two of the biggest, China and India, which were both classified by the World Bank as low-income countries in 1995 and are now ranked as middle-income.[12]

An endowment alone of natural resources may not ensure rapid development. Of the 24 countries that have remained low-income since 1995, 12 are classified as resource-rich; of those, 8 are also fragile-conflict states. The importance of strong institutions and sound policies for managing

[11] "The Changing Wealth of Nations."
[12] "The Changing Wealth of Nations."

resource revenues is essential to transform this capital into sustainable development. On the other hand, carbon-rich countries must mitigate the risks in the face of decarbonization and will require diversifying their total wealth portfolio away from carbon, including belowground natural capital (i.e. oil, gas, coal) and the associated aboveground physical and human wealth.[13]

Methods

The Natural Capital Coalition has laid out several policy objectives that can be achieved by good natural capital management and achieving returns in multiple areas, including societal, economic, and environmental. Societal returns are in the form of poverty alleviation, jobs and livelihoods, and public health and wellbeing. One example includes South Africa's "working for water" schemes that employs 50,000 people a year while restoring 1 million hectares of land.[14] Economic returns are in the form of business and industry, sustainable wealth, and innovation and investment. For example, €1 million spent on Agri-environment schemes in the UK has returned €25 million in natural capital benefits, and investing in key natural systems, such as peatland restoration, is estimated to generate 4:1 benefit to cost ratio over a 40-year period. Another example is a novel insurance policy to protect coral reefs developed in Mexico.[15] Environmental returns come in the form of enhancing ecological resilience, which is essential for our life (e.g. pollinating crops, providing medicines). Mangroves, salt marshes, peat bogs, tropical forests are examples of key ecosystems that ensure essential nature-based solutions for adapting to climate change.

The Natural Capital Coalition advises stakeholders, including governments, businesses, finance institutions, and communities, all of whom depend on natural capital, on how to act. However, each country is unique, as discussed above from the World Bank Report, and change requires a different

[13] "The Changing Wealth of Nations."
[14] "Natural Capital Coalition | Natural Capital for Governments."
[15] "Natural Capital Coalition | Natural Capital for Governments."

combination of actions in each context. The time is now for governments to act and mainstream natural capital approaches into policy areas, by taking decisive steps at the national, regional, and global level.

A framework has been designed to help generate credible and actionable information to help businesses better measure and value their impacts and dependencies on natural capital, enabling them to integrate nature into their operations.[16] This has come to be known as the Natural Capital Protocol, developed jointly by the World Business Council for Sustainable Development, Conservation International, and the International Union for Conservation of Nature, among others. The Protocol already counts the support of 50 major companies, including Coca-Cola, Dow, Hugo Boss, Kering, Nestle, Roche and Shell.[17]

The obvious question companies and governments ask is whether they can reduce carbon intensity of their operations, thereby benefit nature, and still grow from an economic standpoint. PwC's Low Carbon Index found that several G20 countries have reduced the carbon intensity of their economies while maintaining real GDP growth, including nations classified as "developing", such as China, India, South Africa, and Mexico.[18] The UN adopted the Sustainable Development Goals (SDGs) in 2015 as a set of common aims to balance human prosperity with protection of the planet by the year 2030. Similarly, the Paris Climate Agreement was signed by 197 countries and ratified by 187 as of November 2019.[19] Policy changes with a focus on justly pricing natural capital assets is fundamental to how the world will behave. According to Inger Andersen, Director General of the International Union for the Conservation of Nature, creating a more sustainable world is very much affordable. It would just take $300 billion per year – approximately 0.1% of global wealth – to invest in the planet and increase natural capital to the levels at which it is sustainable and stabilize the world without warming above the

[16] "Natural Capital Coalition | Natural Capital Protocol."
[17] "Natural Capital Coalition | Natural Capital Protocol."
[18] Argyriou, "Developing Countries Can Prosper without Increasing Emissions."
[19] "Paris Agreement | Summary & Facts."

two-degree limit set as part of the Paris Agreement.[20] A multifaceted and concerted effort is necessary to demonstrate the shortsightedness of investing in short term profits without considering the consequences to nature.

A recent McKinsey Report on natural capital discusses the accelerating depletion of natural capital due to climate change.[21] The report states that it is particularly hard to manage natural capital losses. The time between human actions that affect natural capital and the environmental and ecological responses to those actions can be long, having severe impacts on vulnerable communities. For instance, looking more closely at the Hindu Kush Himalayan region, they found that it faces significant physical and socioeconomic risk because of glacial melting. Glacial mass in this region could drop by about 10 to 25 percent by 2030, and by 20 to 40 percent by 2050 in some subregions, an area that already faces severe danger of catastrophic flooding.[22]

McKinsey Global Institute suggests in their paper that as climate change accelerates, losses of natural capital are expected to mount, reducing ecosystem services, and affecting local and national economies. They suggest that it will require measures to protect and restore entire ecosystems and, critically, in many instances a coordinated international response, for example in the case of ocean warming. See Figure 3 which shows several stocks of natural capital (including coral reefs, fish stocks, forests, freshwater, land ice, and permafrost) found in different places around the world that are under rising threat due to climate change.

[20] "Natural Capital -- A Movement To Show Nature Is Worth More Alive Than Dead."
[21] Woetzel et al., "Natural Capital: Climate Change May Mean Reduced Dividends | McKinsey."
[22] Woetzel et al.

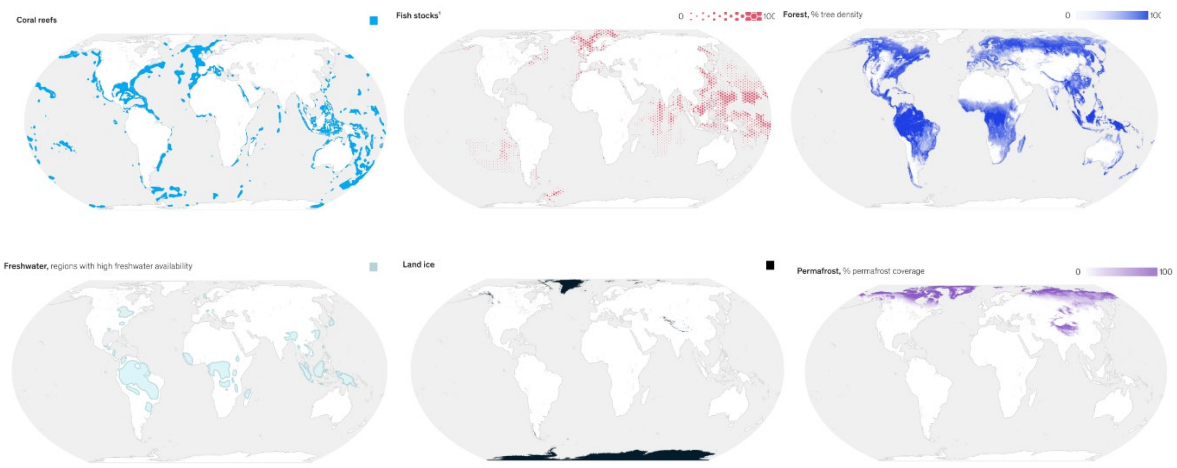


Figure 3: *Various forms of natural capital found throughout the globe.*

Studies

Professor Dieter Helm is chairman of the Natural Capital Committee in the UK, a board of experts who advise the government on the sustainable use of natural capital and is responsible for helping the government develop its 25-year environmental plan. The 2011 White Paper, *The Natural Choice: Securing the Value of Nature*, placed "natural capital at the centre of economic thinking and at the heart of the ways Britain measured economic progress nationally."[23] Helm starts by explaining how natural assets have broadly been in decline for the period since at least the Industrial Revolution. He continues by stating that GDP is growth not sustainable growth, which requires that the value of the services yielded by deploying the assets does not decrease through time. He suggests that countries need to create natural capital balance sheets, or asset registers, and that capital maintenance expenditures are required to maintain the value of assets intact, since renewable natural assets should not be depreciated, but rather treated as assets in perpetuity.[24]

[23] Helm, "Taking Natural Capital Seriously."
[24] Helm.

Countries are beginning to “write their natural capital asset registers” in the form of Nationally Determined Contributions (NDCs) under the United Nation’s Convention framework for Climate Change, which is a commitment to climate action beginning January 2021 through 2030. Some countries receive better Climate Action Tracking (CAT) scores than others based on their current projection of meeting the IPCC climate carbon emission goals, as well as their own self-set goals. For instance, Figure 4 shows which countries are either sufficiently or insufficiently meeting the 2- and 1.5-degree marks. Only a handful of countries are on track to meet the targets set out by the Paris Agreement.

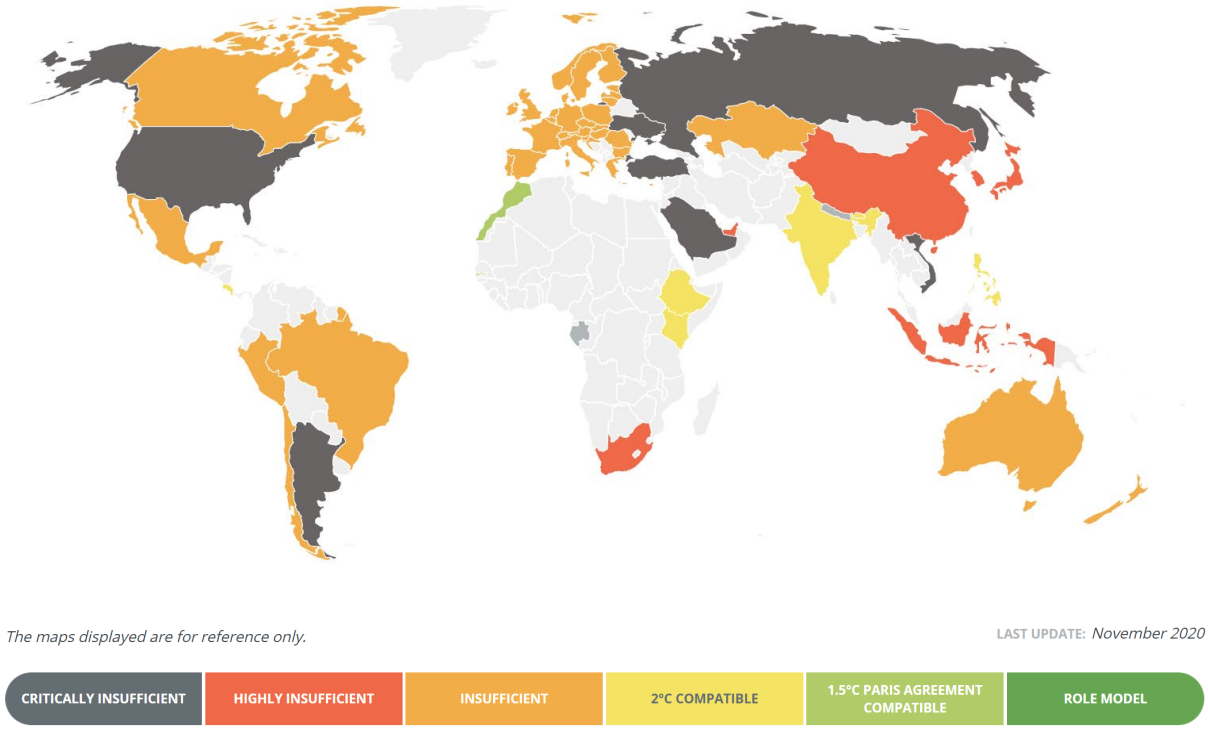


***Figure 4**: Source: Climate Action Tracker (CAT). Countries in light gray were not measured.*

Driven by a high level of ambition and policy support, India has emerged as a global leader in renewable energy. It is on track to achieve the more ambitious portion of its NDC, a 40% non-fossil power capacity target, more than a decade early, according to the CAT Warming Projections Global

Update.[25] As it starts to frame coherent policies in the transport sector and implement market-based mechanisms to control industrial pollution, there is reason to believe that India can significantly increase its NDC commitments to become a global climate leader. On the other side, CAT suggests that for China to be within the 1.5-degree target, China must peak CO_2 emissions as soon as possible, lower the carbon intensity of GDP by more than 75% below 2005 levels by 2030, and increase the share of non-fossil energy carriers of the total primary energy supply to more than 40% by around 2030.[26] A more recent CAT publication has highlighted some countries who have recently announced key interventions in green economic recovery. Regarding energy and electricity supply, China made increases in solar and wind energy targets to 240 GW each for 2020 and expanded its electric vehicle charging network by 50% in 2020, with an additional 600,000 charging stations to be installed the same year.[27] The United States was also acknowledged for the Department of Treasury extending its deadline for solar investment tax credit (TC) and wind production tax credit (PTC) until the end of 2021.[28]

Some smaller emitting countries, such as Morocco, The Gambia, and Costa Rica, are performing much better than the higher emitting countries. According to CAT, Morocco is one of only two countries with a plan to reduce its CO_2 emissions to a level consistent with limiting warming to 1.5-degrees. Morocco's National Energy Strategy calls for generating 42% of its electricity production from renewables by 2020, and 52% by 2030. Already it is at 35%, not least because of its investment in such projects as the Noor Ouarzazate complex (as seen on the cover page), the largest concentrated solar farm in the world, which covers an area the size of 3,500 football fields, it generates enough electricity to power two cities the size of Marrakesh.[29]

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[25] "Warming Projections Global Update - September 2019."
[26] Climate Action Tracker.
[27] "Warming Projections Global Update - September 2020."
[28] "Warming Projections Global Update - September 2020."
[29] "Climate Change Report Card."

The Gambia, a small West African nation that has played almost no role in contributing to climate change, is the other country with a 1.5-degree emissions reduction strategy. As with Morocco, one of its principal pathways to reduction is the use of renewables, in the form of a program that will increase the country's electricity capacity by one-fifth partly through construction of one of the largest photovoltaic plants in West Africa. The country has also launched a large project to restore 10,000 hectares of forests, mangroves, and savannas. As a result, is estimated that roughly 50,000 households will benefit from improved water quality and healthier landscapes.[30] It is also replacing flooded rice paddies with dry upland rice fields and promoting adoption of efficient cook stoves to reduce the overuse of forest resources.[31] Niklas Hoehne, a partner at the New Climate Institute, one of the organizations behind the Climate Action Tracker, says that in the case of The Gambia, "what is considered fair for them is to still increase their emissions a little bit, and that's what they are proposing."[32]

Costa Rica aims for electricity to be 100% renewable by 2021. In 2018, it generated 98% of its electricity from renewable sources (primarily hydropower) for the fourth consecutive year. Costa Rica is also developing its National Plan for Electric Transportation to help them transition its most polluting sector by implementing a switch to a fleet of electric buses. Furthermore, Costa Rica has doubled its forest cover since the 1970s and plans to increase further to 60% of the country's area under its climate plan. The country has also placed a moratorium on oil extraction until 2050.[33] The rest of the world will benefit from the leadership and actions of these governments. Hoehne added that with this new demand, "technology becomes cheaper, and other countries can follow suit."[34]

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[30] Rosen, "Here's How 6 Countries Are Stepping up to Meet the Paris Climate Goals."
[31] "Climate Change Report Card."
[32] Rosen.
[33] "Costa Rica's Intended Nationally Determined Contribution."
[34] Rosen.

A recent study by Zhang et al. (2020) set out to explore the decoupling relationship between the sustainability of land capital utilization and economic development. The area of interest they used in the study was the hinterland of the Three Gorges Reservoir area, a project which was completed and launched in 2009. According to Zhang et al., in recent years, China's "ecological civilization construction" has risen to the core national strategy, emphasizing the need to "establish the concept of natural value and natural capital" and "promote urban and rural natural capital to accelerate value addition", and both natural capital utilization status evaluation and sustainable development path exploration have become important issues in China.[35] The study prefaced that while many scholars have explored the measurement and accounting methods of natural capital, among which the most widely used and highest recognized is the ecological footprint method, no classification of natural capital in this traditional model exists and insufficient attention has been given to capital stock, leading to the questioning of the accuracy of natural capital evaluation.[36] Zhang et al. emphasizes that quantifying the decoupling effect of economic development and sustainable utilization of land natural capital is "helpful to understand the decoupling situation of economic development and natural capital sustainable in different districts and counties in the region, promote the rational allocation of regional ecological resources, and realize the value added of natural capital."

The ratio of capital stock to flows, UR_{flow}^{stocks}, is introduced to characterize the actual use of natural capital in the relationship between stocks and flows. The greater the value, the smaller the sustainability of natural capital utilization, and the formula is shown as Equation 1:

$$UR_{flow}^{stocks} = \frac{LF - LF_{size}}{LF_{size}} = LF_{depth} - 1(LF \leq LC) \quad \text{(Eq. 1)}$$

[35] Zhang et al., "Exploring the Dynamic, Forecast and Decoupling Effect of Land Natural Capital Utilization in the Hinterland of the Three Gorges Reservoir Area, China."
[36] Zhang et al.

Where LF is the Land Footprint (hm^2), LF_{size} is the ecological footprint size of the land use (used to characterize the scale of human utilization of natural capital flows), LF_{depth} is the ecological footprint depth of land use (used to characterize the intensity of human consumption of natural capital stock), and LC is the land capacity (hm^2).

Overall, Zhang et al. found that there was a decoupling relationship between UR_{flow}^{stocks} and GDP, showing that the pressure of economic development on the sustainable use of natural capital always exists.[37] UR_{flow}^{stocks} increased yearly from 2009 and 2014 and the sustainability weakened accordingly, indicating that decoupling was negative. However, the state of decoupling was different among districts and counties. In conclusion, the role of ecological civilization construction on the sustainability of natural capital was found to be insufficient, and related policies are encouraged to be further strengthened.

Another study by van den Berg et al. (2020) explored novel methods for allocating national carbon budgets using effort-sharing pathways. Effort-sharing approaches vary by type, as detailed in Table 2, and are usually discussed around equity principles. Many have been proposed to examine "fairness" in meeting the reduction goals in the Paris Agreement. Results show that effort-sharing approaches that (i) calculate required reduction targets in carbon budgets (relative to baseline budgets) and/or (ii) take into account historical emissions when determining carbon budgets can lead to (large) negative remaining carbon budget for developed countries.[38] Without going into too much detail on the methodology or calculations for each effort-sharing pathway, see Table 2 for a breakdown on the essentials for each pathway.

[37] Zhang et al.
[38] van den Berg et al., "Implications of Various Effort-Sharing Approaches for National Carbon Budgets and Emission Pathways."

Table 2: *Overview of effort-sharing approaches, underlying equity principles, basic tenets and calculation methodology of effort-sharing approaches based on a global emission pathway and carbon budget, based on own methods and existing literature. (van den berg et al., 2020).*

Approach	Equity Principle	Justification	Methodology for the allocation of emissions allowances, reduction targets or carbon budgets to countries or regions
1. Grandfathering (GF*)	Sovereignty	Falling under the category 'acquired rights', that is justified by established custom and usage.	**Emission pathway:** allocations of emission allowances remain in proportion to current (2010) emission shares. **Carbon budget:** allocations of carbon budgets based on current emission shares.
2. Immediate per capita convergence (IEPC*)	Equality	Based on the shared humanity and equal value of all humans, having equal claim to global collective goods (equal individual rights to atmospheric space); i.e. no (relevant) distinctive characteristic disctating some humans should get more/less access to an indivisible/collective good (Pan et al. 2014).	**Emission pathway:** allocations of emissions allowance are immidiately in proportion to population shares. **Carbon budget:** allocation of national carbon budgets based entirely on average (projected) population shares in the period (2010-2100).
3. Per capita convergence (PCC*)	Sovereignty/ equality	Combination of GF* and IEPC*	**Emission pathway:** per capita emission allowances across countries converge linearly over time from current levels towards equal per capita levels by a convergence date, then allowances are allocated based on equal per capita basis. **Carbon budget:** allocation of national carbon budgets based on both current emission shares and population shares (i.e. combination of GF* and IEPC*).
4. Equal cumulative per capita emissions (ECPC*)	Equality/ responsibility	A large amount of cumulative emission allowances per capita in industrialized countries has disproportiantely used global emission space (Pan et al. 2014).	**Carbon budget:** allocation of national carbon budgets based on cumulative emissions per capita in a certain period that is equal across countries. Incorporating historical cumulative emissions (responsibility) and based on the share of the population (equality). **Emission pathway:** not presented, as is usually calculated from a carbon budget.
5. Ability to pay (AP*)	Capability/need	Based on the ability to bear the burdens.	**Emission pathway and carbon budget**: Emission of carbon budget reduction targets from baseline are allocated based on annual GDP per capita (emission pathway) or average GDP per capita over the period 2010-2100 (budget approach), taking into account increasing marginal costs with steeper reductions.
6. Greenhouse development rights (GDR*)	Responsibility/ capability/need	Safeguarding perople's right to 'reach a disgnified level of sustainable human development' (Baer et al. 2008). GDR is based on 'Brazilian Proposal' (UNFCCC 1997; der Eizen et al. 2005).	**Carbon budget:** Considers both responsbility and capability. Emission reduction targets (or global budget) from baseline are allocated based on a Responsibility-Capacity Index (RCI) that includes GDP per capita and measures of the income distribution. As data for RCI is only available until 2030, the RCI is kept constant from 2030 onwards to determine the average RCI over the period 2010-2100. **Emission pathway:** annual RCI numbers are used, and from 2030, a linear convergence to AP* outcomes are assumed.
7. Cost-optimal (CO)	Cost-effectiveness	Allowance according to the least-cost option from marginal abatement cost (MAC) curves.	Allocations of emission allowances based on mitigation potentials. The emissions could be reduced in each country to the extent that the marginal costs of further reductions are the same across all countries. The allocation highly depends on the assumed marginal abatement cost (MAC) curves.

Since countries formulate their own national targets in the form of NDCs, this means that the evaluation of the NDC targets is needed to ensure that their combined effort leads to the overall objective of the Paris Agreement. This evaluation is referred to as the stocktaking process.[39] van den Berg et al. reasons that this question whether the contribution of individual countries (or regions) is in line with the overall goal is rather complex. In fact, discussions regarding the "fair" contribution of countries have been ongoing since the United Nations Framework Convention on Climate Change (UNFCCC) Article 3 in 1992, specifying that the climate system should be protected "in accordance with their common but differentiated responsibilities and respective capability".[40] An extensive literature has emerged using equity principles such as "responsibility", "capability", "equality", and "sovereignty" as the basis for several effort-sharing approaches, as seen in Table 2.[41]

Simultaneously, results of pathway-based effort-sharing calculations are also discussed by van den Berg et al., for instance both GHG emission targets and implied carbon budgets (cumulative CO_2 emissions of mitigation pathways). Both methods are based on the same global data to observe differences and similarities between the novel (carbon budgets) and more conventional (GHG emission pathways) methodologies. Figure 5 lays out the methodology of how fairness principles and allocation rules of various effort-sharing pathways translate into remaining carbon budgets.

[39] van den Berg et al.
[40] UNFCCC, "United Nations Framework Convention on Climate Change."
[41] van den Berg et al., "Implications of Various Effort-Sharing Approaches for National Carbon Budgets and Emission Pathways."

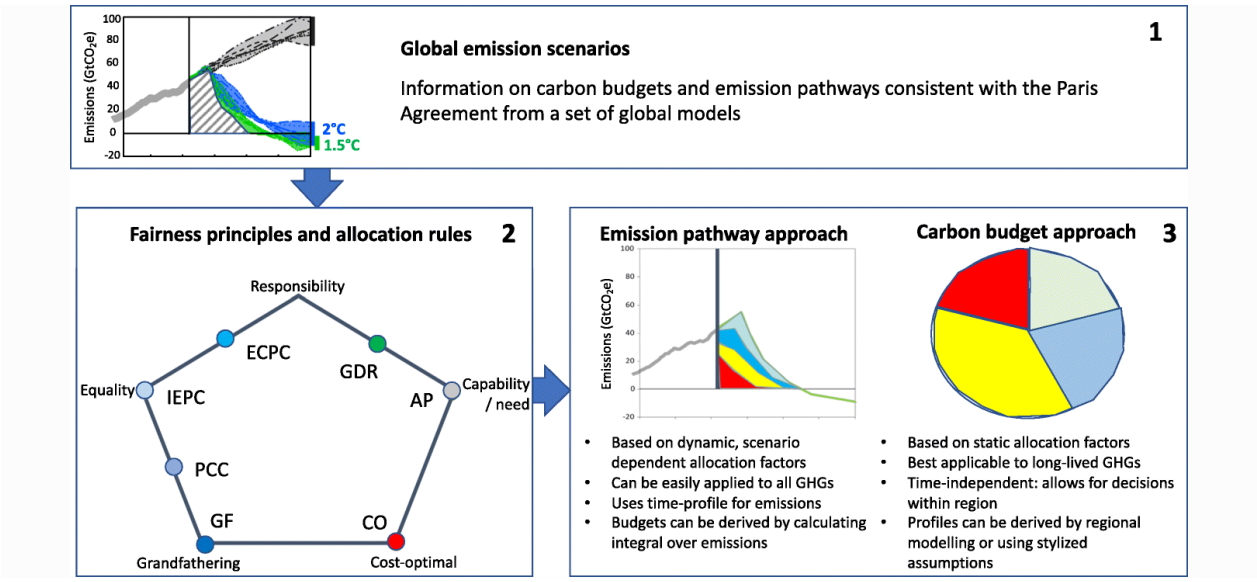

Figure 5: *Methodology including effort-sharing approaches categorized using equity principles. The colors in box 3 represent different regions. (van den Berg et al., 2020, adapted from Hohne et al. 2014).*

Figure 6 summarizes the results of the carbon budget approach in terms of national carbon budgets (2011-2100) relative to each country's 2010 CO_2 emissions for all effort-sharing approaches, compared to the cost of optimal national "budgets", such as cumulative emissions resulting from cost-optimal scenarios.

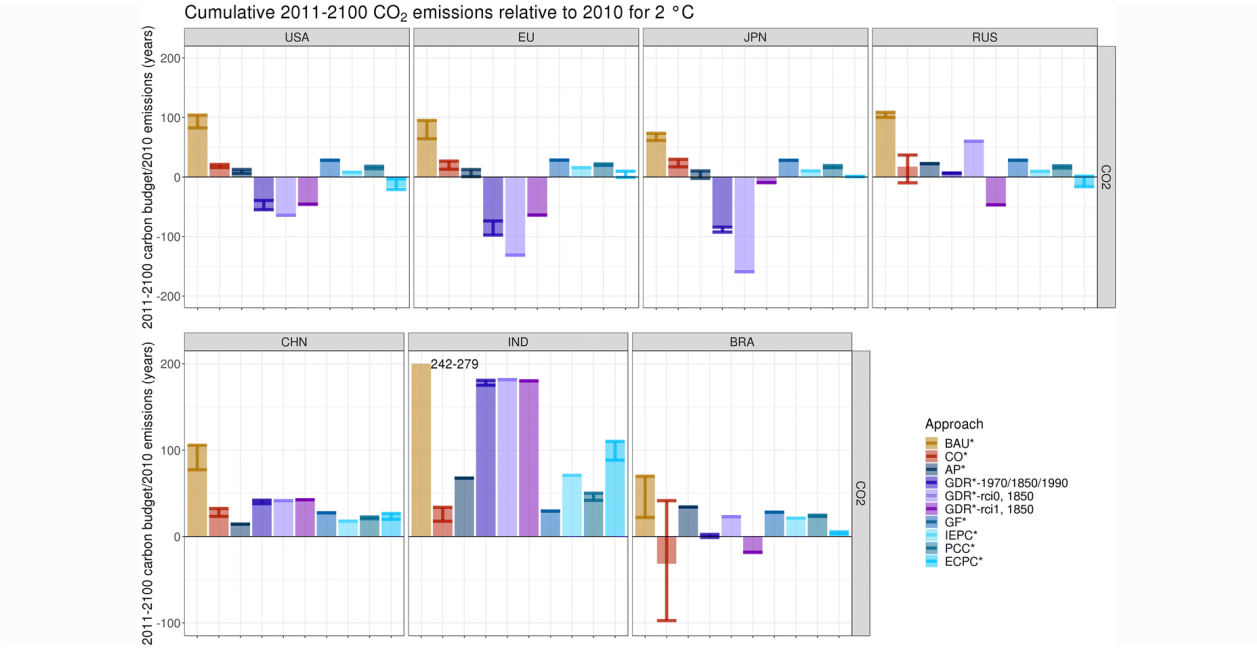

Figure 6: *Carbon budgets of different effort-sharing approaches by country. Carbon budgets are given in emission years (2011–2100 CO2 budget/2010 emissions) and are based on a 1075 GtCO2 global carbon budget for the period 2011–2100.*

Figure 7 illustrates the results for the emission pathways' approach in terms of GHG emission reduction targets in 2030 relative to 2010 GHG emissions. The most salient results are the extreme outcomes of the GDR* approach leading to large budgets or emission allowances allocated to developing countries relative to all other approaches. This is a result of a combination of relatively high historical emissions and high GDP per capita for the latter group of countries – resulting in high RCIs (Responsibility-Capacity Index). The approach even leads to negative budgets for these countries. This is a consequence of a combination of relatively low BAU ("Business as Usual" scenario) budgets, compared to history, and high RCI budgets.[42] Countries will not be using the results of this study as a certain guideline, but the results from these studies shed light on how effort-sharing pathways can be used in considering and deciding carbon policy moving forward.

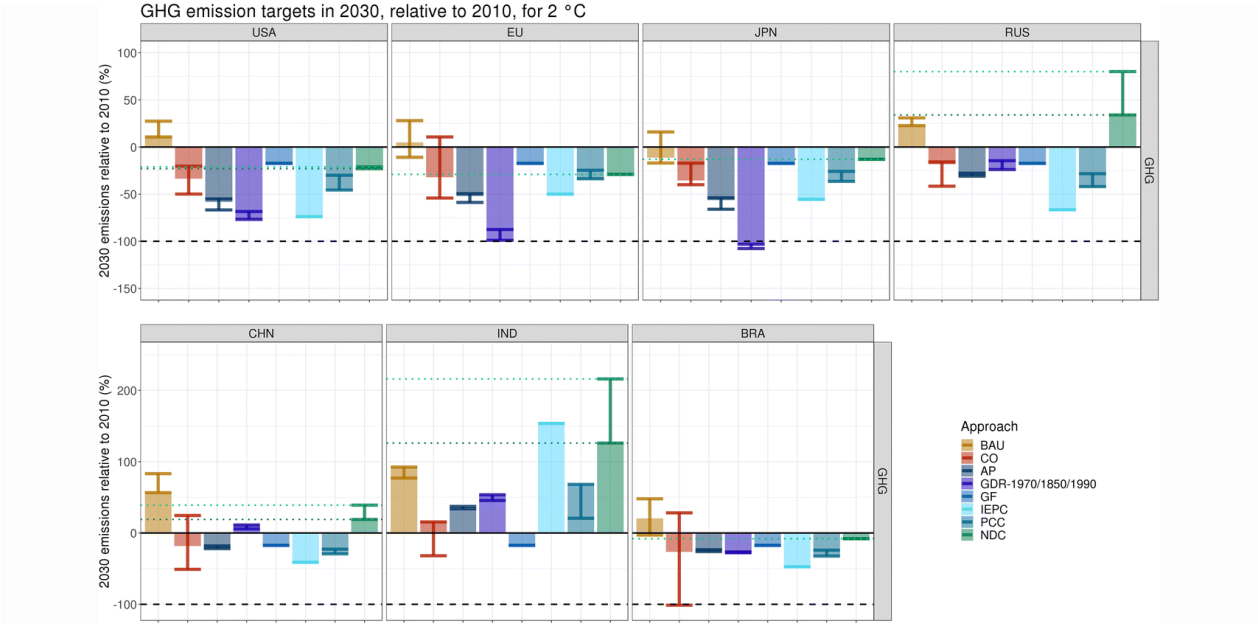

Figure 7: *GHG emission targets in 2030 relative to 2010 emissions.*

[42] van den Berg et al.

Conclusions

This report examined the World Bank's *Changing Wealth of Nations 2018: Building a Sustainable Future*, McKinsey's *Reduced Dividends on Natural Capital*, NDCs from multiple developing countries, as well as several studies that focus on the value of natural capital and natural capital accounting. All these sources help frame the challenges that we are facing globally with respect to managing economic growth and preserving our depleting natural capital. In addition, the solutions that we devise must fairly allocate and distribute the remainder of our carbon budget. Presently, the world is not meeting their set upon emission goals, and countries and individuals both need to create policies and demonstrate change that brings societal benefit and economic growth while protecting the value of our natural resources and planetary system in this time of recovery. If we have learned anything from the COVID-19 pandemic, it is that we are one people residing on one planet and we rely on each other's behaviors. Only when we set ambitious targets and fully cooperate with one another do we benefit from our individual efforts. We must have this same persistence in the fight to preserve our planet from climate change and establishing sustainable practices, which begins with understanding our local conditions and where we can enact regional change. We can only learn from each other and grow together in a collaborative, global effort to reduce emissions, if we are open to accepting responsibility and adapting to the present challenges.

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