A methodology to correlate short-term regional climate action and long-term global temperature goals

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We provide a methodology for assessing short-term mitigation targets for a region against long-term global goals of addressing climate change. We first estimate the per capita fair share of the remaining carbon budget for India from 2018 onwards. Potential long-term emissions trajectories between 2018 and 2100 compatible with this fair share are then constructed. These budget-compatible trajectories are then compared to the Nationally Determined Contribution (NDC) as well as results from five modelling studies for India. The methodology discussed here can be used to assess the adequacy of NDCs and also helps in rationalizing the process of target setting for climate action.

Keywords: Carbon budget, climate change, emissions trajectories, fair share, global temperature.

AS part of its Nationally Determined Contributions (NDCs) under the Paris Agreement, India has set three quantitative targets for the year 2030. It has committed to reducing its emissions intensity by 33%–35% of 2005 levels, increasing the share of non-fossil fuel-based energy sources in its cumulative electric power installed capacity to 40% ‘with the help of transfer of technology and low-cost international finance including from green climate fund (GCF)’, and to create an additional carbon sink of 2.5–3 billion tonnes of CO_2 equivalent through more forest and tree cover[1]. These targets are likely to be revised as the Prime Minister of India, at the 26th Conference of Parties in Glasgow in 2021 (COP-26), has declared enhanced mitigation contributions from the country by 2030. However, at the time of writing this article, these political declarations at the World Leaders’ Summit during COP-26 have yet to be communicated in written form either in a policy document from the Government of India (GoI) or as enhanced NDCs to the United Nations Framework Convention on Climate Change (UNFCCC). We will restrict the analysis in this article therefore to the original NDCs submitted by India to UNFCCC in 2015. The NDCs, since they were announced, have been the subject of much debate in the country and internationally.

India’s NDCs have been pronounced to be good, low ambition, or just right by various reports. The Emissions Gap Report for 2018 published by the United Nations Environmental Program (UNEP), declares that India’s emissions with its current policies, will be 10% below what it has committed to reduce, making its actual achievements better than its NDCs[2]. Mohan and Wehnert[3] explicitly argue that while India is well on track to meet its targets, this may be because targets themselves are fairly modest. Various other individual and synthesized assessments of India’s and other countries’ NDCs can be found in the literature[4–7]. However, one should remember that most NDCs, including India’s, encompass a time horizon going up to 2030 only. On the other hand, global mitigation targets, be they temperature or emissions, are arrived at by running climate models for much longer time periods and typically cover a much broader time horizon, at least up to 2100.

While earth system models and general circulation models have much longer timelines, even among the 19 integrated assessment models considered by the Intergovernmental Panel on Climate Change (IPCC) for the special report on 1.5°C global warming (SR1.5), nine have a time horizon extending to 2100, five extending beyond 2100, and only five have a time horizon of up to 2050 or 2060. On the other hand, regional models typically built for specific nations or economically integrated regions use more detailed socio-economic variables and assumptions and therefore, restrict their time horizons to smaller time periods. Examples for India include the five models commissioned by the Ministry of Environment and Forests in 2010, GoI (ref. 8). The NDCs that nations then declare often are or can be based on assessments of these models built for shorter time horizons. An assessment of whether such targets are compatible with long-term climate goals requires some extrapolation.

In this study, we use the carbon budgets approach to arrive at an estimate of a fair share of the global carbon budget for each country/region. Our analysis includes both the 1.5°C and 2°C temperature targets. We do not claim that a particular estimate of fair share arrived at in this

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study is sacrosanct, as there can be many variables that may be used to determine this fair share, and that is a matter of either negotiations or the prerogative of each country. However, we provide an argument for why this method gives a scientific basis for arriving at the fair share of global mitigation burdens. Using this method, we arrive at an estimate of a fair share of the remaining carbon budget for India. We then construct multiple potential long-term emissions trajectories based on a set of assumptions, and each trajectory cumulates to the estimate of the fair share of the carbon budget. We then compare these trajectories for India to the currently declared NDCs, going up to the year 2030. In the second part of the analysis, we consider multiple model scenarios that have been constructed for India and categorize them into two based on the degree of decarbonization and dependence on as yet unproven technologies assumed in the scenarios. The methodology for categorizing the scenarios is discussed in the subsequent sections. We then compare the emissions trajectories resulting from these select model scenarios for India with the long-term trajectories from the carbon budget analysis.

Scientific and equitable long-term emissions trajectories

Since the Fifth Assessment Report (AR5) of IPCC, it has been established in the scientific literature that cumulative carbon emissions are the best metric to determine maximum and average global temperature rise. The literature clearly establishes that cumulative CO_2 emissions are roughly proportional to the increase in global average temperatures since the Industrial Revolution[9–18]. The Glossary of IPCC's Sixth Assessment Report (AR6) defines the total and remaining carbon budgets as follows: 'the maximum amount of cumulative net global anthropogenic CO_2 emissions that would result in limiting global warming to a given level with a given probability, taking into account the effect of other anthropogenic climate forcers. This is referred to as the Total Carbon Budget when expressed starting from the pre-industrial period, and as the Remaining Carbon Budget when expressed from a recent specified date.' The concept of a carbon budget, to ensure that temperature rise is restricted to below 1.5°C or 2°C, has now become an important tool in informing policy regarding climate action at the global level, at least if not regional[19,20].

There are many differing estimates of the remaining carbon budget[21]. Rogelj *et al.*[22] provide a method to track the remaining carbon budget, while understanding the source and reason for the differences in the carbon budget numbers reported so far. Since the present study will not discuss the relative merits or demerits of different estimates of the carbon budget, we will simply use the numbers from the latest IPCC report, i.e. the Report of WG-I to the AR6 (ref. 23), for analysis. For historical emissions, we use the PRIMAP-HIST v 2.3.1 database[24], which provides data for region and country-wise historical emissions for all greenhouse gases (GHGs) from 1850 onwards (excluding emissions from Land Use, Land-use Change and Forestry (LULUCF)). In AR5 as well as in most of the literature cited above, both the historical and remaining budgets are reported together as the total carbon budget. The additional uncertainties in estimating the relationship between cumulative emissions and temperature rise, due to permafrost melting, non-CO_2, GHG forcers and other factors, play a role in both the past and future estimates of carbon budgets. The most recent estimates for the remaining carbon budget are available in the latest IPCC report, which also reveals the historical CO_2 emissions in the same table and section. In this study, our estimate of past emissions includes all GHGs. The remaining carbon budget estimates are available only for CO_2. However, these are a result of a range of scenarios which are also controlled for the behaviour of non-CO_2 drivers of global warming. According to IPCC, therefore, the remaining carbon budget must be interpreted as the available CO_2 after considering the effect of non-CO_2 drivers. Table 1 shows the estimates for the past emissions and the remaining carbon budget for a 50% probability of restricting temperature rise to below 1.5°C or 2°C.

Approximately 83% of the budget available to the world to restrict temperature rise to below 1.5°C and approximately 65% of the budget available to the world to restrict temperature rise to below 2°C have already been exhausted between 1850 and 2019. Between 1850 and 1990, 70% of the total global cumulative GHG emissions were from the developed countries, of which 76% was from USA and EU (27) + the UK alone. China accounted for 7% of the global emissions in this time period, India for 4% and the least developed countries group (LDCs) accounted for only 3% of the total global cumulative emissions between 1850 and 1990. The larger economies of the Global South started industrializing later and therefore their emissions grew at a much faster pace after 1990, China accounting for a significant share of the emissions from the developing world in this period.

It is in this context that the arguments for equity have been made by developing countries from the beginning of the negotiations itself, urging developed countries to take the lead and increase their mitigation ambitions. This understanding was also what led to the significant phrasing of Article 3.1 of UNFCCC, i.e. that 'Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities'[25].

The next question is regarding the manner in which the remaining carbon space will be used by the different nations and regions of the world. There are various methods that have been proposed for evaluating the same, some

Table 1. Cumulative emissions between 1850 and 2019 and the remaining carbon budget for a 50% probability of restricting temperature rise to below 1.5°C or 2°C

$GtCO_2e$ (all greenhouse gases)	Cumulative emissions between 1850 and 1990*	Cumulative emissions between 1991 and 2019*	Remaining carbon budget (50% probability) – 2020 onwards#	
			1.5°C	2°C
Global ($GtCO_2$)	1361	1155	500	1350

Data source: *Emissions between 1850 and 2019: PRIMAP-HIST Database v2.3.1 (ref. 24). #Remaining carbon budget: IPCC[23].

Table 2. Remaining global carbon budget and simple per capita fair share of the remaining carbon budget for India, for limiting global temperature rise to below 1.5°C or 2°C (all figures in $GtCO_2$)

	1.5°C		2°C	
Probability (%)	Remaining global carbon budget	India's fair share	Remaining global carbon budget	India's fair share
33	650	116	1700	304
50	500	89	1350	241
67	400	71	1150	206

Data source: Remaining global carbon budget numbers from IPCC[23].

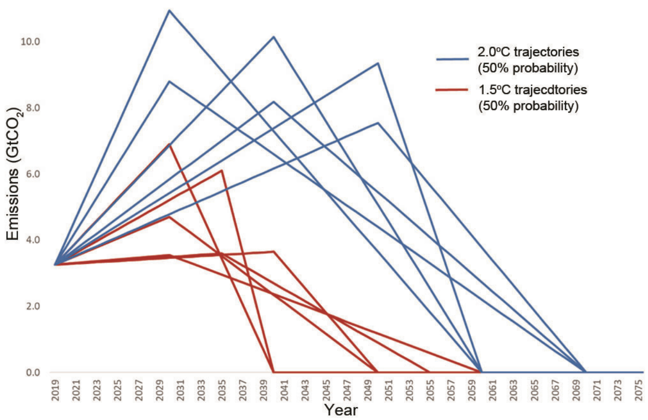

Figure 1. Potential trajectories for India for simple per capita fair shares of the remaining carbon budgets available to restrict temperature rise to below 1.5°C or 2°C with 50% probability.

focusing more explicitly on equity-based burden sharing[26–33]. The discussion in this study will not delve into the implications and relative merits of these approaches. The objective is to merge the implications of results from global models to regional climate action to arrive at some metrics of feasibility of certain temperature and emissions goals, as well as provide an assessment of the ambition and adequacy of the proposed country-level targets.

If we assume that the remaining carbon budget has to be shared equitably, either on a per capita basis or with some weighting for other parameters that account for the capability to mitigate climate change such as incomes or GDP or other human development indicators, then a particular share of the remaining carbon budget accrues to each country. For the purpose of this study, we take India's fair share to be the simple per capita share of the remaining carbon budget. While this does not account for other factors, such as India's responsibility and its capability in mitigating climate change, it also does not account for the country's historically unused carbon space. We simply use this number here, which is a basic minimum and easily accessible estimate, to demonstrate the analysis that is discussed in the next section. Table 2 shows the remaining global carbon budget for a 33%, 50% and 67% probability of limiting temperature rise to below 1.5°C and 2°C. It also shows a simple per capita fair share of the remaining carbon budget for India.

India's emissions between 1850 and 2019 are about 112 $GtCO_2$. The remaining carbon budget available to the world to restrict temperature rise to below 1.5°C, even with a 50% chance, is 500 $GtCO_2$. If India does not claim any historical redressal of its underused carbon budget in the past, a simple fair share of the future accords it 89 $GtCO_2$ beyond 2019, which is less than what the country has used in the past. The constraints on India's share of the budget loosen slightly for the 2°C targets.

Now for each 'fair share' value of the budget for India, there are multiple potential trajectories. As long as each trajectory cumulatively implies the fair share of the total budget, one can construct an infinite number of such trajectories. To demonstrate this, we have built six illustrative emissions trajectories, all corresponding to a particular value of the carbon budget. The other variables that define the trajectories are the timing and level of peak emissions. Neither of these is sacrosanct. As mentioned earlier, an infinite number of different trajectories is possible that all cumulate to the same area under the curve (i.e. correspond to the same value of the carbon budget). Figure 1 shows a few illustrative emissions trajectories for India that fit its minimum fair share of the remaining carbon

Table 3. Required versus declared year to reach net-zero emissions for select countries

Country	Fair share of the remaining carbon budget for a 50% probability of limiting temperature rise to 1.5°C	Year to reach net-zero to remain within the fair share of the remaining carbon budget – immediate reduction with linear trajectory to net zero	Declared year of net zero (either in NDC or Domestic Policy Document or at COP-26)
USA	21	2025	2050
EU (28) (with the UK)	32	2034	2050
Australia	2	2025	2050
Canada	2	2026	2050
Japan	8	2033	2050
Other Annex-I countries	21	2033	~2045–2060
Annex-I as a group	87	2030	~2050
China	91	2033	2060
India	89	2074	2070

Data source: Remaining global carbon budget numbers from IPCC[23]. Population data from World Population Prospects[35].

budget for restricting temperature rise to below 1.5°C and 2°C.

As mentioned earlier, India gets 241 $GtCO_2$ as a potential fair share of the remaining global carbon budget for a 50% probability of limiting temperature rise to 2°C and 89 $GtCO_2$ as a fair share of the remaining global carbon budget for a 50% probability of limiting temperature rise to 1.5°C.

All the emissions profiles corresponding to the remaining carbon budget available for the 1.5°C target require India to start reducing emissions immediately and steeply, and reach net-zero emissions soon. The trajectories, while not tied to any assumptions of economic activity or energy use, nevertheless represent to a certain extent the amount of flexibility that would be available to India to either front or back load its mitigation action. While the 2°C trajectories provide some scope for such policy interventions, it is clear that none of the 1.5°C trajectories allows the same. It must be remembered, however, that the remaining carbon budget for the 1.5°C target is limited. The world is already experiencing a temperature rise of 1.1°C due to historical emissions. An operational understanding of the principles of common but differentiated responsibilities and respective capabilities (CBDR&RC) enshrined in the UNFCCC would mean that developed countries responsible for the bulk of the historical emissions should have in fact reached net-zero emissions much before 2020, so as to allow some carbon space for economic growth to developing countries. However, even if we do not consider past emissions, current pledges for net zero by 2050 from most developed countries fall short of their fair shares of just the remaining carbon budget. For example, for a remaining carbon budget of 500 $GtCO_2$, the fair share of the US is 21 $GtCO_2$. If we assume an immediate reduction in emissions from 2020 onwards in the US emissions, to stay within this fair share, USA would have to reach net-zero emissions by 2025. However, NDCs of the USA commit to only a 50% reduction in emissions, from 2005 levels, by 2030, and they plan to reach net zero emissions by 2050. It is evident, therefore, that the US pledges fall short of what is required for the 1.5°C target. The situation is similar for other developed countries as well. Table 3 shows an assessment of the required year for net-zero emissions for some countries so that they are within their fair shares of the remaining carbon budget for 1.5°C, assuming immediate reduction in emissions starting in 2020 reaching net zero through a linear emissions trajectory.

All Annex-I parties, i.e. developed countries are required to reach net-zero emissions between 2025 and 2034, even if we ignore historical emissions. While Table 3 shows the required year for net zero for India to be 2074, this is assuming linear emissions reductions starting immediately. India's emissions, however, are not going to start reducing immediately, and so this year will be advanced depending on the rate of the country's emissions growth, timing and level of peak emissions, and the rate of reduction in emissions post the peak. It is in this context that the compatibility of India's pledges with both the 1.5°C and 2°C targets must be viewed.

Short-term emissions profiles for India

The actual trajectories and the possibilities they represent will, however, depend upon the extent and nature of economic activity in India, and projecting this till the end of the century is a difficult, if not an unrealistic exercise. What we discuss in this section therefore is, in the first instance, India's NDCs, which currently allows emissions projections up to 2030, and how they compare to the 1.5°C and 2°C budget trajectories. We then discuss a range of model scenarios from models that have undertaken analysis for India and projected energy, emissions and economic indicators for the future, typically for a time horizon of 2030, 2040 or at the most 2050.

NDCs versus long-term budget-compatible trajectories for India

India has submitted a three-part NDC under the Paris Agreement. Of these, the target of reduction in the emissions intensity of GDP by 33–35% from 2005 levels provides a direct measure to estimate emissions trajectories up to 2030. India's emissions intensity of GDP in 2005 was about 1.02 kgCO_2/US$ (in constant 2010 US$ terms). A 35% reduction in this would imply that the emissions intensity in 2030 would be 0.67 kgCO_2/US$ in 2030. If this is achieved linearly, then for different rates of GDP growth one can arrive at a range of different emissions trajectories for India up to 2030. Figure 2 shows some illustrative trajectories for budget-compatible, long-term trajectories, as well as India's potential short-term trajectories till 2030 for three values of GDP growth, 5%, 6% and 7% between 2019 and 2030.

The NDC trajectories indicate the path that India's emissions would take till 2030. Figure 3 shows the potential emissions pathways for India if these NDC trajectories are projected beyond 2030 to stay within the budget. Figure 3 *a* shows trajectories for the 1.5°C compatible budget and Figure 3 *b* shows the trajectories for the 2°C compatible budget.

Even if India can access a simple per capita fair share of the remaining carbon budget for a 50% probability of limiting temperature rise to below 1.5°C, the post-2030 trajectories required to stay within this budget seem unachievable. To stay within the budget without depending extensively on as yet speculative CO_2 removal (CDR) technologies, India would have to start absolute reductions in emissions by 2030 and reach net-zero emissions by 2045 at least. The emissions trajectories for the 2°C compatible budgets provide a little more flexibility and breathing room for peak and reduction, and may also be achievable. However, to make the claim of feasibility, the content of these trajectories has to be evaluated. Hence, these trajectories are compared against emissions estimates made by modelling studies for India for the short and medium term.

Results of five modelling studies for India versus NDC and budget-compatible emissions trajectories

Various global and regional models have been used to estimate India's energy requirements and emissions in the future. It is not possible to study all of them. Here, we discuss some of the models built for India shortlisted based on timelines, the extent of involvement of Government agencies and the approaches used (macro-economic top-down models and bottom-up energy models). Other comparison studies have also used the same set of models[34]. Table 4 provides an overview of the models.

As discussed in Table 4, multiple scenarios have been built using each model. However, not all scenarios are equally valid or feasible. Each model typically has a baseline scenario and other scenarios that are then constructed to compare the trade-offs, costs, etc. These scenarios have assumptions about economic development, availability and costs of energy technologies, efficiency improvement, sector-wise transitions, among other aspects. Each model also has baseline projections and scenarios constructed for sustainable development. Figure 4 shows a comparison between the 2°C budget-compatible trajectories for India (with an assumption of India meeting its NDCs by 2030 at a 6% GDP growth till 2030), and the baseline trajectories from each of the five modelling studies chosen for this analysis.

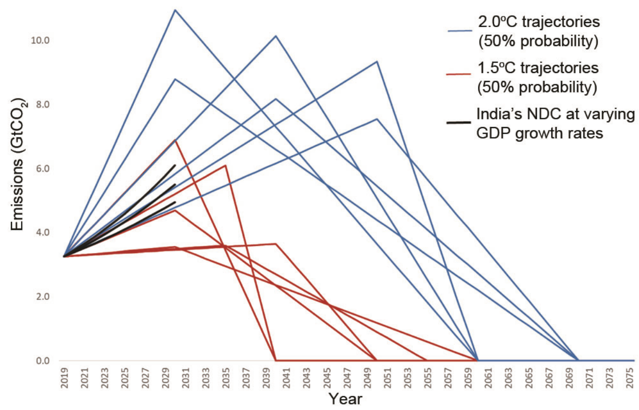

Figure 2. India's NDCs versus 1.5°C and 2°C budget-compatible fair share trajectories.

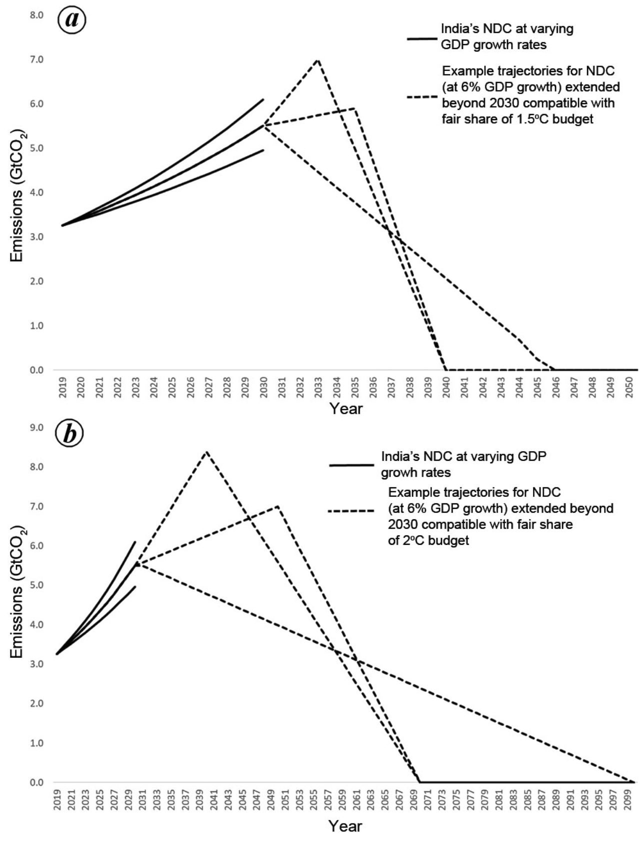

Figure 3. Long-term trajectories for India compatible with fair shares of (***a***) 1.5°C and (***b***) 2°C budgets.

Table 4. Overview of five modelling studies for India's energy requirements and emissions

Model no.	Model	Model description	Time horizon
1	DDPP(a)[36]	It is a soft-linked system of global CGE and ANSWER-MARKAL. The project deals with two scenarios – 'conventional' and 'sustainable', where various CO_2 mitigation strategies are considered. The conventional scenario is a 'forward-looking neoclassical economic paradigm', whereas the sustainable scenario is developed from the National Sustainability Goals for 2050.	2015–50
2	TERI–WWF(b)[37]	This report assesses the possibility of having near 100% renewable energy for India by 2051 using two scenarios – reference energy and renewable energy. This is a bottom-up integrated analysis model using MARKAL.	2010–51
3	LCIG(c)[38]	The model used in this report is a combination of bottom-up and top-down approaches. The scenarios are baseline inclusive growth (BIG) and low-carbon inclusive growth (LCIG). Both scenarios have strategies that enable inclusive growth, but differ significantly in terms of fuel mix and efficiency strategies.	2007–30
4	IESS(d)[39]	This is an energy pathway building tool for India with a group of pre-set scenarios. One can design scenarios by selecting the energy supply, efficiency criteria and demand choosing one out of the four levels available for each category. The results for fuel mix for energy cost, energy flows, land requirement, electricity structure, etc. can then be obtained. Four scenarios from the model are considered in this study: heroic effort, aggressive effort, maximum energy security, maximum clean and renewable energy pathway.	2012–47
5	IEO(e)[40]	This report analyses India's energy choices for the future considering existing policies. Two scenarios are considered in this model – new policy scenario (NPS) and the Indian vision case (IVC).	2013–40

(a) Deep decarbonization Pathways Project (DDPP) published in 2015.
(b) The energy report – India, 100% renewable by 2050 published in 2011 by World Wildlife Fund (WWF) International in collaboration with The Energy and Resources Institute (TERI), New Delhi.
(c) Report on LCIG published by the erstwhile Planning Commission of India in 2014.
(d) India's energy security scenarios 2047, an initiative of NITI Aayog, Government of India.
(e) India Energy Outlook published in 2015 by the International Energy Agency, Paris, France.

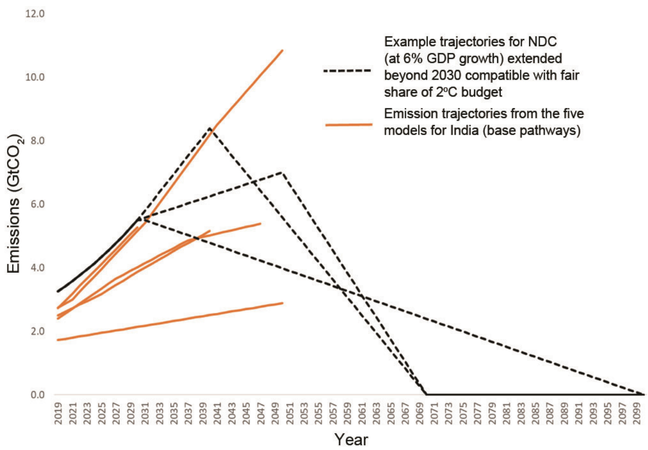

Figure 4. Comparison of baseline emissions trajectories from modelling studies and 2°C budget-compatible trajectories post-2030 NDC-compliant emissions trajectories for India.

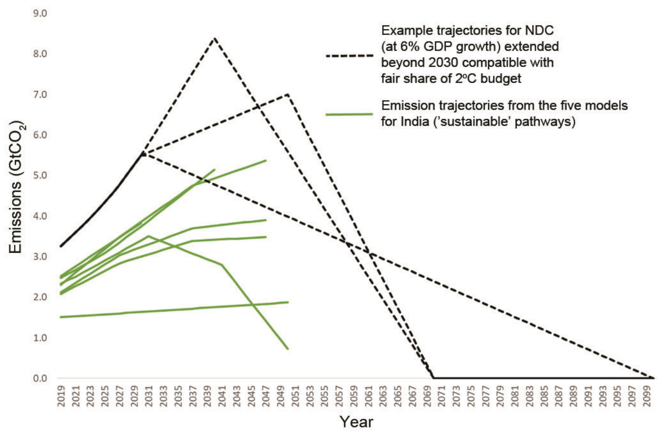

Figure 5. Comparison of 'sustainable development' trajectories from modelling studies and 2°C budget-compatible trajectories post-2030 NDC-compliant emissions trajectories for India.

India's actual emissions, given its NDC targets, as well as most of the baseline scenarios in the models built for the country seem to be within the range of 2°C trajectories. Given the stringent requirements of the 1.5°C target, however, remaining within the fair share of the budget available for the target becomes extremely difficult. If we compare the other scenarios from these models with the same potential long-term trajectories, a slightly different picture emerges (Figure 5).

The 'sustainability' scenarios are all below the 2°C compatible trajectories, indicating that it may be possible for India's emissions to be within the long-term budget constraints, as assumed here. However, not all the model scenarios are realistic. Often assumptions made in the

Table 5. Assumptions for parameters used in model scenarios, associated scores and their justification

Parameter	Explanation for scores: Score 5–S5	Explanation for scores: Scores 1–S1	Range	Remarks
Solar	Scenarios with assumptions matching (not exceeding or not too low) compared to the total solar potential estimated for India were marked 5. Also, these estimates were reasonably compatible with growth in solar capacity in the country in the past decade[41,42].	Solar potentials that were 40% more or less than the total potentials considered under score 5 were given a score of 1.	1 to 5	S4 – 10% ± potential in S5 S3 – 20% ± potential in S5 S2 – 30% ± potential in S5
Concentrated solar	Model scenarios without concentrated solar power capacity were marked 5 – there is disagreement on total concentrated solar potential, and it is an expensive technology with less existing installed capacity. Plans for future plants are also speculative[41–46].	Model scenarios with assumptions for concentrated solar power installations were given a score of 1.	Either 1 or 5	
Onshore wind	Rates of growth for wind energy systems between 2013 and 2018 were used to pro rata validate the total wind growth considered in the study. Matching assumptions were scored 5. Estimates of wind potential were also considered for feasibility assessment. Estimates that do not assume very high land availability or hub heights were given higher scores[2,47,48].	Wind energy estimates that were 40% more or less than the total potentials considered under score 5 were given a score of 1.	1 to 5	S4 – 10% ± potential in S5 S3 – 20% ± potential in S5 S2 – 30% ± potential in S5
Offshore wind	As there is no existing installed capacity, studies with no offshore wind have been marked 5. Then the growth rate implied by meeting the targets set by the Government of India was considered to make projections for target years used in the model scenarios, and figures adhering to these were also marked 5 (refs 41, 47–49).	Estimates for offshore wind energy installations that were 40% more or less than the estimates of S5, and scenarios in which the installed capacities were not clearly stated were marked 1.	1 to 5	S4 – 10% ± potential in S5 S3 – 20% ± potential in S5 S2 – 30% ± potential in S5
Carbon capture and storage (CCS)	As CCS is not an established technology in India, model scenarios without CCS were marked 5. Also, scenarios with CCS estimates in the same range as the projections of Draft National Energy Policy (NEP) were given a score of 5 (ref. 50).	Scenarios with CCS estimates 40% more than the estimates for score 5 were marked 1.	1 to 5	S4 – 10% ± potential in S5 S3 – 20% ± potential in S5 S2 – 30% ± potential in S5

Table 6. Model scenarios ranked and shortlisted based on their scores for assumptions made on parameters

	Parameter	Score
'S-I' (tested assumptions)	TERI-WWF reference	4.5
	LCIG_BIG	4
	LCIG_LCIG	4.4
	IESS MaxClean	4
	IEO NewPolicy	4
	IEO IndiaVision	4
'S-II' (untested assumptions)	DDPP conventional	1.5
	DDPP sustainable	2.3
	TERI-WWF renewable	3.5
	IESS heroic	1.4
	IESS aggressive	1.3
	IESS energy secure	3.5

scenarios include high dependence on as yet unproven technology, or they focus on aggressive integration of existing and nascent renewable energy (RE) – which is a challenge for a developing country like India. In this study, we have evaluated all the scenarios for the models discussed in Table 4 to categorize them into scenarios with tested assumptions (S-I) and scenarios with untested assumptions (S-II), based on whether they include the use of carbon capture and storage (CCS) technologies, and the scale of RE integration assumed for them. The RE parameter mainly includes solar, concentrated solar, onshore wind and offshore wind. Table 5 shows the parameters and explains the criteria for scoring the scenarios.

Table 6 shows the summary of scores for all scenarios. Score for REs is an average of individual scores across different REs for each scenario.

Higher scores for the parameter indicate that the assumptions made are more realizable compared to ones scored lower. While this method would result in discarding the very ambitious estimates, it also discards the conservative estimates by giving the latter low scores as well. Figure 6 shows model scenarios from the S-I category.

The model scenarios with realizable projections for RE deployment in the short-term considering existing policies and estimates of future potential, can be reconciled with long-term trajectories for India if it gets a fair share of the remaining carbon budget for limiting temperature rise to below 2°C. To avoid dependence on as yet unproven carbon dioxide removal (CDR) technologies, India would still have to restrict its emissions and start reducing its absolute emissions by around 2050, or so. Figure 7 shows the model trajectories plotted against the 1.5°C budget compatible trajectories.

It is clear that model results having reasonable projections for RE deployment in the short term do not fit the 1.5°C target budget for India. It is only the extremely 'ambitious' pathways which use untested assumptions, unprecedented growth rates for the deployment of certain as yet unproven technologies, that may be compatible.

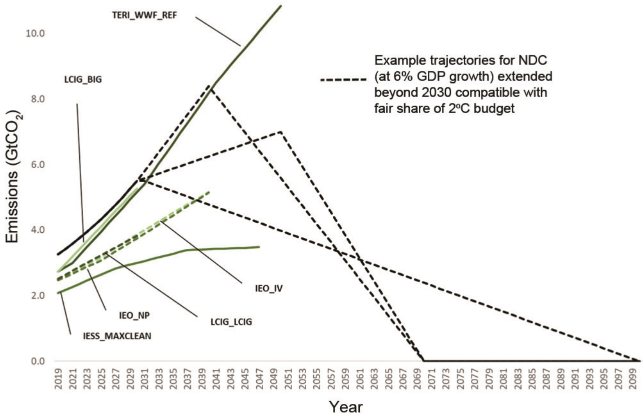

Figure 6. The 2°C budget-compatible emissions trajectories versus 'S-I' model trajectories for India.

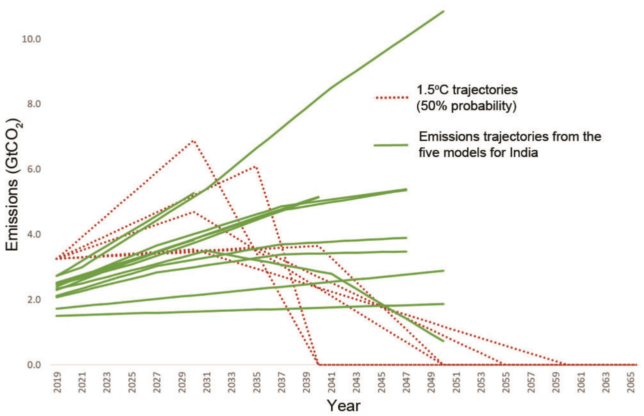

Figure 7. The 1.5°C budget-compatible trajectories versus model trajectories for India.

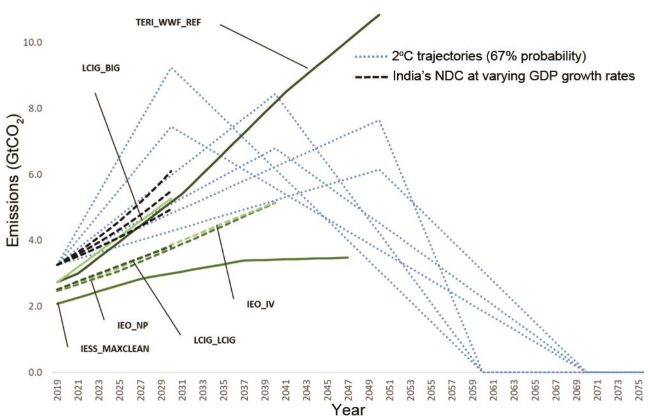

Figure 8. 'S-I' model projections versus emissions trajectories compatible with a 206 $GtCO_2$ budget for a 67% probability of limiting warming to below 2°C.

Different estimates of carbon budgets and their associated trajectories

It should be remembered that the estimate of fair share of the carbon budget for India or for any country will change if either the global budget estimates are different, and/or if other parameters than only the population are used to assess the fair share of a region. For example, for a 67% probability of restricting temperature rise to below 2°C, the remaining global budget itself would reduce by about 15%. India's share of this remaining carbon budget would then be 206 $GtCO_2$ changing the corresponding emissions trajectories. Figure 8 shows a set of potential trajectories with the 'S-I' model scenarios and the NDC trajectories.

Most selected model pathways are compatible even with this reduced budget of 206 $GtCO_2$ for India; just one of the selected pathways is not compatible with this budget.

Conclusion

In this study, we have established a methodology to reconcile long-term climate goals with short-term emissions trajectories. While carbon budget as a concept has been established as the best metric to estimate global temperature rise in the scientific literature, its use as a policy tool has been limited by contestations regarding the way in which the budget can be distributed amongst countries and regions. While these contestations can occupy the realm of negotiations, in the academic literature all approaches must be studied with equal rigour. In this study, the fair share of the remaining carbon budget for India based on a simple per capita share of only the remaining global carbon budget for a 50% probability of limiting temperature rise to below 2°C and 1.5°C is estimated to be 241 and 89 $GtCO_2$ respectively. On converting these shares for India to illustrative long-term emissions trajectories and comparing them to India's NDCs, we observe that the NDCs are compatible with 2°C trajectories. This analysis holds even when the long-term emissions trajectories are compared with model scenarios constructed for India. The remaining budget and consequently the fair share for India is small for the 1.5°C target. Most of the trajectories with the more ambitious assumptions for RE, CCS, and energy efficiency achievements are not compatible with the 1.5°C budgets, and this is true for the NDCs as well. This is because the remaining global carbon budget for the 1.5°C target is itself small. The results show that the infeasibility of limiting temperature rise to below 1.5°C is in fact a result of the historical over-occupation of the atmospheric commons by developed countries. We also show that what is remaining of the global carbon budget will also be occupied by developed countries in the future as their recent net-zero declarations are not compatible with their fair share of the carbon budget for 1.5°C.

A similar analysis can be done for a range of different estimates for the global carbon budget, depending on the probability of limiting temperature rise to below a certain level and also different measures of equity or differentiation in allocating fair shares of the budgets.

We submit that the methodology presented here provides a robust way of assessing the short-term targets and possibilities for a region against long-term global goals of addressing climate change. The progress on achievement of NDCs under the Paris Agreement must be monitored for all countries and the Global Stock Take, which is to be conducted every five years as per Article 14 of the Paris Agreement, must assess the adequacy and ambition of NDCs in the light of equity and best available science. The method proposed here uses the results of science in a direct and simple manner. It demonstrates the use of results of climate science for making and/or checking policy assumptions and assessing the adequacy and ambition of NDCs against considerations of equity and national circumstances. At a regional level, this methodology can also help in rationalizing the process of target setting for climate action.

Conflict of interest: The authors declare that they have no conflict of interest.

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