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PERSPECTIVE

Net zero targets in science and policy

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Abstract

Since the adoption of the 2015 Paris Agreement and the publication of the 2018 Special Report on Global Warming of 1.5°C of the Intergovernmental Panel on Climate Change, net zero targets have become a central feature in climate policy. This Perspective looks back at the scientific foundations of this recent policy development, the current state of play, and next frontiers for research on this topic.

1. Introduction and context

November 2021, delegates of over 190 countries met at the 26th Conference of the Parties (COP26) of the United Nations Framework Convention on Climate Change (UNFCCC) in Glasgow, UK. It was the latest annual global meeting of international climate policy, and also a key milestone in the implementation process of the UNFCCC's Paris Agreement [1]. Countries were expected to bring updated pledges—known as Nationally Determined Contributions (NDCs)—to the conference. These NDCs communicate countries' near-term emissions reduction goals, most often for the year 2030 [2]. In addition, countries were also invited to submit long-term low greenhouse gas (GHG) emissions development strategies. These long-term strategies typically have a mid-century or longer time horizon and must be seen in the context of Article 4.1 of the Paris Agreement. That Article indicates that 'in order to achieve the long-term temperature goal [of the Paris Agreement], Parties aim to reach global peaking of GHG emissions as soon as possible […] and to undertake rapid reductions thereafter […] so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of GHGs in the second half of this century […]' [1].

During the period leading up to COP26, the high expectations and the increasingly louder societal calls for urgent climate action resulted in a deluge of targets that aim to reduce carbon dioxide (CO_2) or GHG emissions to net zero [3–5]. These targets typically focus on reaching net zero emissions by 2050 or at some point during the 21st century, and can be seen as countries' attempts to translate the global emissions reduction aim of Article 4 of the Paris Agreement to the national level. Besides targets set by countries also a wide range of non-state actors came forward with new targets [5]. Most notably as part of the UNFCCC-backed 'Race to Zero', thousands of businesses, investors, cities, regions, and other organisations committed to reaching net zero CO_2 emissions by 2050 [6].

Net zero targets are now a central feature of the climate policy landscape. This Perspective piece looks back at the scientific foundations of this recent policy development, the current state of play, and some of the next frontiers for research on this topic.

2. From physical science foundations to policy targets

The scientific puzzle pieces that underpin net zero targets date back decades. They include the clear understanding that atmospheric CO_2 concentrations are increased for centuries to millennia by anthropogenic CO_2 emissions [7–10] and that projected global temperature remains approximately constant if CO_2 emissions are set abruptly to zero in climate or Earth system models [8, 11–13]. It was, however, only in the late 2000s that a series of papers clearly communicated the consequences of these insights: if global warming is proportional to the cumulative amount of CO_2 emissions ever emitted, keeping warming from further increasing requires anthropogenic CO_2 emission to be kept to within a so-called 'carbon budget'

[14–17]. These and other studies were subsequently assessed in the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) (see [18] for a full literature overview). Their combined insights led to the high-confidence IPCC conclusion that cumulative emissions of CO_2 are the dominant factor determining global warming. Halting global warming therefore implies a cap on the total net amount of cumulative CO_2 emissions ever released by human activities [19]. Capping cumulative emissions is of course only possible if global CO_2 emissions eventually decrease to net zero.

Once the physics of net zero targets was clearly established, a next step was to operationalize the concept for use in climate policy. The IPCC AR5 Synthesis Report did not provide much quantitative information, only highlighting that pathways that limit warming to 2 °C relative to pre-industrial levels with a greater than 66% probability achieve near zero emissions of CO_2 and other long-lived GHGs by the end of the 21st century. The 2014 and 2015 Emissions Gap Reports by the United Nations Environment Programme (UNEP) provided more detail with explicit estimates of net zero target years consistent with pathways that would keep warming to 1.5 °C or 2 °C [20, 21]. These UNEP Gap Reports play a prominent role in informing the UNFCCC negotiations on aspects of mitigation challenges and opportunities.

With the prominence of net zero targets rapidly expanding in the UNFCCC negotiation cycles, the first peer-reviewed quantification of net zero targets followed in 2015 in *Environmental Research Letters* [22]. Besides global net zero target quantifications, the latter study also highlighted the importance of conceptual clarity about the nature of net zero targets. Depending on how targets are defined they can cover economy-wide CO_2 emissions or individual sectors only, or cover all GHGs (that is, CO_2 together with CH_4, N_2O and fluorinated gases) [22]. The latest IPCC assessment report now clearly describes the implications of these differences [23]: achieving net zero CO_2 emissions results in a stabilization of CO_2-induced global warming. However, achieving net zero GHG emissions (where aggregated emissions of all GHGs are net zero after having been converted to CO_2 equivalence by multiplying them with a metric called the 100 year Global Warming Potential) is projected to result in a peak and decline in global warming [23]. For net zero targets that cover all GHGs, the choice of metric can strongly determine the climate outcome or alternatively the implied mitigation requirements [24]. Indeed, using other metrics to determine net zero can result in a different and potentially less ambitious climate outcome [24].

Several other reports and processes were instrumental in bringing the net zero concept from science to policy. Firstly, a key avenue through which the net zero target concept entered the international policy discussions in preparation of the Paris Agreement was the UNFCCC 2013–2015 Review. This process carried out a multi-year dialogue between experts and delegates (referred to as the Structured Expert Dialogue) which took into account the combined body of scientific evidence available at the time [25], including the IPCC AR5 and UNEP Emissions Gap reports. The report of this process mentions the importance reaching net zero and indicative net zero target dates [25]. Secondly, the 2018 IPCC Special Report on Global Warming of 1.5 °C (SR1.5) highlighted that pathways in line with limiting warming to about 1.5 °C had to reach net zero CO_2 emissions by mid-century [26]. More detailed information, including on net zero dates for all GHGs was available in the SR1.5's underlying chapter on mitigation pathways [27]. In addition, since 2015, also the literature on national pathways towards net zero has vastly expanded (see [28] for an example). Together with the progressive strengthening of the focus on 1.5 °C [29], net zero targets have now become central to international and national climate action [30].

3. State of play

Since the adoption of the Paris Agreement, the number of net zero targets has increased drastically. From no net zero targets before 2015, some tracking organisations now estimate that around 83% of global GHG emissions, 91% of global gross domestic product and 80% of the global population is currently covered by a net zero target of some sort [5]. UNEP, who uses a more strict definition of what constitutes a target, estimates that only approximately 79% of global GHG emissions are covered by net zero targets [30]. If successfully implemented, these net zero targets lower projected global warming over the 21st century by about half a degree Celsius, setting median projections of global surface temperature increase relative to preindustrial levels to just below 2 °C [4, 31, 32]. That is still far removed from limiting global warming 'well-below 2°C' or to 1.5 °C as required under the Paris Agreement [33] and re-emphasized in the Glasgow Climate Pact [29]. A key aspect that undermines scientific confidence in how effective net zero targets will be in limiting warming is that near-term policies or NDCs in many cases are not yet tracing a believable path from emissions in 2030 towards the achievement of ambitious net zero targets [30, 34].

Net zero targets also vary markedly in their quality [3]. The strongest targets at the country level are set in national law. Others are presented in policy documents such as NDCs or long-term strategies. The weakest net zero targets are those that are only supported by a political pledge but have no accompanying policies yet that are required for their implementation. Of the 88 countries with net zero targets identified by UNEP by the end of 2022, 21 are set in law, 47 are in an NDC, long-term strategy or other policy document, and the remaining 20 have been

simply announced by a high-level government official [30]. In light of the varying quality of net zero targets, scientific scholars have proposed guidelines on how to improve them [35–37]. For example, these proposals include a ten point checklist to ensure that targets that are transparent, rigorous, fair and credible [35], or a description of seven key attributes of credible net zero targets [37].

Besides countries, many non-state actors such as businesses or cities have also come forward with net zero targets, very often as part of the UNFCCC-back 'Race to Zero' [6]. However, these targets often come with a whole set of additional challenges related to their scope, their monitoring and verification, the use of offsets and quality thereof, and their compliance (for example, see [38] for a critique).

4. Next frontiers for net zero

Although the scientific foundations for net zero targets have been solidly established and their take-up in policy has been remarkable over the past few years, important avenues for further research and policy development remain.

First, despite the popularity of net zero targets and the many target announcements, in many cases it remains unclear what 'net zero' is supposed to mean for a given actor or categories of actors. For example, not all countries or sectors have the same opportunities to reduce their emissions and reach net zero emissions [35, 37, 39]. New research should reflect what these differences in turn mean for the distribution of net zero targets. While a broad literature on the topic of international equity and fairness of climate action between countries exists (for example, see [40].) no framework is available to understand how these considerations translate to net zero targets. It has been suggested that for countries that can achieve more, net zero should not be the end point of their climate change mitigation efforts [35].

In addition, the gap in knowledge in how net zero is defined and how to set 'fair' net zero targets is particularly pertinent for businesses, companies and other non-state actors. Which activities are counted towards a non-state actor's emissions, and which role do they play in a global net zero transformation? Are some business activities simply undesirable, for example, because they imply a broader societal system transformation with important sustainability trade-offs? Thousands of net zero targets have been announced by non-state actors in absence of an elaborated literature on these aspects. Think tanks have started to reflect on these issues (e.g. see [41]), but fundamental questions remain unanswered.

Second, on the policy front, a strict and robust compliance framework for tracking progress towards net zero is currently lacking. Particularly, reliable frameworks that can be applied to non-state actors, companies, and businesses are urgently needed to prevent greenwash of net zero targets. A recent report by United Nations' Expert Group on the Net Zero Commitments of Non-State Entities [42] provides ten recommendations to improve the integrity of net-zero commitments. These include not only technical matters but also the alignment of lobbying activities and broader sustainability agendas. Broad principles and recommendations now still require operationalisation.

Third, most broadly, given the real-world uncertainty in emissions and removals of CO_2 emissions [43] keeping global emissions at net zero or at a lower constant net negative level will involve continued adjustments to incentives and policies. Current scenario and policy literature focusses on systems where emissions reductions and mitigation are pursued consistently and with ever-increasing stringency. The policy architectures and system configurations that work for such a unidirectional transformation might well be less applicable in a world beyond net zero. It are still early days, but a literature starting to anticipate and explore these challenges could provide timely and valuable insights in the years to come.

To conclude, net zero targets are important milestones on the global path towards managing the current climate crisis. They are founded in well-established science but overcoming their implementation challenges now becomes key.

Data availability statement

No new data were created or analysed in this study.

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