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PERSPECTIVE

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A pathway design framework for national low greenhouse gas emission development strategies

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The Paris Agreement introduces long-term strategies as an instrument to inform progressively more ambitious emission reduction objectives, while holding development goals paramount in the context of national circumstances. In the lead up to the twenty-first Conference of the Parties, the Deep Decarbonization Pathways Project developed mid-century low-emission pathways for 16 countries, based on an innovative pathway design framework. In this Perspective, we describe this framework and show how it can support the development of sectorally and technologically detailed, policy-relevant and country-driven strategies consistent with the Paris Agreement climate goal. We also discuss how this framework can be used to engage stakeholder input and buy-in; design implementation policy packages; reveal necessary technological, financial and institutional enabling conditions; and support global stocktaking and increasing of ambition.

The climate goal of the Paris Agreement is "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C" (Article 2.1). This requires net-zero greenhouse gas (GHG) emissions in the second half of the century (Article 4.1), as a necessary condition to stay within the remaining cumulative emissions budget of approximately 420–1,200 gigatonnes (Gt) of equivalent CO_2 in the twenty-first century[1,2]. No region, nor sector, is exempt from this requirement; any excess emissions must be compensated with negative emissions.

The Paris Agreement requires Parties to submit Nationally Determined Contributions (NDCs), representing voluntary commitments formulated by each country with a 10–15 year horizon in light of the above collective objective (Articles 3 and 4.2). These NDCs are to be designed within the context of other development goals defined by national circumstances (Paris Agreement preamble), including the Sustainable Development Goals (SDGs) relating to energy access and security, air quality, poverty alleviation, and employment creation[3,4]. Given the widely acknowledged lack of collective ambition in the first round of NDCs, the Paris Agreement requires Parties to submit a revised, more ambitious NDC every five years (Articles 4.3 and 4.9). It also mandates global stocktaking exercises every five years to assess progress against the collective objective (Article 14).

To inform these processes, country parties are invited to "formulate and communicate long-term low GHG emission development strategies" (Article 4.19), filed with the United Nations Framework Convention on Climate Change. We argue here that these long-term strategies can be a central enabling instrument for reconciling the long-term and global nature of the climate objective with the medium term horizon and national scale of the NDCs, and thus inform policy. Strategies based on pathways reverse-forecasted from

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the long-term goal to the present, or 'backcasted', would ensure consistency of national near-term planning, investment and policy decisions with long-term social, economic and environmental goals in the context of inertia, lock-in risks and mitigation innovation[5,6]. These strategies can also reveal the key international enabling conditions required for nations to adopt ambitious mitigation, such as technology development and transfer, finance for investment and adaptation, and institutional support.

For a long-term strategy to play these roles, it must be sufficiently understood and accepted by a working majority of stakeholders, both those responsible for implementation and those affected by the transformation (for example, governments, indigenous peoples' organizations, sector associations, firms, energy utilities, unions, experts, households and non-governmental organizations). To enable this, a process is required to educate these stakeholders, gather their essential inputs, and create a structured space for dialogue among them to design and rigorously debate such pathways. This requires that the strategies be formulated in a qualitative or semi-quantitative language understandable to all stakeholders. But it also requires that they be expressed in comparable quantitative scenarios, characterized by economy-wide, internally consistent sets of parameters describing the evolution of emissions drivers at the sectoral level, as well as key socioeconomic and development indicators.

The first section identifies four key methodological principles to develop and combine qualitative narrative strategies with quantitative scenarios that can feed into national and global pathway development processes. We then describe how these methods were developed and used in the Deep Decarbonization Pathways Project (DDPP). The third section, 'A Paris-compatible pathway design framework', synthesizes the approach by articulating them in a consistent pathways design framework, before we conclude with implications, recommendations and further research needs.

Methodological challenges to inform the post-Paris process

There is already a rich literature on global low emission scenarios using Integrated Assessment Models (IAMs)[7], which formed the backbone of analysis in the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5)[1] and Special Report on Global Warming of 1.5°C (ref. [2]). This 'data spine' helped demonstrate that a global low emission pathway is possible, while clarifying that the global temperature goal of "well below 2°C, towards 1.5°C" requires reducing global emissions to net-zero and likely net-negative by 2050–2075[1,2]. Recent studies on ambitious climate goals from this literature have analysed socio-economic aspects, such as economic growth and fossil fuel availability[8], the distributional consequences among major economies[9], and the interplay with the SDGs[10]. Some studies have also assessed the effect of current NDCs on achieving the Paris Agreement climate objective[11], and the conditions for reaching 1.5°C climate stabilization[2]. Country-level scenarios consistent with ambitious mitigation objectives have even been investigated through multi-model comparisons, for example, for Asian[12] and Latin American countries[13].

This global IAM approach has limitations, however, that need to be addressed to support the national policy processes envisaged in the Paris Agreement[14–16]. On the practical side, IAMs are resource-intensive models that require specialized teams to build and run, beyond the capacity of many countries and of most national actors that would like to contribute to policy debate and planning. In addition, the IAM storylines are arranged in 'Shared Socioeconomic Pathways'[8], which do not distinguish technological and policy deviations due to individual country circumstances. Finally, the mathematical representation of complex climate–economy systems in IAMs requires simplifications that limit their ability to represent specific national circumstances, objectives and policy approaches[17]. IAMs conventionally adopt aggregate sectoral and regional representations, as well as simplified economic and behavioural assumptions, that can miss country-specific mitigation options and limitations[18]. These modelling choices lead to a superficially simple focus on price-oriented mitigation policies based on cost-benefit approaches[19], restricting consideration of a wider range of policy instruments[20,21] and objectives. In particular, many IAMs face structural challenges, including to represent context-specific aspects of non-climate co-benefits or costs[22].

There is also a 'bottom-up' literature[23], designed around national circumstances and policy, which conducts country-scale investigation of development and ambitious climate objectives for a wide range of countries across Asia[24–28], Latin America[29–34], Africa[35,36], Europe[37–43] and North America[44–49]. Several studies describe multi-country exercises in which country teams co-explored their domestic pathways[50–52]. To date, however, these studies have lacked the overarching global context inherent in the IAM approach because the boundary conditions of national studies are not systematically defined according to a consistent cross-country vision of the global transformation (for example, carbon budgets, technological assumptions on learning and transfer, fossil fuel prices and their supply and international demand assumptions)[53].

We propose that a new approach is needed to support the Paris Agreement, one that combines key elements of the global IAM and national bottom-up modelling literatures to provide a structured global context for policy-relevant analyses of national low GHG emission development strategies. Its purpose would be to: allow formation of national strategies consistent with country circumstances, place-specific development objectives and national political priorities; reflect a coherent cross-country global context; and be compatible with the collective ambition towards the temperature goal[11].

This hybrid approach requires addressing four key methodological challenges.

First, the design of low emission strategies is faced with many global and country-specific uncertainties, making a multi-scenario approach exploring different plausible futures necessary. To support the design of robust national strategies and policies, the different futures must be defined from the key uncertainties affecting the trajectory of the specific country under consideration.

Second, to be useful for policymaking, quantitative national scenarios should not only describe emissions trajectories but also provide transparent sectoral detail of the broader social, economic and technological changes within which they are founded. Modelling is useful for this purpose, but no single model is able to encompass all the sectoral and socio-economic indicators required to characterize development trajectories. A flexible, inclusive approach to modelling is needed.

Third, comparability across different countries is also important to facilitate knowledge sharing and enable a global composite to emerge from national visions. This requires a systematic, quantitative structure that identifies key sectoral and development metrics and is built to accommodate scenarios from different sources. We refer to this reporting structure as a 'dashboard'.

Fourth, pathway analysis should help identify the options to reach mid-century development objectives and emissions neutrality starting from the present. The design of these pathways starts from the definition of realistic future benchmark values, for example for 2050, for the key indicators listed in the dashboard. A backcasting approach is then needed to identify the systemic changes required to move these indicators from their present values to ranges in line with these benchmarks.

In the following section, we provide insights on how to concretely address these challenges through an approach that is bottom-up, country-driven, policy-relevant and consistent with a global mitigation goal. We derive these insights by documenting methodological lessons from the DDPP[54–56], wherein sectorally detailed mitigation scenarios were designed to reflect national development and political circumstances according to the four principles outlined above. The project, coordinated by the Institute for Sustainable Development and International Relations (IDDRI) and the Sustainable Development Solutions Network (SDSN), was composed of country research teams from 16 developed and emerging economies representing 74% of 2010 global energy-related CO_2 emissions. The DDPP studies subsequently influenced the climate policy debate in several of these countries[57,58].

This Perspective does not focus on the details of the DDPP results, as published in 2015–2016, for two reasons. First, because the DDPP was conducted before COP21, the climate objective was chosen as a 50% probability of maintaining 2°C, therefore less ambitious than the 'well below 2°C, towards 1.5°C' framing introduced in the Paris Agreement. Second, while some DDPP teams included agriculture and land-use emissions, the aggregate project results focused on energy-related combustion and process emissions, hence failing to capture all GHG sources. Here, we will discuss the methodological lessons that were learned from the DDPP and that would be useful for implementation of the Paris Agreement. In the concluding section, we discuss how a DDPP-type exercise could be re-done with the Paris Agreement framing, that is, considering more ambitious climate objectives and non-energy emissions.

Guidelines for national low-emission development pathways

We describe key features of the DDPP method, designed to address the challenges presented above. They constitute the four building blocks of the DDPP pathways design framework, synthesized in the next section, 'A Paris-compatible pathway design framework'.

Country-driven strategies in a context of deep uncertainty. In the DDPP, given the focus on energy-related emissions, the strategies were structured around three key drivers: (1) energy efficiency and conservation, including structural and behavioural changes; (2) decarbonization of energy carriers (electricity, heat, liquids and gases); and (3) end-use switching to these low-carbon carriers. How these three 'pillars of decarbonization' were applied, however, depended on national circumstances, including a country's development priorities, institutions, economic structure, political situation, endowment in renewable energy and other key resources, and many other factors.

A multi-decade evolution of technologies, socio-economic conditions and politics[17,59], such as that associated with a transition to a net-zero energy system[60], is characterized by 'deep uncertainty'[61]. In this context, standard methods for risk and decision analysis[62], based on probability distributions surrounding a 'best-guess' of the future, may not be appropriate. Instead, the identification of different strategies in response to various plausible futures supports an adaptive decision-making process[63] that allows policymakers to learn and adjust to evolving information, technology and events[64,65]. This approach allows the definition of robust strategies that perform well under a range of future conditions[66].

Each country team in the DDPP, therefore, developed a small number of internally consistent narrative strategies, developed and expressed in the language of stakeholders. All strategies implement the three pillars of decarbonization, but each variant reflects sensitivity to key uncertainties, as freely chosen by the country teams according to their national circumstances. Some teams focussed on international conditions, for example varying oil prices driving oil production volumes during the transition in the Canadian DDPP study[67]. Others focussed on socio-economic drivers, for example different skill profiles of the labour force determining the plausibility of alternative low GHG economic structures in the South African DDPP study[68]. The Italian study addressed the social acceptability of carbon capture and storage[69]. The Indian team focussed on the policy implications of climate-centric versus sustainable development approaches to GHG emissions[70] . The French team explored different strategies under varying effectiveness of energy efficiency programs, notably in the building sector[71].

Modelling development pathways. National models play a key role in translating the above narrative strategies into quantified scenarios, consistently assessing key socio-economic and technological indicators. The socio-economic metrics non-exclusively include unemployment rates, skill profiles and population by income class (South Africa[68]), the import-dependency index (Japan[72], India[70] and Germany[73]), local air pollutant levels (China[74] and India[70]) and the energy-poverty index (UK[75]). Country-relevant identification of these indicators and their assessment in a transparent manner is key to the design and ownership of strategies by public and private decision makers and stakeholders.

Different model types are appropriate for different scales and sectors. The DDPP pathway design framework (synthesized in 'A Paris-compatible pathway design framework', below) was conceived to accommodate different modelling paradigms and tools, as appropriate for quantification given the specific focus of the analysis[76]. The choice of models and their level of complexity should be made while considering their capacity to inform the practical needs of political dialogue and policy formation[23]. The modelling approach must also be pragmatic and sensitive to ease-of-use, data availability, budget and timescales.

The national DDPP studies were supported by a variety of modelling tools, chosen by the research teams in each context, with varying areas of focus and level of detail[23]. The DDPP study of South Africa investigated poverty alleviation and unemployment reduction[68,77], combining an energy system model with a computable general equilibrium (CGE) model that portrayed disaggregated labour skill classes and their sectoral employment. The Japanese analysis focussed on energy security concerns[72,78], requiring a detailed energy supply and demand bottom-up model. The study for China highlighted the air quality co-benefits of mitigation by coupling energy system and air pollution models[74]. The study of India combined analysis of air quality and energy security benefits[70]. The Australian analysis included dedicated examination of land-based sequestration options, requiring a land-use model[79]. A key focus of the Brazilian study was on inequality and land use, employing a hybrid CGE model that portrayed the evolution of income distribution across household income classes while also including biofuel, agriculture and forestry mitigation options[80]. The study of the USA discussed issues posed by integration of substantial variable electricity generation, combined with electricity-based synthetic net-zero GHG hydrocarbon production, requiring the use of an electricity dispatch model.[81]

Comparable scenario data reporting. Model outputs vary from one tool to the other depending on paradigm, research focus and scope, which can lead to stakeholder confusion as well as difficulties in policy design and implementation. A consistent set of comparable and quantified results gathered in a spreadsheet 'dashboard', reported systematically across modelling tools and country studies, can serve three complementary purposes relevant to the post-Paris process.

First, the dashboard serves as a 'driver dictionary'. It expresses the main determinants of a country's sectoral transformation through a common language, enabling cross-country comparisons, benchmarking and learning. These commonly defined drivers allow a country team to compare its ambition with the collective requirements characterized by sectoral benchmarks (see 'Backcasting using long-term benchmarks', below).

Second, the dashboard variables characterize the physical sectoral and sub-sectoral transformations at a sufficient level of granularity and technical transparency for dialogue with sectoral and technology experts. This detailed information can serve policy instrument selection within the context of sectoral and national circumstances.

Third, the dashboard serves as an aggregator in a bottom-up approach, where the global vision emerges as a composite of sectoral and national pathways. Beyond emissions accounting, the dashboard provides a physical view of the global transformations (such as solar panel capacity and the number of electric vehicles). This information can serve, along with analysis of learning rates and economies of scale, as inputs for assessment of investment needs at the national and global level[56]. This enables a transparent analysis and discussion of where global-scale cooperation is needed to decarbonize key sectors, such as power generation, transport and industry, notably for technology development and transfer, financing and institutional capacity[82,83].

Given the focus of the DDPP on energy-related emissions, the dashboard was based on a decomposition of activity, energy intensity and energy mixes for key energy end-use demands (buildings, transport and industry) and energy supply (electricity, liquids and gases). In addition, the dashboard included cumulative data on power generation capacities (in gigawatts (GW), by technology), passenger vehicles (number of vehicles, by energy type) and liquid energy carriers (in exajoules (EJ), by energy source)[54,56]. The Supplementary Information presents full detail of the dashboard content in the DDPP.

Backcasting using long-term benchmarks. To guide their self-determined contributions to the global effort, countries need to identify national pathways that satisfy key long-term socio-economic objectives, reach very low GHG emission levels and maximize co-benefits, all in an economically efficient way. Approaching these pathways as country-driven back-casts from these objectives puts the long run constraint at the centre of the process, questioning how short-term investment and policy choices affect the capacity to reach long-term objectives. This approach directly confronts analysts with the consequences of potential sector lock-ins and stranded assets (for example, investments in coal plants, natural gas networks or liquified natural gas terminals, depending on their potential for retrofitting with carbon capture and storage or renewable methane) and the necessary domestic and international conditions to avoid them, notably when considering long-lived assets like infrastructure, buildings and industrial facilities.[83]

Country teams, governments or other parties, working independently on their national pathways, need *ex-ante* guidance to define the necessary physical transformations to meet their emissions and development objectives. To this aim, common overall and sectoral benchmarks can be used that are mapped against the variables listed in the dashboard (see Comparable scenario data reporting, above). These benchmarks characterize the scale and detail of transformative change required by 2050 to achieve the objective of net-zero emissions in the second half of the century, or by 2050 in the case of 1.5°C (ref. [2]).

In the DDPP, the benchmarks for emission levels in 2050 compatible with a given climate objective and corresponding sectoral emissions intensities were based on the IAM informed global averages from Working Group III (WG3) of the IPCC AR5. For example, an electricity sector generation benchmark for 2050 was set at −30 to +50 grams CO_2 per kWh (based on Figure 7.7 in Ch. 7 of WG3 AR5)[84].

To ensure a coherent cross-country global context, collective assumptions were also made regarding the availability of some technologies that would depend on large-scale research and development, involving international cooperation and transfer. The nature and speed of the deployment of these technologies and the resulting domestic sectoral transformations towards the common benchmarks would then differ by country, according to national circumstances and priorities affecting the relevance of different options. For example, the previously mentioned electricity benchmark could be reached through different power generation mixes according to country circumstances (for example, endowment of renewables and the capacity to balance them, storage capacity for carbon capture, or social acceptability of nuclear). Another key example included the different combinations of electric, biofuel or hybrid personal vehicles across countries as a key strategy to decarbonize passenger transport.

The next section discusses how this backcasting approach using long-term benchmarks is embedded in the complete DDPP pathways design framework, built from the four points discussed in this section.

A Paris-compatible pathway design framework

In the DDPP pathways design framework, synthesized in Fig. 1, the process began with the definition of multiple country-driven strategies reflecting key uncertainties. These narrative strategies were then converted into quantitative scenarios with technical, social and economic characteristics using analytical assessment tools, including national-scale models but also other tools as appropriate. Transparent and detailed scenario results were then reported against a common set of indicators in the dashboard. The results were analysed to assess if these overall and sectoral national indicators, as well as cumulative global emissions, were consistent with the backcasted benchmarks[85,86].

A key design point of the DDPP pathways design process was its iterative nature, supported by two learning processes. On the one hand, the country teams could compare the dashboard results against the benchmark national and sectoral emission drivers compatible with the collective climate objective. On the other hand, the common dashboard enabled comparison of assumptions across countries and learning about the possibility of different actions. These two learning processes led the teams to progressively revise their strategy and scenario assumptions, notably regarding technical potentials for decarbonisation in the different sectors. This allowed those that were initially out of compliance to get closer to the benchmarks, while the already ambitious went further. The pathways presented in the DDPP country and global synthesis[54] reports are the final outcomes of these iterations. They constitute a self-assessment by in-country researchers of what physical sector transformations can be chosen to put the domestic economy on track with the net-zero emissions objective.

First, the DDPP approach does not guarantee consistency with the climate goal as defined by cumulative global emissions. But, even if national cumulative emissions were not prescribed *ex-ante*, the final pathways were collectively compatible with the cumulative emission reductions required for the chosen climate objective. More specifically, when extrapolating emission trajectories to include all sources of emissions not explicitly covered in the DDPP (see Supplementary Information for details), cumulative GHG emissions over 2010–2050 fell in the range of 1,185–1,555 Gt CO_2. This is consistent with the 1,166–1,566 Gt CO_2 range for a 50% chance of 2°C (see Table SPM.1 in WG3 AR5 IPCC report)[1]. These results provide a proof of concept for the DDPP approach to finding domestic mitigation actions that countries could take to meet the global mitigation goal of the Paris Agreement.

Second, the DDPP approach does not assume *a priori* the exact nature of cross-country interactions. However, the DDPP results show how country-driven studies can inform the collective enabling conditions that make the domestic mitigation actions possible, such as technology learning and transfer, or financial requirements to support investment needs[56,82]. Such global assessment is made possible because country pathways are built from a coherent cross-country context on technology availability (see 'Backcasting using long-term benchmarks', above), and because the individual country

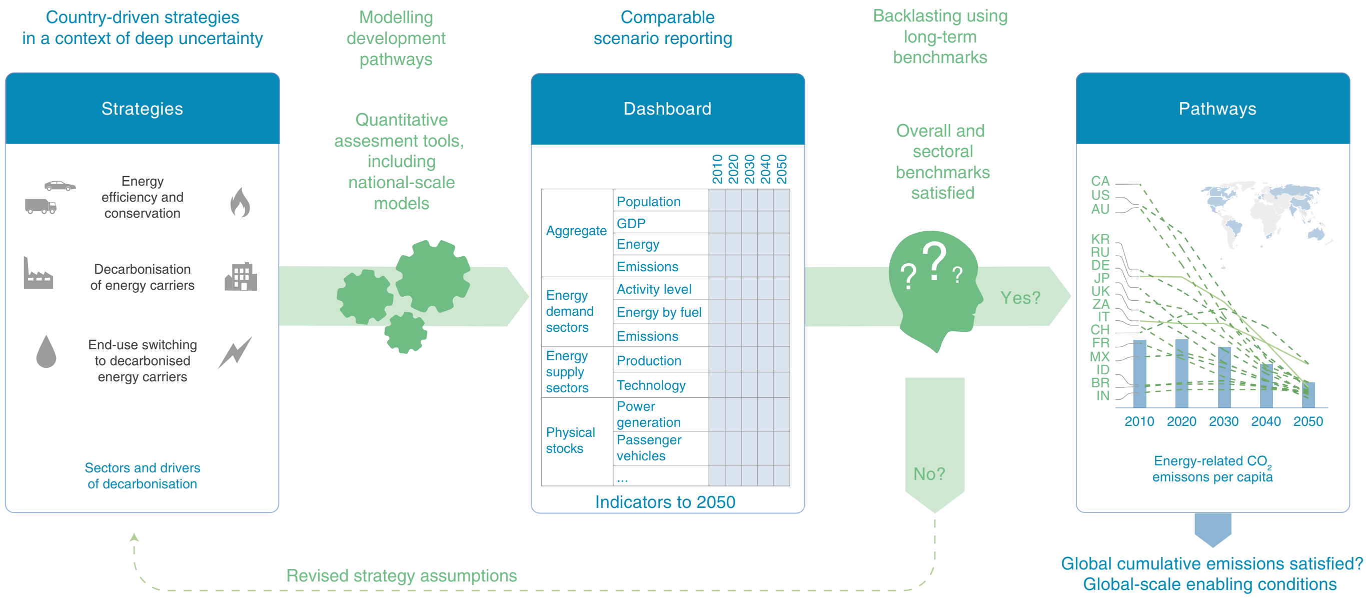

Fig. 1 | The DDPP pathway design framework. The DDPP results illustrate how the pathways design framework can help inform the key issues of ambition, cooperation and equity. Credit: Ivan Pharabod.

results were reported into a common dashboard, making possible the reconstruction of the global transformations emerging from national studies (see 'Comparable scenario data reporting', above).

Finally, mindful that countries would favour different equity principles and criteria[87,88], the analysis does not state how the costs or benefits of mitigation are to be shared among countries, nor how much each country contributes to the international cooperative efforts. The allocation of effort in support of other countries' domestic measures will be grounded in analysis of domestic and international equity[88–90], including reference to norms of responsibility, capability, need, equality, and implications for international financial and technology transfers[87,88,91–93]. This equity issue was beyond the scope of the DDPP analysis, which therefore does not directly define how the contribution that a country submits under the Paris Agreement can be 'fair and ambitious' (decision 1/CP.21, paragraph 27). It does, however, provide a basis to assess this equity question from a bottom-up perspective against the physical regional and sectoral requirements of net-zero decarbonization, however they are paid for. A collective discussion and negotiation is one of the key purposes of the regular global stocktake in the Paris Agreement, which is to be viewed 'in the light of equity' (Article 14.1). Explicit documentation of global enabling conditions, as permitted by the above pathways design framework, will be in particular a core input to this global stocktaking effort.

Conclusion

New analytical processes and tools are needed to support the process codified in the Paris Agreement. They should support the design of national low GHG emission development strategies that are consistent with global climate ambition and can support national policy formation and implementation. They should also inform the sectoral and international discussions needed to reveal the key priorities of global cooperation. Based on the DDPP, we have described principles and methodologies for such an approach. These include: the definition of multiple country-specific strategies framed by common drivers of decarbonization in a context of deep uncertainty; the use of a variety of national modelling tools to translate narrative strategies into quantified scenarios and indicators reported in a common dashboard; and national and sectoral benchmarks to provide guidance towards collective mid-century mitigation ambition. These building blocks are combined in an iterative integrated framework for pathway design, encouraging cross-stakeholder communication and learning, enabling the assessment of compliance with national development and global emissions goals, and providing concrete support to policy formation in the context of the Paris Agreement. This has direct practical implications for the revision of all countries' NDCs in 2020, and the formal stocktake under the United Nation Framework Convention on Climate Change in 2023.

The DDPP pathways design framework provides organizing principles for the definition of the national long-term strategies specified in the Paris Agreement. It is not a methodology to be owned and run by a specific institution or government. It is rather an approach to support a shared process for strategy and pathway design among diverse groups of stakeholders to inform policy formation, which is eventually the responsibility of governments. It provides a structure for national governments to conduct stakeholder consultations, educate them, solicit their input, and identify mitigation measures and implementation policy packages. It also can help reveal key enabling conditions, such as technology development and transfer, finance for investment and adaptation, and institutional support, thus enabling more ambitious national NDCs. The framework could also be used by non-state actors (such as firms and sectoral associations, as well as regional and city governments), non-governmental organizations or international bodies to define their contribution to the Paris objectives. One important channel where the framework could be mobilized is the 2050 Pathways Platform[94], which aims to support nations, regions and cities seeking to devise long-term, net-zero GHG, climate resilient, and sustainable development pathways.

At the global level, the DDPP pathways design framework also provides a unifying frame for analysis of collective transition effects and implementation challenges from a national perspective. This could provide concrete insights into the collective conversation on global-scale cooperation in the 2023 global stocktake introduced in the Paris Agreement. The framework also provides an organizing principle for the emergence of a bottom-up literature on national transitions informing policy packages in the context of global changes and objectives. As such, it could particularly provide a foundation for literature feeding into Chapter 4 of the future WG3

AR6 IPCC report, *Mitigation and development pathways in the near to mid-term*.

Future work includes addressing the following priorities. First, the DDPP methodology needs to be applied with the 'well below 2°C, towards 1.5°C' Paris Agreement framing. This means notably adopting more ambitious benchmarks, consistent with global scale estimates from the IPCC Special Report on Global Warming of 1.5°C[2]. These revised benchmarks would help guide the identification of the additional physical sector changes required beyond those for 2°C, and highlight where domestic action and international cooperation should be strengthened. This will notably involve a more granular analysis of challenging sectors such as transport and heavy industry. The latter, for example, requires analysis regarding enhancing technology research and development, commercialization support, and trade policies where it is necessary to protect and encourage first adopters of low, zero or negative emissions technologies[83]. Non-energy emission sources should also be considered; the DDPP study on Indonesia provides a concrete example of how emissions from agriculture, forest and land-use can be treated using the DDPP methodology[95].

Second, more countries, beyond the 16 analysed explicitly here, must be included to improve representation of the global economy, especially developing economies. This will require programs to enhance the analytical capacities of developing countries[23], and a generalization of the DDPP framework methodological principles to capture the specifics of development challenges (for example, access to modern energy services). To this effect, a regional DDPP network covering six Latin American countries—DDP–LAC—was launched in February 2018 in cooperation between the Inter-American Development Bank and IDDRI. Another DDPP project in partnership with the German International Climate Initiative (IKI)—DDP–BIICS—that focuses on Brazil, Indonesia, India, China and South Africa, was launched in December 2018.

Third, upfront decision maker and stakeholder involvement was, in general, low in the DDPP. The new projects include an explicit engagement dimension, with the objective of continuous dialogue with domestic decision makers to ensure broad ownership of the approach and analysis. Engagement with policymakers is a mandatory component for the DDP–LAC country teams, including the offering to policymakers of a modelled low-emission development scenario to help inform their NDC. DDP–BIICS will follow the same approach by involving decision makers right from the start in the pathway design.

Fourth, global drivers matter for national-based modelling (for example, cumulative innovation and technology learning, projected fossil and renewable fuel prices, or supply and demand throughout the transition[53]), and provide a fruitful avenue for cooperation between national pathways and global IAM models. A clear mapping between national and global scales of analysis will be essential for clearly articulating the enabling conditions for global technology development and transfer, the finance needed for investment and adaptation, as well as the necessary institutional support. This information will be key to the collective stocktaking dialogues.

Finally, the DDPP pathways design framework could provide a concrete articulation of theoretical principles identified by the social sciences transition literature to enable constructive dialogue amongst stakeholders and decision-makers on system-wide transitions[17,59,96,97]. Notably, the framework could be used to coordinate techno-economic modelling, socio-technical analysis and political analysis. Strategies, modelling, dashboards and pathways could be used for the alignment of conceptual languages, bridging of understanding of key ideas and the iteration of alternative visions, until a working understanding is achieved amongst stakeholders and decision makers[98]. Based on this, flexible and robust policy packages could be designed to meet national development and global emissions goals, taking into account the considerations of equity and poverty reduction. To deepen incorporation of these social science insights, new analytical tools and benchmarks are required to allow the evolution from the standard techno-economic point of view to a broader perspective on low-emission development for all countries based on, for example, the Sustainable Development Goals. The 2015 South African[68] and Indian DDPP reports[70], which used explicit development indicators, provide examples of how this evolution may happen.

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Author contributions

H.Wa. and C.B. conceived, drafted and revised the manuscript, and led the underlying analysis as coordinators of the Deep Decarbonization Pathways Project (DDPP). H.Wi and M.C contributed to the conception of the manuscript, the drafting of 'Backcasting using long-term benchmarks' and 'A Paris-compatible pathway design framework' sections, and to revisions of the manuscript. F.J. and P.S. contributed to the conception of the paper and to revisions of the manuscript. All authors substantively contributed ideas through their active participation in DDPP and critically reviewed the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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