

Pathways to Deep Decarbonization

INTERIM REPORT – July 8, 2014

Executive Summary

This interim 2014 report by the Deep Decarbonization Pathway Project (DDPP) summarizes preliminary findings of the pathways developed by the DDPP Country Research Teams with the objective of achieving emission reductions consistent with limiting global warming to less than 2°C. The DDPP is a knowledge network comprising 15 Country Research Teams and several Partner Organizations who develop and share methods, assumptions, and findings related to deep decarbonization. Each DDPP Country Research Team develops an illustrative roadmap for the transition to a low-carbon economy, with the intent of taking into account national socio-economic conditions, development aspirations, infrastructure stocks, resource endowments, and other relevant factors. The interim 2014 report focuses on technically feasible pathways to deep decarbonization.

This executive summary starts with a short outline of key results from previous global studies (discussed from chapter I to IV) and then turns to what is new and special about the country-level approach of the DDPP (explained in chapter V). It summarizes the main preliminary findings from the Deep Decarbonization Pathways (DDPs) developed by the Country Research Teams (included in chapter VI) and draws some lessons for the international negotiations leading up to the 21st Conference of the Parties (COP-21) of the UN Framework Convention on Climate Change (UNFCCC) to be held in Paris in December 2015.

Climate change and sustainable development

The economic, social, and environmental risks of unabated climate change are immense. They threaten to roll back the fruits of decades of growth and development, undermine prosperity, and jeopardize countries' ability to achieve even the most basic socio-economic development goals in the future, including the eradication of poverty and continued economic growth. These risks affect all developed and developing countries alike.

Avoiding dangerous climate change and achieving sustainable development are inextricably linked. There is no prospect of winning the fight against climate change if countries fail on poverty eradication or if countries do not succeed in raising the living standards of their people. Addressing climate change requires deep emission reductions of all greenhouse gas (GHG), including the deep decarbonization of energy systems. To be successful, this transition to deep decarbonization must ensure that socio-economic development needs are met within the constraints of very low emissions.

The results from previous global studies, including the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports (AR), show that deeply reducing GHG emissions and achieving socio-economic development are not mutually exclusive. Robust economic growth

and rising prosperity are consistent with the objective of deep decarbonization. They form two sides of the same coin and must be pursued together as part of sustainable development. The DDPs developed by the Country Research Teams assume continued, sometimes rapid, economic growth. The forthcoming report from the Global Commission on the New Climate Economy provides additional insights on how to pursue these twin objectives.

The carbon budget and emissions reduction trajectory to stay below 2°C

In 2010, all governments operationalized the objective of the UNFCCC to “prevent dangerous anthropogenic interference with the climate system” by adopting the target of keeping the global rise in mean surface temperature below 2°C compared with the pre-industrial average. They did this in recognition of the extreme risks to future human wellbeing resulting from a rise in temperature above 2°C. The latest scientific research analyzed by the IPCC Fifth Assessment Report (AR5) Working Group 2 (WG2) concludes that even an increase in global temperatures of 2°C constitutes a serious threat to human wellbeing. Keeping below 2°C of global warming is indispensable to maintain climate change within the boundaries of manageable risks and to our ability to adapt to climate change.

Limiting the increase in global temperatures to less than 2°C imposes a tough constraint on cumulative GHG emissions, in particular CO₂ emissions, the largest single source (76%) of GHG emissions. To have a likely chance—defined as a probability higher than two-thirds—of staying within this limit, the level of cumulative CO₂ emissions from land use, fossil fuels, and industry must be in the range of 550-1300 billion tons (Gigatons or Gt) by mid-century. If one excludes a significant contribution from net negative emissions,¹ the CO₂ budget to 2050 is reduced to 825 Gt. Staying within this CO₂ budget requires very near-term peaking and a sharp reduction in CO₂ emissions thereafter, especially in energy-related CO₂ emissions. The scenarios reviewed by the IPCC that give a likely chance of staying within the 2°C limit project CO₂ emissions from energy use (“CO₂-energy emissions”) close to 11 Gt in 2050 on average (down from 36 Gt in 2010). The IEA Energy Technology Perspective (ETP) 2°C scenario (2DS), which gives only a 50% chance of staying within the 2°C limit, reaches 15 Gt CO₂-energy in 2050. Assuming a world population of 9.5 billion people by 2050—in line with the medium fertility forecast of the UN Population Division—this means that countries would need to converge close to a global average of CO₂-energy emissions per capita of 1.6 tons in 2050, which is a sharp decrease compared to today's global average of 5.2 tons, especially for developed countries with current emissions per capita much higher than today's global average.

Why the 2°C limit should be taken seriously

The world is not on track to stay within the 2°C limit. While awareness of climate change is rising, and a large and growing number of countries, cities, and corporations have pledged to reduce their GHG emissions, these pledges taken together are not sufficient to stay within the 2°C limit. The IPCC AR5 WG3 calculates that in the absence of additional commitments to reduce GHG emissions, the world is on a trajectory to an increase in global temperatures of 3.7°C to 4.8°C

¹ The sustainability of the large-scale deployment of some net negative emissions technologies, such as Bio Energy with Carbon Capture and Sequestration (BECCS), raises issues still under debate, in part due to the competition in land uses for energy and food purposes.

compared to pre-industrial levels. When accounting for full climate uncertainty, this range extends from 2.5°C to 7.8°C by the end of the century.

The consequences of such a temperature rise would be catastrophic. A recent report prepared by the Potsdam Institute for Climate Impact Research (PIK) for the World Bank² describes a dramatic picture of a 4°C warmer world, where climate and weather extremes would cause devastation and intense human suffering. It would have severe repercussions on human and physical systems and potentially unleash positive feedback mechanisms that further amplify the human drivers. The IPCC AR5 and a large number of other international and national assessments validate this finding. It is therefore vital that the world become much more serious about the operational implications of staying within the 2°C limit. Governments, businesses, and civil society must understand and operationalize the profound transformations required to reach this target.

We do not subscribe to the view held by some that the 2°C limit is impossible to achieve and that it should be weakened or dropped altogether. The science is clear that global warming beyond 2°C carries the risk of grave and irreversible harm to human wellbeing and development prospects in all countries. The political risks of jettisoning the 2°C limit are also significant. If the world fails to mobilize in support of the 2°C limit or if countries try to weaken it there will be no realistic prospect for the international community to agree to another quantitative target. Countries would find themselves on a slippery downward slope with no quantitative foothold to organize an international and coordinated response to climate change. The 2°C limit is an invaluable tool for international mobilization that must be preserved.

The latest scientific research indicates that keeping below the 2°C limit is challenging but feasible. Global studies—including the scenarios reviewed by the IPCC AR5 WG3, the IEA World Energy Outlook (WEO) and Energy Technology Perspectives (ETP) reports, and the Global Energy Assessment (GEA) led by the Institute of Applied Systems Analysis (IIASA)—show that reducing global GHG emissions to a level consistent with the 2°C limit is still within reach. Clearly, though, the window of opportunity is closing fast. Countries therefore need to act quickly and in a determined and coordinated manner to keep the 2°C limit within reach.

Operationalizing the global 2°C limit

Very few countries have looked seriously at the operational implications of staying within the 2°C limit. All large emitting countries now have quantified targets to reduce their GHG emissions by the year 2020. But these targets—which sometimes are yet to be backed by detailed policy actions and implementation plans—are collectively insufficient to put countries on a trajectory consistent with the long-term global objective of deep decarbonization. In fact most 2020 emissions reductions targets were framed as deviation from Business-As-Usual (BAU) trends, reductions in the carbon intensity of GDP, or relatively modest decrease in absolute GHG emissions compared to a base year. By and large national targets are not derived from an assessment of what will be needed to stay within the 2°C limit.

² Schellnhuber, HJ, et al. *Turn down the heat: climate extremes, regional impacts, and the case for resilience - full report*. Washington DC; World Bank. June 2013.
<http://documents.worldbank.org/curated/en/2013/06/17862361/turn-down-heat-climate-extremes-regional-impacts-case-resilience-full-report>

Only an internationally coordinated, goal-oriented approach to operationalizing the 2°C limit will allow humanity to avoid dangerous climate change. As this interim DDPP report and many other analyses make clear, staying within 2°C will require deep transformations of energy and production systems, industry, agriculture, land use, and other dimensions of human development. It will require profound changes in the prevailing socio-economic development frameworks. Many of the technologies that will need to underpin these transformations are available, but many others are yet to be developed. Making critical low-carbon technologies commercially available and affordable and enabling countries to pursue long-term transformations will require long-term international cooperation and trust. One important purpose of the DDPP is to lay out an analytical approach to operationalizing the 2°C limit that can underpin a goal-oriented international response to mitigating climate change, taking into account country-specific socio-economic conditions and development aspirations.

The need for country-level Deep Decarbonization Pathways (DDPs) to 2050

The DDPP aims to help countries think through how to pursue their national development priorities while achieving the deep decarbonization of energy systems by mid-century consistent with the 2°C limit. Following the launch of the DDPP in October 2013, the DDPP Country Research Teams have collaborated to identify key principles and requirements for successful DDPs. A broad consensus has emerged on the role of DDPs and criteria for success.

Staying within the 2°C limit requires that countries develop long-term pathways to deep decarbonization to explore options and develop a long-term strategy. The nature and magnitude of the decarbonization challenge are such that there is no quick and easy fix. Deep decarbonization will not happen overnight, and there is no silver bullet. Deep decarbonization is not about modest and incremental change or small deviations from BAU. In particular, it requires major changes to countries' energy and production systems that need to be pursued over the long-term. Decisions made today with regards to, say, power generation and transport infrastructure, will have a long-term impact on future GHG emissions, which must be mapped out carefully and understood quantitatively.

The DDPs developed by the Country Research Teams “backcast” from the global goal of limiting the rise in temperature below 2°C to explore the transformations for deep decarbonization required to reach the goal. We use the term “backcasting,” to describe a process where the future GHG emission target is set, and then the changes needed to achieve that target are determined. Backcasting is not to be confused with rigid, central planning. A process of deep decarbonization must be adaptive, as strategies and pathways will have to be continually revised and updated based on new results from climate science, technological innovation, and lessons learnt from implementation.

The DDPP follows a two-stage approach to problem solving. The first, which is the focus of this report, is to identify technically feasible DDPs for achieving the objective of limiting the rise in global temperatures below 2°C. At this stage, we have not looked in detail at the issue of costs and benefits, not considered the question of who should pay for them. In a second—later—stage we will refine the analysis of the technical potential, exploring the options for even deeper

decarbonization pathways, and better taking into account infrastructure stocks. We will also take a broader perspective, beyond technical feasibility, by quantifying costs and benefits, estimating national and international finance requirements, mapping out domestic and global policy frameworks, and considering in more detail how the twin objectives of development and deep decarbonization can be met. These issues will be described in the 2015 DDPP report. But technically feasible DDPs are a vital first step towards achieving the 2°C limit, by illuminating the scale and nature of technological and structural changes required and their related investment needs.

The technical DDPs developed by the Country Research Teams rest on a number of national and global policy assumptions that will be investigated in more detail in the 2015 DDPP report. These policy assumptions include:

- All countries take strong, early, and coordinated actions to achieve deep decarbonization.
- All countries adopt adequate nationally appropriate policies, regulations, and incentives.
- Financial flows are re-directed from high-carbon to low-carbon portfolios and projects.
- Financial support is provided to countries that appropriately require financial assistance to implement mitigation policies and finance low-carbon investments.

The DDPs developed by the Country Research Teams presented in this report are intended to provide a complementary analysis to existing global-level studies of deep emissions reductions. To make a strong and convincing case for action at the national level, DDPs must be country-specific and developed and owned by local experts. They need to fit within countries' development strategies and align with their other socio-economic and environmental goals. They need to demonstrate that the short- and long-term challenges countries face, such as economic development, poverty eradication, job creation, inequality reduction, energy and food security, and biodiversity protection, can be addressed in parallel to deep decarbonization. DDPs must take into account country-specific infrastructure stocks and natural resource endowments. They must also take into account the systemic implications and the inherent gradual pace of changing technology, infrastructure, and capital stocks within countries. None of this can be accomplished through aggregate global models and studies, which are not granular enough to present a detailed technical roadmap for policy implementation at the country level

DDPs are indispensable for promoting a national dialogue on decarbonization and launching a process of intense and complex problem solving. Transparent DDPs can enable a public discussion in every country on how best to achieve emission reduction objectives, understand possible trade-offs, and identify synergies or “win-wins.” Such technical analysis and national dialogue on deep decarbonization will involve business, civil society, and various expert communities (e.g. engineers, geologists, climatologists, economists, social scientists) to debate the best options for decarbonization, identify bottlenecks, and propose new approaches. DDPs can become a framework for organizing a dynamic process of discussion and problem solving in every country.

DDPs equally are indispensable for building trust across countries, shaping their expectations, and identifying where international cooperation and assistance is required. DDPs show how each country aims to achieve deep decarbonization and demonstrate the seriousness of national commitments to reduce GHG emissions. Transparent DDPs can enhance

trust among countries, which is critical for a concerted international response to climate change. They will also help highlight areas that require international assistance and increased international cooperation, particularly on RDD&D of low-carbon technologies.

Interim results from the 15 Deep Decarbonization Pathways (DDPs) developed by the Country Research Teams

In aggregate, the initial DDPs developed by the Country Research Teams outlined in this report achieve deep absolute emissions reductions by 2050. Total CO₂-energy emissions from the 15 preliminary DDPs already reach a level of 12.3 Gt by 2050, down from 22.3 Gt in 2010. This represents a 45% decrease of total CO₂-energy emissions over the period, and a 56% and 88% reduction in emissions per capita and the carbon intensity of GDP, respectively. The interim DDPs do not yet achieve the full decarbonization needed to make staying below the 2°C limit “likely,” defined as a higher than two-thirds probability of success. The Country Research Teams have identified additional opportunities for deep decarbonization that will be incorporated in the next version of the DDPs (see Chapter VI) to be published in 2015. Nonetheless, the aggregate decarbonization pathway is already very substantial and well on its way to becoming consistent with the 2°C target.

The preliminary DDPs already provide key insights and identify unique elements of deep decarbonization in each country. These include the key components of nationally appropriate strategies and the most promising country-specific technology options for deep decarbonization. The initial DDPs also identify the principal challenges that still need to be addressed by the DDPP. Finally, the DDPs provide initial indications of the enabling conditions for the successful implementation of deep decarbonization. Understanding and meeting these conditions will require further refinement through careful analysis, public consultation, and learning by doing.

The three pillars of the deep decarbonization of energy systems

The 15 DDPs developed by the Country Research Teams share three common pillars of deep decarbonization of national energy systems:

- 1) **Energy efficiency and conservation:** Greatly improved energy efficiency in all energy end-use sectors including passenger and goods *transportation*, through improved vehicle technologies, smart urban design, and optimized value chains; residential and commercial *buildings*, through improved end-use equipment, architectural design, building practices, and construction materials; and *industry*, through improved equipment, production processes, material efficiency, and re-use of waste heat.
- 2) **Low-carbon electricity:** Decarbonization of electricity generation through the replacement of existing fossil-fuel-based generation with renewable energy (e.g. hydro, wind, solar, and geothermal), nuclear power, and/or fossil fuels (coal, gas) with carbon capture and storage (CCS).
- 3) **Fuel Switching:** Switching end-use energy supplies from highly carbon-intensive fossil fuels in transportation, buildings, and industry to lower carbon fuels, including low-carbon

electricity, other low-carbon energy carriers synthesized from electricity generation or sustainable biomass, or lower-carbon fossil fuels.

Within the three pillars that are common to all countries, individual DDPs show a wide variety of different approaches based on national circumstances. Differentiating national circumstances include socio-economic conditions, the availability of renewable energy resources, and national preferences regarding the development of renewable energy, nuclear power, CCS, and other technologies. For example, the DDP developed by the Indian team decarbonizes power generation using primarily renewable energy and nuclear power, but not CCS, because the scale of the potential for geological carbon sequestration in India is still uncertain. At the other end of the spectrum, the DDPs developed by the Canadian, Chinese, Indonesian, Mexican, Russian, and UK teams project a significant share of coal and gas-fired power generation with CCS by 2050.

The main decarbonization challenges at the sectoral level

The preliminary DDPs also reveal the sectors in which deep emissions reductions are most challenging, particularly freight and industry. Relative to the state of knowledge about low-carbon strategies in other areas such as power generation, buildings, and passenger transport, decarbonization strategies for freight and industry are less well developed and understood. These two sectors constitute a key focus area for future analysis by the DDPP and a future challenge for global RDD&D efforts.

Some potential solutions have been identified for freight and industry. Decarbonization options for freight include improved propulsion technologies (battery electric, hybrid, compressed or liquefied (natural or synthesized) gas, and hydrogen); modal shifts (e.g. from road transport to trains and ships); and sustainable biofuels and synthesized fuels for air and maritime transport. Decarbonization options for industry include improved efficiency, electrification of boilers, re-use of process waste heat, sustainable biomass (both energy crops and waste material), and CCS.

Some of the identified decarbonization options for industry and freight have yet to be included in all DDPs. Some Country Research Teams will include additional decarbonization options in their revised DDPs. They will also ensure consistency of national projections for industrial production, in particular for energy and mining products, with the forecasted global demand and the domestic needs for infrastructure development by 2050. Given the technological challenges associated with deep emission reductions in the freight and industry sectors, complementary measures to reduce or limit the growth of demand for their products and services will be explored, taking into account countries' socio-economic goals and strategies.

The need for a global technology push

The analysis by the 15 Country Research Teams also confirms that the technical feasibility of deep decarbonization rests on the large-scale deployment of several low-carbon technologies, some of which are not yet fully commercialized or affordable. For this reason, countries and the international community as a whole must undertake a major research, development, demonstration, and diffusion (RDD&D) effort to develop low-carbon technologies and ensure their widespread availability and their affordability.

All Country Research Teams have adopted project-wide assumptions regarding the development and deployment of critical low-carbon technologies:

- There will be sufficient global RDD&D and international cooperation to make all the relevant pre-commercial low-carbon technologies commercially viable and widely available in a timely and scaled manner.
- Critical low-carbon technologies will become competitive and affordable, through the combined effects of carbon pricing, policy incentives, and cost-reduction through learning effects and economies of scale.
- Low-carbon technologies will be made available to all countries through mechanisms for technology cooperation, including funding as necessary, and all barriers to technology diffusion will be removed.

Some key technologies, which are critical for deep decarbonization in all DDPs, are not yet technically mature or economically affordable. They include:

- Advanced energy storage, flexible load management, and integrated portfolio design for balancing power systems with high penetrations of variable renewable energy (e.g. wind and solar)
- Very high performance appliances, controls, and materials for buildings
- Zero emissions vehicles with adequate range, notably battery electric or fuel cell light-duty vehicles
- Sustainable biofuels or synthesized fuels for air and marine transport

Some emerging low-carbon technologies are key in a subset of the 15 DDPs. These include:

- New types of renewable energy technologies (e.g. advanced geothermal, deep offshore wind, and tidal energy)
- Carbon-capture and sequestration (on fossil-fueled power plants and industries)
- Advanced nuclear power technology that sustains public confidence and support

The Country Teams underscore that successful implementation of national DDPs depends on “directed technological change”—that is technological change that is propelled through an organized, sustained, and funded effort engaging government, academia, and business with targeted technological outcomes in mind. No Country Research Team was comfortable assuming that their country alone could develop the requisite low-carbon technologies. Likewise, market forces alone will not be sufficient to promote the required RDD&D at the right scale, timing, and coordination across economies and sectors—even when these market forces are guided by potential large profits from the generation of new intellectual property. Technological success will therefore require a globally coordinated effort in technology development, built on technology roadmaps for each of the key, pre-commercial low-carbon technologies.

Directed technological change should not be conceived as picking winners, but as making sure the market has enough winners to pick from to achieve cost-effective low-carbon outcomes. While directed-technological change is essential to meeting the challenge of deep decarbonization, there are many alternative technologies under development now and that may emerge in the future. Technology roadmaps and policy coordination should always leave room for new developments. Efforts aimed at building public support and acceptance for key technologies will also play an important role.

Early lessons for the global deal to stay within 2°C

The preliminary results and the approach of the DDPP itself reveal the critical importance of preparing country-level DDPs to 2050. These pathways, and the discussion of their results and input assumptions, are essential tools for learning and problem solving. This process is crucial to developing a long-term vision for deep decarbonization and shaping the expectations of countries, businesses, and investors about future development opportunities. The DDPP and similar processes afford a unique opportunity for teams to work together across countries to map out how the global 2°C limit can be operationalized and achieved at the country level.

It highlights the need to introduce long-term backcasting into the scope of the climate negotiations preparing COP21. The current focus of the international negotiations on mitigation is on emission reduction targets to 2025 or 2030. Yet if countries do not work with a longer time horizon and backcast from this long-term target, they are likely to adopt strategies that fall far short of what is needed to stay below the 2°C limit. By its structure, the current incremental approach will fail to consider the deep systemic changes and the key technologies that are still pre-commercial but necessary to reach the target.

What the DDPP process illustrates is that at least two new elements will need to be part of the global deal in 2015 at COP21 in Paris. These do not cover the full scope of the agreement, in particular the need to provide adequate support (financial, technological, and capacity building) to countries that appropriately require it to undertake the necessary mitigation and adaptation actions. But they are nonetheless an essential component of a successful global deal to operationalize the 2°C target, and deep decarbonization would lower the needs and costs of unavoidable adaptation:

- **Country DDPs:** A shared global commitment that each country will develop and make publicly available a (non-binding) DDP to 2050 that is consistent with the 2°C limit and their national circumstances. Official country DDPs (as distinct from illustrative DDPs, developed by researchers) would be predicated on a shared commitment to the global target and to all aspects of global cooperation needed to achieve it, including technology cooperation, financial support, and policy coordination.
- **Global, large-scale RDD&D of low-carbon technologies:** A massive and sustained global public-private effort to develop, demonstrate, and diffuse various low-carbon technologies that are not yet technically mature or competitive and are key to the success of deep decarbonization.

It is our hope that this interim 2014 report and upcoming DDPP reports will make a useful contribution to operationalizing the 2°C target. In particular we hope that the DDPP can help spur the design and international comparison of national DDPs and promote the necessary global cooperation to achieve them. To further this discussion we invite comments and suggestions for improvement on this interim 2014 report before August 15, 2014.