Deep Decarbonization Pathways (DDPs): A catalyst for the Climate Change Debate

During 2015, most national governments submitted Intended Nationally Determined Contributions (INDCs) as part of the process towards a new global climate agreement under the United Nations Framework Convention on Climate Change. These INDCs, codified in the Paris agreement, are mostly focused on emission targets set by 2025 or 2030. Hence they do not provide a clear vision of the profound transformation of energy systems required by mid-century to maintain the 2 °C threshold

DOI 10.12910/EAI2016-015

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Rationale for Deep Decarbonization Pathways (DDPs) Analyses

What are DDPs?

In the climate discussions, it is now recognized that all countries need to act according to their respective capabilities, as formalized in the national bottom up, voluntary, low-carbon strategies (or INDCs). Furthermore, it is clear that meeting the internationally-agreed 2 °C threshold will require a long-term perspective, consistently with the assessment by IPCC (2014) that such threshold demands that all economies reach near-zero greenhouse gas emissions by the second half of this century.

These changes in the nature of the climate policy debate have important consequences for the methodological approaches applied to inform this process. When considering full decarbonization, a "backcasting" approach centered on the long-term objective is required, which allows the exploration of the sequence of policy options enabling to achieve this desired target (Fay et al., 2015).

Given the domestic orientation of the INDC process, there will be no global, binding policy guidance on how each country approaches decarbonization. In-country analysts will need to develop detailed decarbonization trajectories for each sector of the economy, describing a sequence of changes in physical infrastructure, deployment of technologies, investment, consumption patterns, all based on available and anticipated technologies. We call such a trajectory Deep Decarbonization Pathway, or "DDP".

DDPs are exploratory in nature,

non- prescriptive, and meant to help structure debates around different visions of the country-specific decarbonization challenge. A DDP needs to: 1) be national-scale, with sectoral disaggregation to take into account national priorities, circumstances, and be relevant for policy. 2) have a long-enough time scope to capture the necessary changes for decarbonization and, finally, 3) be transparent to be useful for stakeholders and policymakers.

The Deep Decarbonization Pathways Project (DDPP)

The Deep Decarbonization Pathways Project is a collaborative global research initiative, convened by the Institute for Sustainable Development and International Relations (IDDRI) and the Sustainable Development Solutions Network (SDSN), that aims to encourage national teams to develop DDPs in order to understand how countries can reduce emissions consistently with the 2 °C threshold.[1] As of late 2015, the DDPP comprised of sixteen country research teams from industrialized and emerging economies, covering 74% of global energy-related CO_2 emissions.[2] The teams do not represent the positions of their national governments, but are all engaged in their domestic policy debates. Each team has developed a set of national DDPs to explore what is physically required to achieve deep decarbonization in their own country's economy, while taking into account socio-economic conditions, development priorities, existing infrastructure, natural resource endowments, and other relevant factors. These DDPs are not meant to give normative visions on the future evolution, yet are aimed at serving as a basis in the country-led debates to reveal the points of discussion to define the adequate national policy and actions according to the specificities of the country's context.

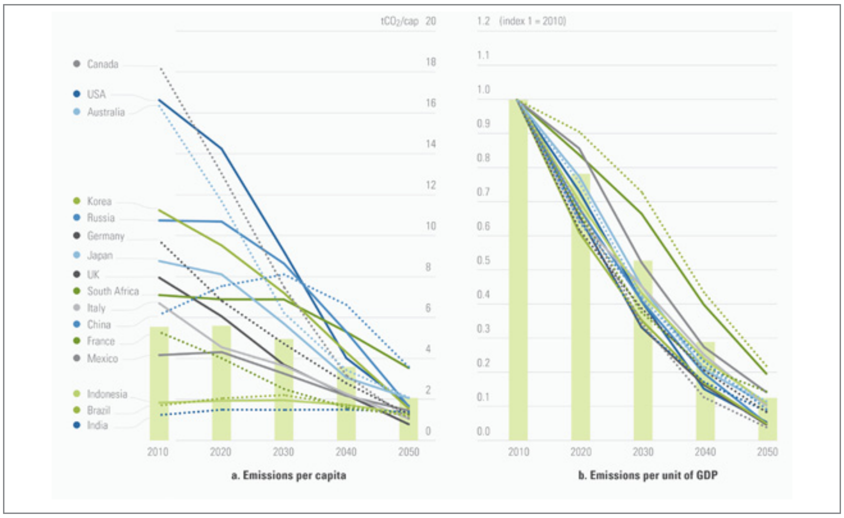

Fig. 1 (L) Energy-related CO_2 emissions per capita for DDPP countries, (R) Energy-related CO2 emissions per unit of GDP for DDPP countries 2010 to 2050, indexed to 2010
Source: DDPP (2015)

Process

The DDPP considers the issue of emission reductions from a bottom-up approach, by which each country research team defines its emission trajectories independently of any *ex-ante* allocation rule. In order to ensure consistency with the amount of emission reductions required to maintain the 2 °C threshold, the DDPP consortium chose to use the IEA (2014) 2DS scenario as a benchmark for global average emissions, which translates into a global average of energy-related emissions of 1.7 tonnes CO_2 per capita by 2050 to reach a 50% chance of staying within the 2 °C threshold.[3]

Adoption of a common accounting framework (referred to as the "dashboard"[4]), which tracks carbon, energy, infrastructure stocks, and investment costs at the sector and subsector levels, provides a basis for cross-country benchmarking and comparison.

Results of the DDPP 2015 Analysis

What emission profiles for different countries?

The DDPs reach a 80-90% decrease in the energy-related emissions intensity of GDP for all countries; however, very different rates and timing of absolute emission reductions occur between groups of countries (Figure 1). This heterogeneity reflects different rates of 2010-2050 economic growth, initial per capita incomes, rhythms of capital stock renewal and deployment, and initial physical energy-related infrastructure that define the potential for deployment of low-carbon options.

What physical changes occur?

Cross-cutting analysis of national DDP scenarios indicates that ambitious mitigation requires simultaneous action on “three pillars” of energy system transformation: energy efficiency and conservation; decarbonization of energy carriers like electricity, biofuels and hydrogen; and fuel switching of energy end-uses to decarbonized energy carriers like electricity.

Because of the synergies between the pillars (e.g. using low-carbon electricity to power vehicles), deep decarbonization cannot be achieved if any of the pillars are absent or implemented at insufficient scale. On average across 16 DDP studies, the energy intensity of the economy reduces by 65% from 2010 to 2050; carbon intensity of electricity supply drops by 93%; and the share of electricity in final consumption more than doubles to over 40% (DDPP 2015).

However, the national DDPs are very different in terms of technologies and sequences of actions. This reflects the specifics of each country regarding the initial nature of infrastructure, building stock and speed of development, societal preferences (e.g. the acceptability of nuclear power), geographic specifics (e.g. amount of renewable resources available, spread-out vs. dense, hot vs. cold climate, availability of geologic sequestration) and economic factors (e.g. production structures and trade). The country-specific strategies to operationalize the deep decarbonization transformation are presented in-depth in the DDPP country reports, available at: http://deepdecarbonization.org/countries/

Is mitigation compatible with domestic socio-economic aspirations?

DDPP investigates the interplay between decarbonization and domestic socio-economic priorities. In all the DDPs, economic growth and development were not constrained by carbon concerns, but rather the energy system was designed to provide all the energy services needed to meet the national objectives, including expanded access to energy in developing countries. This is shown by activity levels associated with crucial energy services in physical quantities (e.g. passenger-km, industrial production).

In addition, each team was able to define the most sensitive socio-economic issues posed by decarbonization in their country, and design their scenarios to explicitly meet these national priorities. Conclusions reached in the DDPP analysis include:

- It is possible to simultaneously improve income distribution, alleviate poverty, and reduce unemployment and transition to a low-carbon economy, as demonstrated in the South-African DDP.
- Reducing fossil fuel demand and developing domestic renewables capacity can increase the energy security of energy-importing countries, as seen for example in the Italian, Indian or Japanese DDPs.
- The reduction of uncontrolled fossil fuel emissions significantly benefits public health, as seen in the Chinese DDPs, where deep decarbonization resulted in a 42-79% reduction of primary air pollutants.
- The aggressive energy efficiency required under deep decarbonization is a way to improve access to energy and address energy poverty, as demonstrated in the UK analysis.
- The implementation of energy efficiency in residential buildings and personal transport under deep decarbonization can lower net energy costs for households. This is illustrated in the Australian DDPs, where the costs of private energy and transport use per household falls by 13% from 2012 to 2050 in parallel with a 55% income increase per household.

What are the investment requirements and the costs?

Deep decarbonization is essentially the process of improving infrastructure and equipment by replacing inefficient and carbon-intensive with efficient and low-carbon technologies that provide the same (or better) energy services. At the global scale, this will require the deployment of vast amounts of new equipment based on clean technologies.

Assessment of the investments needed for the deployment of low-carbon infrastructure is done by developing technology cost learning curves consistent with these market demands to derive investment requirements in the DDPs. Applying historically-based assumptions about technological learning to key low-carbon technologies for power generation, fuel production, and transportation shows dramatic reductions in the cost of these technologies can be expected at the required scale of production, relative to the cost without learning. Those savings illustrate how international cooperation in developing markets for low-carbon technologies can reduce costs for all countries relative to a go-it-alone approach, while providing large markets for technology providers and large incentives for further innovation.

The result of this assessment is that energy investment under deep decarbonization does not represent a large increase over the energy investment required in the absence of climate policy, but rather a transition from fossil fuel to low carbon technologies. The gross investment requirement for low-carbon technologies in the DDPs constitute 1-2% of GDP for the DDPP countries, or an increase of 6-7% in the total investment in these economies, on average about 1.2% GDP (Table 1).

Under deep decarbonization, the scale of investment in low-carbon technologies will be orders of magnitude higher than current levels, creating major economic opportunities for forward-looking countries and businesses, provided there is sufficient certainty in climate policy. Policies may be required to aid firms and consumers with the higher upfront capital costs of low-carbon technologies. This, however, is compensated by avoided expenditure on fossil fuels, as illustrated in the DDP analysis for the United States, in which the net cost of supplying and using energy for a deeply decarbonized scenario in 2050 rises by less than 1% over the period from 2014 to 2050.

Photovoltaic system built by Conergy on the roof of the shopping center Romagna Valley Shopping in Savignano sul Rubicone

Deep Decarbonization in Italy

Three alternative pathways that could reduce Italian CO_2 emissions by 80% by 2050, compared to 1990, were developed by ENEA and FEEM, in the framework of this project. To contribute to the national debate on deep decarbonization, DDPs are designed around the challenges the Italian energy system faces and the future technological developments that will need to be pursued to chart feasible deep decarbonization pathways, in particular:

(i) the limited social acceptability of some technology options (CCS);

(ii) obstacles to further increasing the supply of some renewable sources,;

(iii) the technological difficulty to manage power generation from intermittent renewables;

(iv) the current lack of CCS technologies at reasonable costs.

		2020	2030	2040	2040
Annual Investiments in the 16 DDPP scenarios ($)	Low-carbon power generation	270	514	701	844
	Low-carbon fuel production	57	117	124	127
	Low-carbon transport vehicles (passengers + freight)	157	333	626	911
	Total (Billion US $)	484	963	1452	1882
Annual Investiments in low-carbon technologies as % of GDP		0,8%	1,2%	1,3%	1,3%

Tab. 1 Annual investment in key low-carbon technologies and their share of GDP for DDPP countries (billion USD2015)
Source: DDPP (2015)

The three pathways analyzed differ in their underlying assumptions about which of the various technologies will be available and able to penetrate the Italian energy system.

1. The *CCS + Renewables scenario (CCS):* couples availability of abundant renewable sources with capture technology and CO_2 storage sites also for industrial process emissions

2. The *Energy Efficiency scenario (EFF):* relies on advanced energy efficiency technologies and a greater renewable energy use compensating for smaller CCS potential.

3. The *Demand Reduction scenario (DMD_RED):* the energy system responds to limited availability of CCS and high cost of decarbonization.

The decarbonization scenarios have been produced by combining insights from a very detailed bottom-up energy system model (TIMES-Italy), with two top-down Computable General Equilibrium models (GDyn-E and ICES).

Results show that to reduce domestic emissions by at least 80% (compared to 1990) by 2050, a smooth and efficient transition is needed. All three DDPs achieve energy and process emissions below 90 $MtCO_2$, or 1.5 tCO_2 per person. The carbon intensity of energy is drastically reduced (3.0% to 3.2% average annual rate). Renewable sources and electricity (electrification of final consumption up to 46%) progressively replace fossil fuel consumption (30% to 35% of fossil fuel consumption by 2050), and improvements in energy efficiency further reduce their demand. The faster or slower development of CCS determines the long-term role of fossil fuels. Yet, limiting their role has significant impacts on energy source diversification and energy security: while in 2006 Italy's import dependence reached 87%, by 2050 it may drop to below 30-35%.

Decarbonization of power generation processes is almost complete (a -96% decrease in their emissions in 2050 compared to 2010 level). Renewable energy sources (RES) can provide up to 93%of power generation by 2050 and the contribution of variable RES expands after 2030 reaching 55% to 58% of total net generation by 2050. End-use technologies efficiency is crucial to achieving the 2050 targets in all DDPs.

The DDPs require considerable effort in terms of low-carbon resources and technologies and in economic terms. Compared to a Reference Scenario, cost changes are significant: from 10% to 30% higher cumulative net costs over the period 2010-2050. The emphasis switches from fossil fuel costs and operating costs towards investments in power generation capacity and more efficient technologies and processes.

The macroeconomic analysis, in line with cost estimates for other EU countries, points at increasing decarbonization costs in the range between 7% and 13% of GDP relative to the reference scenario. All DDP scenarios estimate per capita GDP to grow over the examined period, although less rapidly when decarbonization policies are implemented. But decarbonization is likely to induce a structural change in the economy that could benefit both the electricity generation sectors and energy-intensive industries. Such change will also reallocate employment across sectors, from fossil fuel extraction, refining, and commercialization towards renewable energy generation and energy-intensive industries.

The DDPs examined are technically feasible: they rely on the deployment of already available or close-to-the-market technologies. Still, some technical hurdles remain to be addressed with appropriate R&D and investment efforts: the management of variable renewable energy, concerns over the contribution of biomass, and challenges with respect to the deployment of CCS technologies.

What DDPs Contribute to the National Climate Policy Practice

DDPs fill a gap in the climate policy dialogue by providing a more concrete understanding of what is required for countries to reduce emissions consistently with the 2 °C threshold through an explicit plan for deep decarbonization actions by sector and over time. By making the long-term emissions consequences of investment decisions explicit, DDPs can help avoid "dead-end" investments that are not compatible with deep decarbonization in the long term.

DDPs allow stakeholders to concretely envision the path to decarbonization and to catalyze a mutual learning process, structured around a positive vision. The emphasis on technological possibilities encourages stakeholders to focus on the opportunities inherent in the technological change and transformation of existing systems.

DDPs can provide a framework to coordinate policy formation and investment across jurisdictions, sectors, and levels of government. By providing a transparent and concrete understanding of what a low-carbon transition entails – scope and timing of infrastructure changes, technology options, investment requirements, RD&D needs, market potential – DDPs can help align public and private sector interests and expectations.

DDPs provide a framework for understanding synergies between deep decarbonization and other sustainable development priorities including prosperity. They can help countries ensure that the energy transformation and other decarbonization measures (e.g. land use) also support long-term goals, such as energy access, employment opportunities, environmental protection, and public health.

DDPs could increase trust in the international climate policy process. A transparent approach to understanding the long-term challenges in different countries can place greater focus on opportunity-seeking and collective problem-solving. Making long-term national aspirations and the underlying assumptions that inform DDPs clear to other countries can help to identify areas for policy cooperation, joint technology RD&D, market development and transformation, trade, and mutual assistance.

Finally, undertaking national DDP exercises will be essential for understanding the ambition of current INDCs focused on 2025 and 2030, and increasing the ambition of future national commitments to reduce their greenhouse gas emissions.

Conclusions

The sixteen national analyses in the Deep Decarbonization Pathways Project have demonstrated how deep decarbonization is technically and financially possible in a set of countries representing 74% of global energy system emissions, based on an innovative approach to the 2 °C threshold. The combined DDPs in the DDPP potentially cut the Gordian knot of burden sharing that has bedeviled climate negotiations, and offer an approach to deep decarbonization that complements the INDCs.

The DDPP has also raised a host of fruitful research questions to be addressed under the twofold objective of increasing the robustness and relevance of the analysis, and helping catalyze the national discussions amongst policymakers and stakeholders that are necessary to establish policy to decarbonise the global economy.

1 Further information on the DDPP initiative, the 2015 Global Synthesis Report, and country level reports can be found at www.deepdecarbonization.org

2 Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, South Africa, South Korea, the United Kingdom, and the United States

3 The IEA 2DS reaches 15 Gt of global energy-related CO_2 emissions by 2050 and we assume a global population of 9 billion by 2050, in line with the medium fertility projection of the UN Population Division)

4 http://deepdecarbonization.org/research-methods/ddpp-collective-toolkit/