# Carbon prices in national deep decarbonization pathways
# Insights from the Deep Decarbonization pathways Project (DDPP)

## 1. The Deep Decarbonization Pathways Project (DDPP)

### *1.1 The DDPP approach*

This note discusses the lessons learnt from the Deep Decarbonization Pathways Project (DDPP) on 2°C-compatible transformations to 2050 built on an analysis of national-scale scenarios to 2050 developed by country partners from 16 countries representing 74% of 2010 global emissions.[1]

The DDPP approach is explicitly and inherently consistent with the bottom-up framing of climate talks as defined by the Paris Agreement, that is to say grounded in national self-determination of mitigation objectives and implementation of measures to reach them (Art. 4.2), while cumulatively consistent with the global goals (Art 2). The approach is framed by two fundamental methodological principles (DDPP Network, 2016).

On the one hand, the mitigation ambition adopted by each country is not imposed ex-ante from burden-sharing allocation or cost optimization, but instead results from the self-selection by each country team of its own emission pathway, in a way that is compatible with domestic socio-economic and physical circumstances. To ensure consistency with climate mitigation requirements, country scenarios were guided by “downward attractors”, notably the goal of keeping temperature below 2 °C and associated emissions intensity milestone ranges by 2050.

On the other hand, a common reporting template ensured a detailed and transparent representation of regional and sectoral transformations at different time horizons in each scenario. This “DDPP dashboard” makes explicit the physical changes required by the

[1] Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, South Africa, South Korea, UK, USA

domestic low-emission pathways, in a way suited to inform concrete long term transition plans, including unavoidable changes and key short-term priorities needed to meet the long-term objectives when considering infrastructure lock-in, capital stock inertia and frictions affecting the adjustment of technical and socio-economic systems.

### *1.2 The DDPP results*

Using these two key principles, the DDPP scenarios provide a tangible vision of the national and sectoral transformations, while taking into account the specifics of the contexts in which they apply, all with the purpose of informing policy design to implement them (Bataille et al, 2016). DDPP was able to make findings on the global scale, based on 16 detailed studies and assumptions about the 'rest of the world'; the global picture is a 'composite' rather than a single model run.

The cross-cutting results of the DDPP are summarized in the executive summary of the 2015 report (DDPP, 2015a), and described in detail the 2015 synthesis report (DDPP, 2015b). The country-by-country conclusions are detailed in the country reports[2]

The main conclusions are:

- It is feasible in all the countries we have studied to design truly transformative scenarios, consistent with domestic, country-specific socio-economic priorities, that achieve deep decarbonization of the energy system.
- When aggregated and extrapolated with assumptions about the emissions not explicitly covered (energy emissions outside the 16 countries and non-energy CO2 emissions), global cumulative CO2 emissions over 2010-2050 corresponding to the scenarios defined under the DDPP are estimated to range between 1185 Gt and 1555Gt. This falls within the range of 2010-2050 cumulative emissions consistent with an "about as likely as not" likelihood of staying below the 2°C limit in IPCC 2014 (1166 Gt – 1566 Gt). This means that emission reductions to 2050 achieve under DDPP are in line with a 50% likelihood of staying below the 2°C
- In all national scenarios, **the deep decarbonization of energy systems requires strong action on three pillars of decarbonization: i) energy efficiency and**

[2] http://deepdecarbonization.org/countries/

**conservation, ii) decarbonization of energy carriers (electricity and fuels), iii) fuel switching towards low-carbon energy carriers in end-use sectors**. Land use management and direct CO2 capture will also be important for some countries and has been considered as an explicit fourth pillar in countries where it plays a major role.

- The technologies, strategies and sequences considered to operationalize the three pillars vary from one country to the other, according to the specifics of national circumstances.
- It is possible to simultaneously meet country-specific socio-economic aspirations and transition to a low carbon economy in both developing and developed countries; we invite you to see the examples of South Africa in Altieri et al (2016) and Japan in Oshiro et al (2016).
- Several pathways could be defined in each country, which are all consistent with ambitious long-term deep decarbonization but follow different routes, according to the main uncertainties affecting the specifics of individual country transformations. The widely varying nature of these long term visions is necessary to support robust sequential decision-making that takes place under short term political horizons and high uncertainty, building on progressive arrival of information. This decision making would support the design and implementation of policies that trigger ambitious early emission reductions while inducing innovation and preserving long term options. This “adaptive management” approach is discussed more in depth on the example of France and Germany in (Mathy et al, 2016).
- Global low-carbon investment flows for three key sectors (power generation, passenger transport and liquid fuel production) have been distilled from the set of national DDPP scenarios. This evaluation gives low-carbon investment needs in these three sectors of around 1.2-1.3% of GDP in 2050 if global economies of cooperation on technology are achieved (costs double without cooperation).
- In the case of carbon-intensive goods (e.g. iron & steel, and cement), the reconstruction of global trends from national-scale DDPP scenarios shows that the national DDPP scenarios are consistent with conventional production estimates and are close to the production possibility frontier (Denis-Ryan et al, 2016). This points to the need for coordinated international R&D and trade policies in these key sectors in absence of a massive breakthrough of material uses. In a less optimistic situation where the efficiency of production is not at the frontier, a stronger action would required on the material demand side.

## 2- Insights from the DDPP on carbon prices

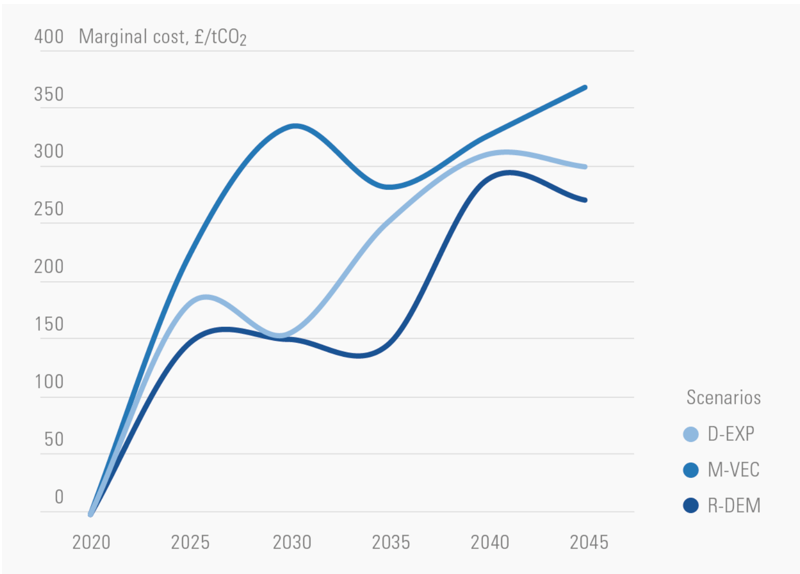
A key methodological point of the DDPP is the accommodation of different modelling paradigms supporting national decarbonization studies in different countries, ranging from sophisticated combinations of macroeconomic, technology stock turnover and land use models to simple spreadsheets (Pye & Bataille, 2016). This wide range of analytical methods allows derivation of insights on carbon prices from the set of national DDPP studies, including findings in relation to a global composite, together with the richness and specificity of understanding of 16 major economies.

### *2.1 – Shadow carbon prices*

The DDPP teams worked with models different in nature and their numerical findings may have different interpretation. However they have in common to give trajectories of 'shadow carbon prices' which underpin the considered decarbonisation policies consistent with a normative emission target. These prices provide a measure of the social value attributed to mitigation actions at each point in time. It can be expressed in terms of the price signal that would be necessary and sufficient to incentivize rational choices by economic agents to curb carbon emissions according to the objective and hence avoid these future costs.

Two main general conclusions can be derived from examples in the DDPP scenarios:

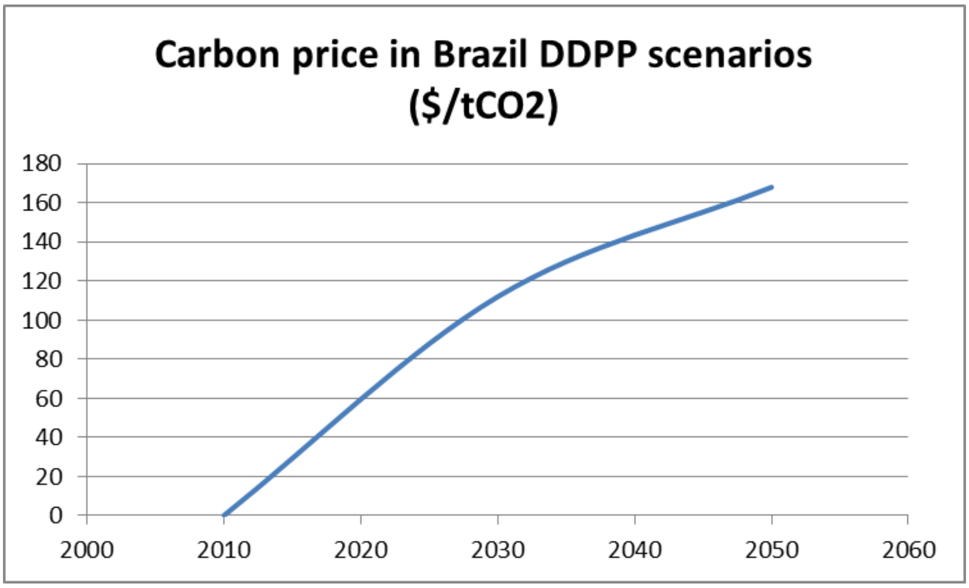
**a) To make long-term decarbonization happen, a rapid increase in the signal on the shadow cost of carbon to emitting firms and households is needed in the short-term**. This price increase is faster than the trends obtained when assuming intertemporal optimization and flexible adjustments like in many Integrated Assessment models, because a strong short-term price signal is required to provide early incentives to ensure the requisite innovation and investment in mitigation, including long-lived infrastructure and R&D which will only bear their necessary fruit in the longer term. As decarbonization objectives become more stringent, the incentives (as reflected by a carbon value) will need to increase over time, but at a slower pace than in the short-term. The three scenarios of the UK DDPP study illustrate this conclusion (see (Pye et al, 2015) for more in-depth presentation and discussion of the UK scenarios). All scenarios feature a similar trend for the carbon value, although with ranges according to the assumptions. The modelled estimates of carbon prices required under the scenarios highlight the increasing challenge of the 4th carbon budget, shown by the increase between 2020 and 2025. The continued increase under M-VEC to 2030 indicates delayed and lower uptake of key mitigation technologies in the power sector, namely nuclear and CCS. R-DEM is consistently lower than D-EXP due to the higher efficiency gains, and lower demand observed under this scenario. By 2045, estimates are between £270-370/tCO2, up from £150 – 250/tCO2 observed in 2025. The results for 2050 are not plotted but indicate an extremely challenging situation (>£1000/tCO2), driven by residual emissions that are difficult to mitigate.




**b) The need for high and rising carbon prices is also valid in national modeling for developing countries, but the value appears lower in absolute terms in these countries than analysis of developed countries.** Two structural explanations can be put forward for this difference. On the one hand, under the institutional and policy context of developing countries, where markets are incomplete because of a strong role of informal exchanges, instability of institutions and fast evolving infrastructures affecting the access to information and visibility at different time horizons, economic signals may be swamped in a myriad of contradictory signals and incentives and the carbon price signal cannot be, at least in a transition period, at the core of the decarbonization.

On the other hand, these lower nominal values have a strong effect in triggering bifurcations in the domestic economies. Indeed, the carbon price level is not sufficient to measure its impact, which instead depends on the effect of higher energy prices in the specific context of the economy considered. A rise of energy process affects proportionally more the developing economies, because price-elasticities are higher at lower income and because these economies have a higher ratio of the energy to labour cost (which is the core driver of general equilibrium effects of higher costs of energy (Waisman et al, 2012)).

This is illustrated by the South African and Brazilian scenarios developed under DDPP. Both scenarios achieve ambitious decarbonization, as measured by a 80% decrease of the ratio of carbon emissions to GDP between 2010 and 2050 in both cases. But this is achieved with lower ranges of absolute carbon prices compared to those reached in developed countries. Both studies use national models, the COPPE team analysing an explicit carbon price, the ERC team an implicit carbon price. In both studies, the socio-economic implications of mitigation are considered highly policy-relevant. The difference between South African scenarios and Brazilian scenarios, the latter showing higher values of carbon price for a comparable decarbonization, can be explained by two main reasons (see (Altieri at al, 2015) together with (Merven, Moyo, Stone, Dane & Winkler 2014); and (La Rovere et al, 2015) for more in-depth presentation of the South African and Brazilian analyses, respectively). On the one hand, the nature of the transformations is different, given different country circumstances. Massive decarbonization of electricity, which can happen even at moderate carbon prices, is the core of the technical transformation in South Africa, given a coal-based energy economy. In the Brazilian analysis, whereas renewable biomass both from forestry and modern first and second generation liquid biofuels, energy efficiency and electrification are more intense, where the resource endowment of hydro and more recently wind power has led to a relatively low-emissions grid historically that may be continued in the future complemented by the development of solar and biomass. Second, the nature of the strategies themselves is different; while in the Brazilian case mitigation actions are essentially triggered by carbon prices in the context of a broader mitigation policy package, the South African scenario considers a set of structural transformations that support the decarbonization process but are not essentially triggered by carbon prices. In this latter case, relatively low carbon prices are sufficient to reach the 80% decoupling of emissions. This suggests that the economic and policy context in which the carbon price applies is a key driver of price levels compatible with a given mitigation objective.




An explicit example is provided by another study conducted by the ERC team (Merven, Moyo, Stone, Dane & Winkler 2014), which compared the results of implicit carbon price due to a Renewable Energy programme to a carbon tax, using the tax rate in the policy design by National Treasury. In this study, treasury's proposed tax rates (National Treasury 2013) are approximated by a CO2 tax runs starting at $5 (R48)/ ton CO2) in 2016, increasing to $12(R120)/ton CO2 in 2025. Figure 5 shows a comparison of the emissions resulting from explicit and implicit carbon pricing in the power sector under different renewables energy programs.

In Brazil, even though a wide spectrum and high abatement potential of low cost mitigation options are available, higher carbon prices are not sufficient to overcome the barriers of insufficient domestic savings and financial sector imperfections. Carbon pricing is seen as part of a broader mitigation policy to de-risk low-carbon investments and make them attractive to public-private partnerships. The right regulatory framework is required to foster innovation and grow the market share of low carbon technologies enabling to redirect financial flows towards them.

The next section discusses this more in-depth on two other examples.

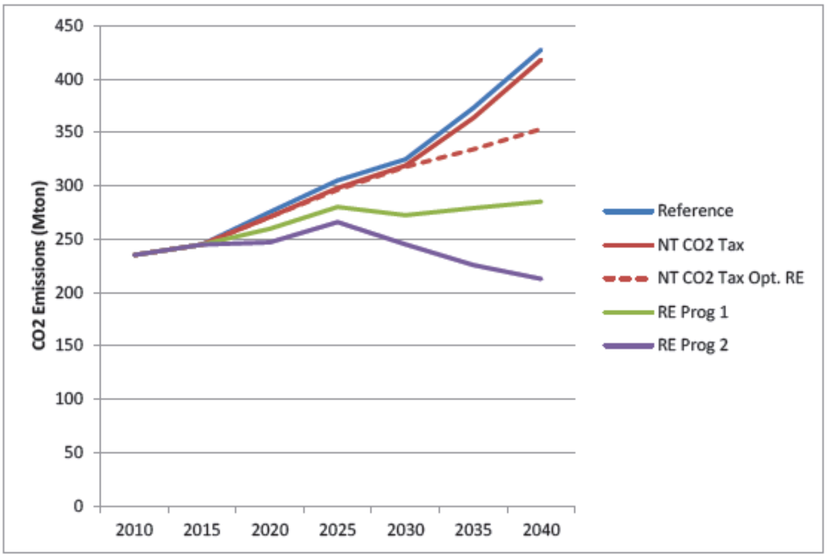



**Figure 5:** $CO_2$ **emissions from power sector**

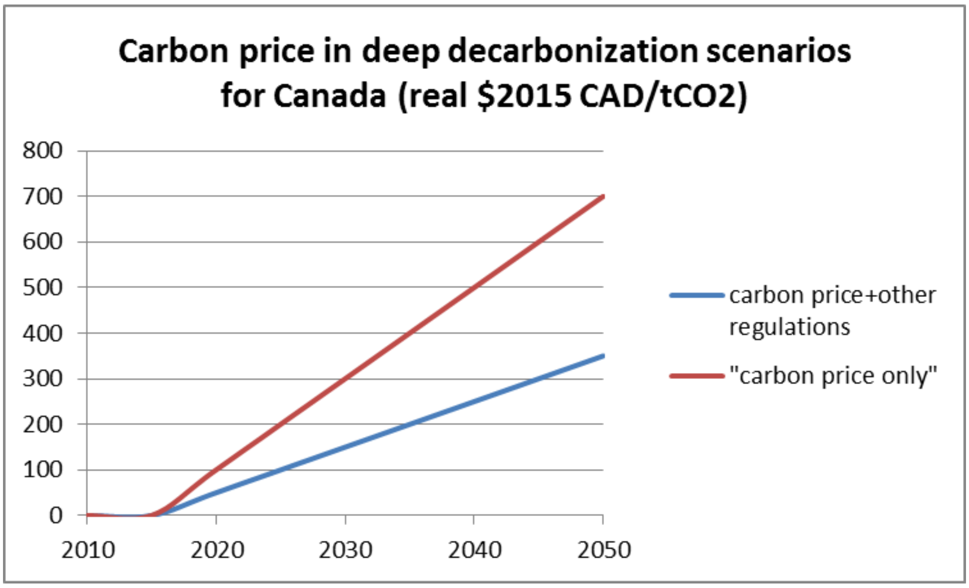
### 2.2 – Carbon prices, as instruments of a policy package

In contrast to the underlying economy wide, equimarginal carbon shadow value needed to reach a given target, trajectories of explicit carbon prices (i.e., the pricing instrument concretely introduced in the national tax system and actually paid by firms and households) are obtained using models with a high level of granularity suited to represent the details of the socio-economic system. This can be thought of as an implicit carbon price, resulting from national models even if they do not model carbon pricing instruments (taxes or ETS), but other policies. In these policy orientated models, the evolution of the economy in a low emission pathways depends on the interplay between end-use demand, energy prices, the carbon price stringency and sector coverage, recycling methods and non-price instruments (e.g. technology efficiency or GHG intensity regulations).

Two main conclusions can be derived from the DDPP studies in this regard

a) **The explicit carbon price needed depends upon the combination and interaction with other actions and measures in the national "policy package"**

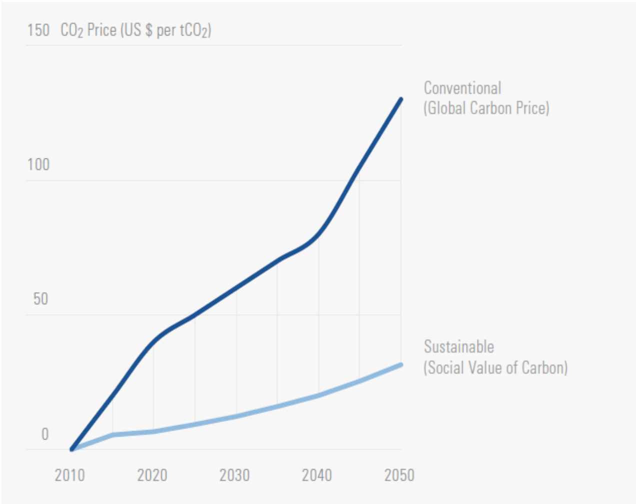
The same emission reductions can be reached with low carbon prices, if less price-sensitive sectors are addressed by targeted policies. While carbon pricing is essential, especially for directing innovation towards GHG mitigation, it may prove politically impossible or practically infeasible to raise prices high or fast enough for some sectors (e.g. personal and freight transport, residential and commercial buildings). For these sectors, performance based, potentially tradable GHG intensity regulations that closely mimic the efficiency and effectiveness of carbon pricing may be necessary. Other sectors, like iron and steel, while sensitive to carbon pricing, are very exposed to trade pressures and potential carbon leakage. They may instead require regionally and sectorally specific policy mechanisms to maintain political buy-in and the pressure to innovate and invest in the cleanest technology possible. This may involve conditional exemptions or free emissions permits that require strong innovation, or creative recycling systems that have the same effect (e.g. cap and trade with output based recycling). Finally, some sectors, like land use and diffuse methane fugitives, may be impossible to price and will require some form of regulation. As discussed more in depth in (Bataille et al., 2015), the Canadian team for one, to maximize long term political acceptability, used a combination of: economy wide carbon pricing starting at \$10/tonne $CO_2$e (CAD 2015) and rising \$10 per year steadily through time, recycled equally to corporate and income taxes; sector specific performance based regulations for new and retrofit transport and buildings falling to net zero emissions by 2025-2040; an intensity based, tradable performance standard falling to -90% by 2050 for large emitters using output based allocations; and methane and land use regulations to achieve its DDPP target at the lowest possible carbon "sticker price". The below figure compares carbon price levels needed to reach below 2tCO2 per capita in 2050 under the above described policy package ( 350 real\$2015CAD/tCO2 in 2050), vs the carbon prices needed to reach the same emission levels in absence of the above regulations (around 700 real\$2015CAD/tCO2 in 2050)




b) **Articulating the climate goal with other sustainable development targets allows achievement of the same climate objective with a lower carbon price and economic gains compared to a climate-centric approach.**

A climate-centric perspective focused on the carbon price as the only driver of transformation fails to capture the broad set of potential complementarities between the climate and other sustainable development objectives. Integrating the thinking about carbon prices with a broader perspective of the integrated social, economic and environmental value of mitigation action (SVMA) recommended by the article 108 of the Paris decision, shows the extent to which land use policies, transport infrastructure and urbanplanning, laws and development, building codes, education, technology substitution, and investment flows can deliver the same level of cumulative carbon emissions at much lower carbon "sticker price".

The Indian DDPP team implemented two scenarios subject to the same carbon budget (see (Shukla et al, 2015)); a solely climate focused "Conventional Scenario" and a "Sustainable Scenario" met in combination with other sustainable development goals. The top line in the figure below is a global carbon price introduced exogenously in the 'Conventional Scenario' and taken from carbon price levels obtained for India in a '2$^{o}$C' scenario from an IAM study. The sustainable scenario also considers additional measures targeting non-carbon emissions indicators (local pollution, energy security, urban planning, decentralized energy for rural areas etc., water management) which were driven by stronger demand-side push, behavioral change, and infrastructure push measures compared to using the carbon price as the sole instrument. The analysis of the scenario shown in the figure below shows that the carbon price needed to reach the same carbon budget is much lower in this second case, illustrating the benefit of exploiting synergies between climate and other sustainable development goals.

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