

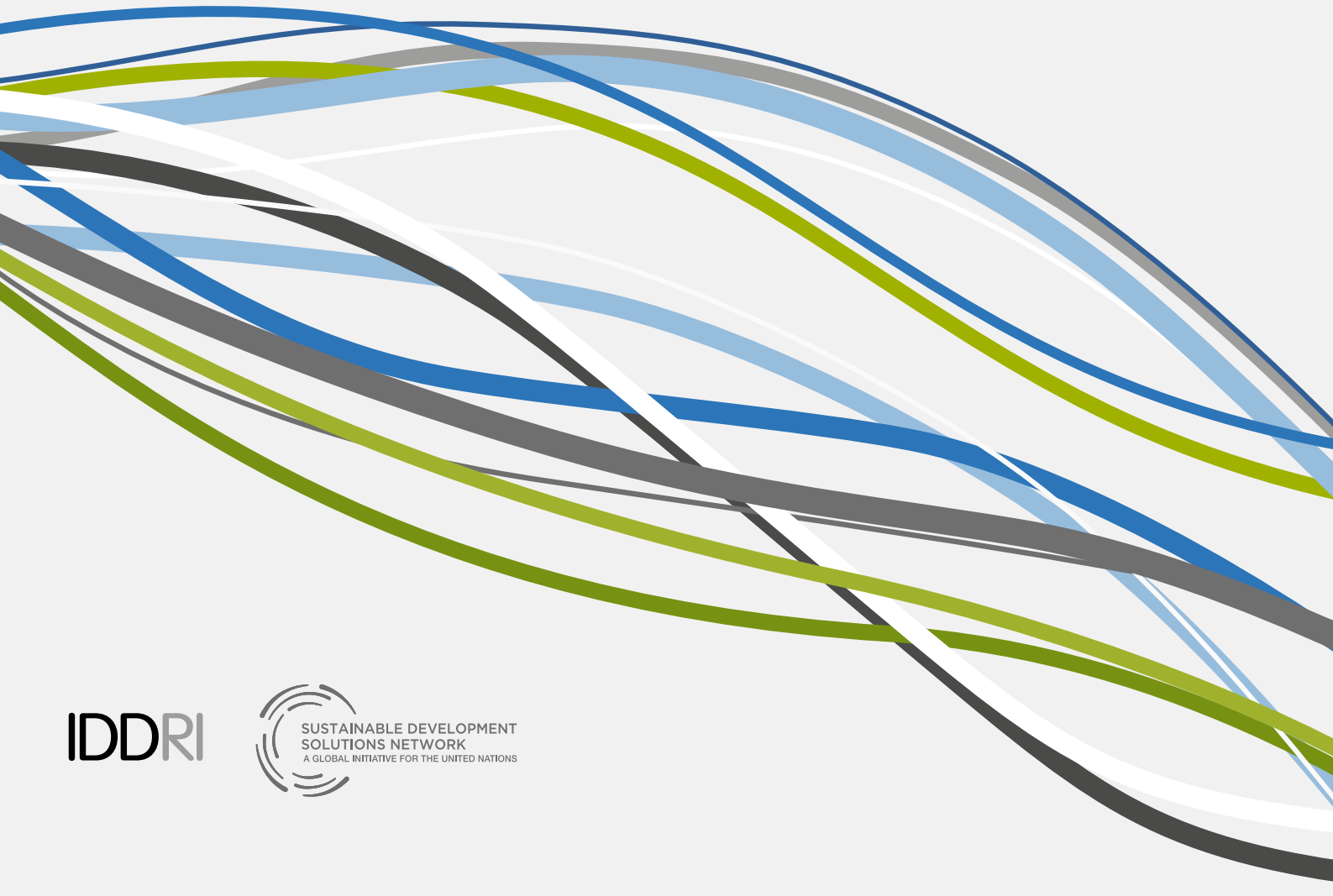
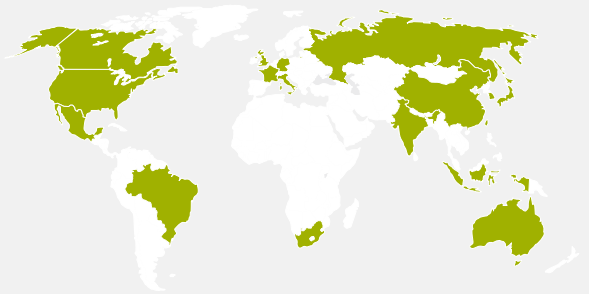


DEEP
DECARBONIZATION
PATHWAYS
PROJECT

2015 report

supplementary material

pathways to
deep decarbonization



IDDRI



SUSTAINABLE DEVELOPMENT
SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS

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IDDRI

The Institute for Sustainable Development and International Relations (IDDRI) is a non-profit policy research institute based in Paris. Its objective is to determine and share the keys for analyzing and understanding strategic issues linked to sustainable development from a global perspective. IDDRI helps stakeholders in deliberating on global governance of the major issues of common interest: action to attenuate climate change, to protect biodiversity, to enhance food security and to manage urbanization, and also takes part in efforts to reframe development pathways.



The Sustainable Development Solutions Network (SDSN) was commissioned by UN Secretary-General Ban Ki-moon to mobilize scientific and technical expertise from academia, civil society, and the private sector to support practical problem solving for sustainable development at local, national, and global scales. The SDSN operates national and regional networks of knowledge institutions, solution-focused thematic groups, and is building SDSNedu, an online university for sustainable development.

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pathways to deep decarbonization

Supplementary material

This supplementary material contains case studies presenting specific aspects of the DDPP country pathways. They illustrate and complement the cross-cutting analysis included in the 2015 DDPP synthesis report, available at:

http://deepdecarbonization.org/wp-content/uploads/2015/12/DDPP_2015_REPORT.pdf

Detailed, comprehensive presentation of the country pathways can be found in the country reports available at:

<http://deepdecarbonization.org/countries/>

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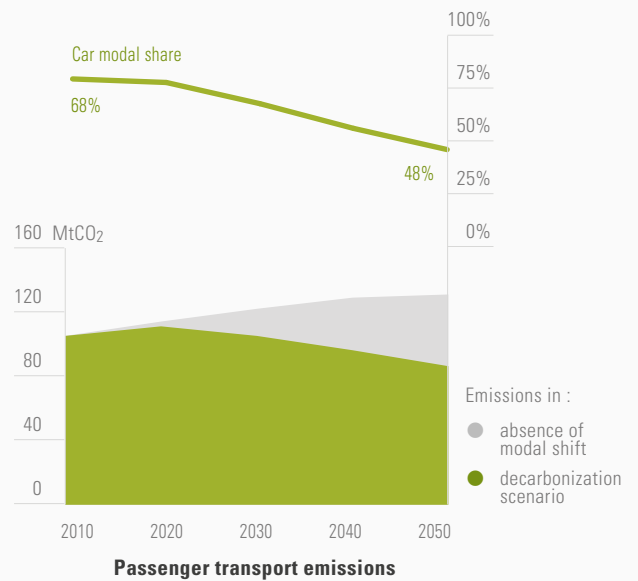
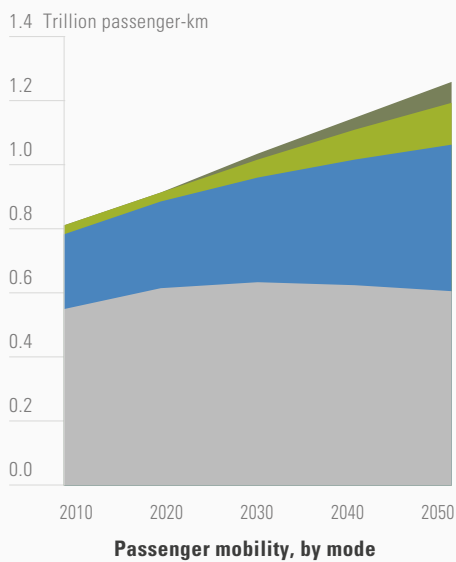
1 Country Case Study Mexico

Modal Shift in Passenger Transport

The transport sector is currently the largest single source of GHG emissions in Mexico. It accounts for approximately 30% of all energy, close to 70% of which is used by passenger transport alone. The demand for transportation could increase from the present level of

0.9 trillion passenger-kilometers to 1.4 trillion passenger-kilometers by 2050, a total increase of 56%, in line with the increase of individual mobility from 7800 to 9200 passenger-kilometers per capita between 2010 and 2050. In 2010 approximately two-thirds of motorized

Figure SM 1. Mexico. Passenger road transport modal shift and emissions, 2010-2050



journeys were made in light-duty vehicles, such as cars and taxis, and the rest in buses and other forms of transportation (planes, urban-trains and motorcycles). In 2010 the average occupation rate was estimated at around 1.4 people per car, and the amount of vehicles at 207 vehicles per 1000 people.

If actual trends are maintained, where the use of light vehicles with fewer people on board is favored, the amount of energy consumed would increase from 250 million barrels of oil every year today to 300 and annual CO₂ emissions would increase to 130 MtCO₂ by 2050 (108 MtCO₂ today).

Deep reductions in CO₂ emissions in this sector require convergent strategies:

- Modal shift towards mass transit to increase person kilometers km per unit of energy.
- High efficiency in all vehicles.
- Electrification & fuel switching to lower the emissions intensity of final energy consumed.

In the deep decarbonization scenarios, light-duty vehicles' share of travel is reduced to below 50% of demand, through stabilization of total mobility satisfied with this mode in parallel with development of mass-transit and low-carbon modes (Figure SM 1). This modal shift, together with efficiency improvements in vehicles, results in energy savings of nearly 30% compared to the reference scenario when one extrapolates the trends of the last 20 years. The resulting CO₂ emissions abated would be around 45 MtCO₂e by 2050, a reduction of 34% against the reference scenario.



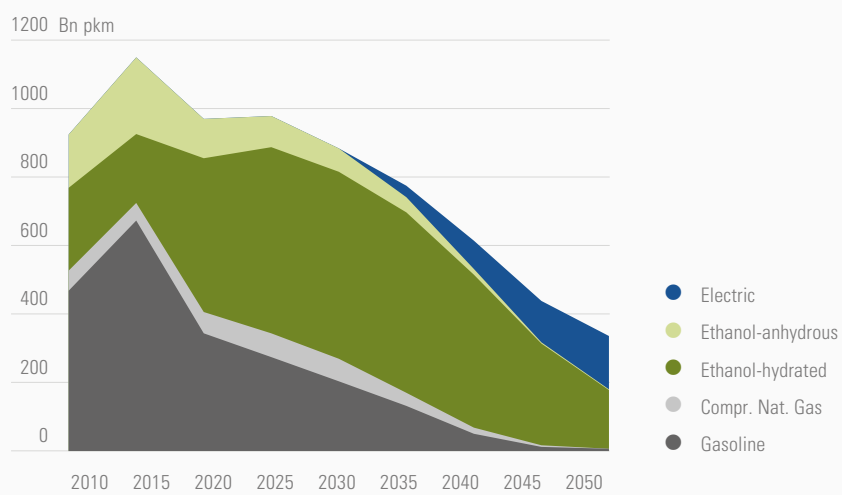
2 Country Case Study Brazil

Biofuels

Endowed with vast tracts of land suitable for agriculture, animal breeding and sustainable forestry exploitation, Brazil has sought to leverage these natural resources in fields beyond food production. The production of biofuels, especially ethanol and biodiesel, has been increasing since 1975, as a response to the country's once strong dependence on oil imports.

Ethanol, from sugarcane, is manufactured through a highly energy-efficient and land-efficient process with further potential gains from known technology. The ethanol adoption strategy is in a very advanced stage. Anhydrous ethanol is currently added to all gasoline sold in the country, forming gasohol in a mandatory 27% proportion (25% for premium gasoline), the maximum level with current vehicles. On the other hand, hydrat-

Figure SM 2. Brazil. Passenger Cars and Taxis - Activity per energy source



Source: MCTI, 2013: *Estimativas Anuais de Emissões de Gases de Efeito Estufa no Brasil*.

ed ethanol is also available everywhere as a standalone fuel, powering the country's large fleet of flex fuel cars, which now comprises the bulk of cars sold domestically, with a large potential for ethanol's further expansion.

By contrast, biodiesel from soybeans and animal fat produce fuel less efficiently, and it is currently added to fossil-based diesel oil in a B7 (7%) proportion, which is expected to rise at to the B22 level in the coming decades. Biodiesel's share has great expansion possibilities as long as biodiesel production costs remain economically feasible. Both sugarcane ethanol and soybean biodiesel compete with food usage of the same plants. Eventual rises in international sugar prices may divert producers away from ethanol, resulting in market shortages and price hikes that turn away potential ethanol-run car users (this is happened in the 80's and 90's and almost collapsed the market for such cars). Nevertheless, while the recent discovery of large offshore oil reserves is making Brazil self-sufficient in crude oil and its derivative products, the clear environmental benefits from the use of biofuels, not limited to climate change mitigation, have influenced the current official midrange policy of directing all additional oil production to export, while promoting the expansion of biofuels nationally.

Both fuel change strategies, although not designed primarily for climate mitigation, have proven very successful in decarbonizing the transport sector. But their continued success depends on consistent government policies over the coming decades, including removing subsidies for fossil fuels and using the recovered revenues to promote policies for biofuels. Furthermore, adhering strictly to such policies is a precondition for reaching deeper decarbonization with the current Brazilian fuel strategy.

In the Brazilian DDP scenario, the use of cars will continue to grow, induced by the rise in per capita income and increased urbanization; but the total fossil fuel consumption by cars does

not grow in the same proportion, because of efficiency gains and flex fuel car drivers' preference for ethanol. This requires that the government tax policies concerning biofuels and fossil fuels be fine-tuned so that the final price per volume of hydrated ethanol is always kept below 70% of the price of gasoline, the reference that car drivers use for fuel choice trade offs, given gasoline's higher car mileage per volume.

If the price gap between the two fuels is further widened, car buyers might have an extra incentive not to buy gasoline-only cars, which would also contribute to the increase in ethanol's market share. Through the combined use of these strategies, gasoline consumption by cars should drop considerably, reaching around 5% of today's levels in 2050. It is noteworthy that the DDP scenario also considers an increasing share of electric vehicles starting from 2030 to a 6.2 million-vehicle fleet associated with a fully decarbonized power sector in 2050. Electric vehicles displace both gasoline and ethanol cars, given their advantages of less noise and air pollution.

Unfortunately, in the early 2010s, Brazil has been departing from the fuel consumption pattern proposed in the DDPP 2015 scenario. As [Figure SM 2](#) shows, gasoline usage has increased more than 40% from 2010 to 2014, while hydrated ethanol sales slumped. The fuel tax policies adopted in this period and the resulting relative prices were the opposite of what is needed to reach a desirable renewable fuels share by 2020. A sharp trend reversal must happen if a deep decarbonization path is to be pursued, which can only be achieved with adequate taxation schemes. The government should also adhere to its plans to export the extra crude oil produced in the next few years and resist the temptation to divert it to the internal market when international prices drop.

3

Country Case Study Indonesia

Hydropower for Decarbonization

In the Indonesia country analysis, the large scale deployment of renewables in electricity generation, with a central role for hydropower, solar PV, and geothermal, is a crucial strategy to reach deep decarbonization, allowing further electrification of end-uses. A crucial challenge to implementing this strategy is that Indonesia is an archipelago with a very uneven distribution of population and economic development. Population and economic development is concentrated in the western part of Indonesia i.e. Java and Sumatera (see [Figure SM3](#) below). Renewable energy resources are instead spread over all the

islands and do not match with the location of demand centers.

In the case of hydropower, the major resource is located in the eastern part of the country while the major demand center is in western Indonesia, particularly Java. Notably, out of a total of 75 GW hydropower potential, around 25 GW (30%) is located on Papua Island. To decarbonize the electricity sector, around 63 GW of this hydropower potential has to be deployed by 2050. Assuming that the location of the demand center remains in western Indonesia, deployment of the Papua hydro resource could only be material-

Figure SM 3. Indonesia. Illustration of hydro resource vs. demand mismatch in Indonesia

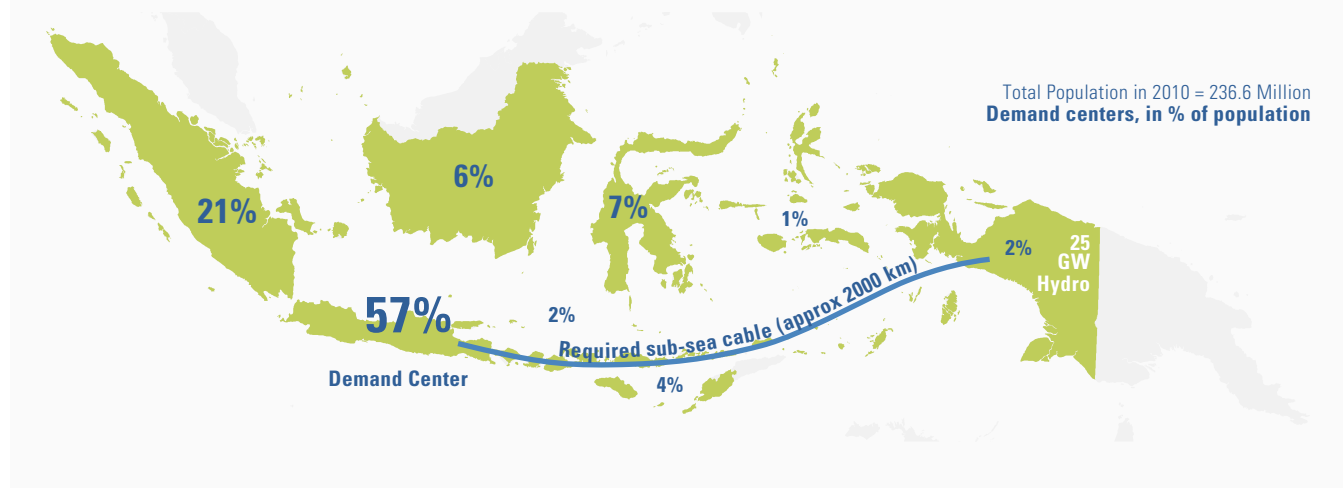
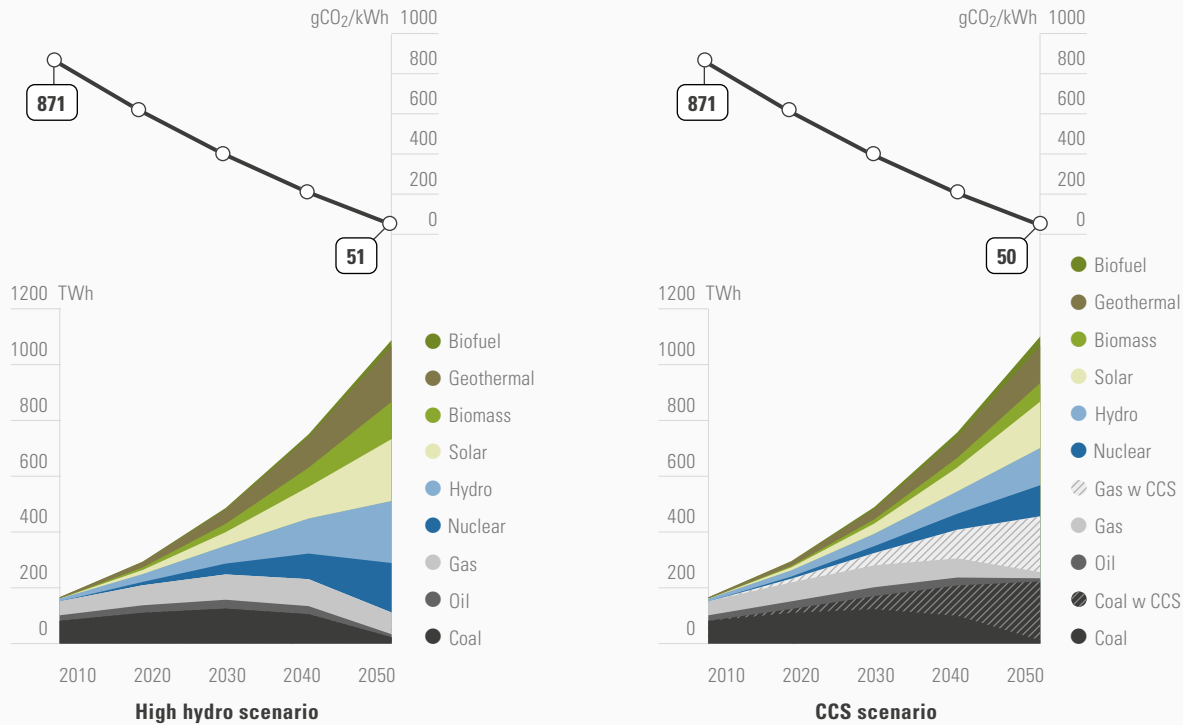


Figure SM 4. Indonesia. Scenario of decarbonization of electricity sector in Indonesia



ized if a long distance deepwater subsea cable is available at competitive cost. Considering the current state of subsea cable technology, the utilization of remote hydropower resources in Indonesia's decarbonization strategy therefore poses an uncertainty. As an alternative, if a subsea cable is not feasible in 2050, to achieve the decarbonization target Indonesia has to adopt other low-carbon technologies, such as coal and natural gas equipped with a CCS system. Figure SM 4 shows a comparison between two major decarbonization options, depending on whether hydropower with a subsea cable is available (left-hand side) or not, where natural gas and coal equipped with CCS play a dominant role in bridging the gap.

4

Country Case Study Brazil

Hydropower

Brazil has among the five largest potentials for hydro power worldwide. In 2015, there are 197 hydroelectric power plants and 741 small hydropower plants (SHP)¹ in operation, accounting respectively for 61.6% and 3.5% of the total installed power generation capacity, which is about 138 GW (ANEEL, 2015). The Brazilian technical hydraulic potential is estimated at 247 GW (see Table SM 1), of which between 180 GW and 200 GW are economically feasible. However, there are a number of controversial issues related to these projects, including potential disturbance of the Amazon biome, their location

far from the large consuming centers, and social and environmental hazards associated with their construction.

Other relevant energy sources are base load nuclear power plants and thermal plants that are used primarily to balance variable renewable resources. Wind and solar energy, even though still incipient, are expanding fast. Wind energy, in particular, is well suited to complement hydropower, since periods of low rainfall coincide with higher wind energy production.

When analyzing the Deep Decarbonization Pathway electricity generation share, striking features appear. First, the share of hydropower in the electricity mix decreases over time. This is the logical outcome of a very fast increase

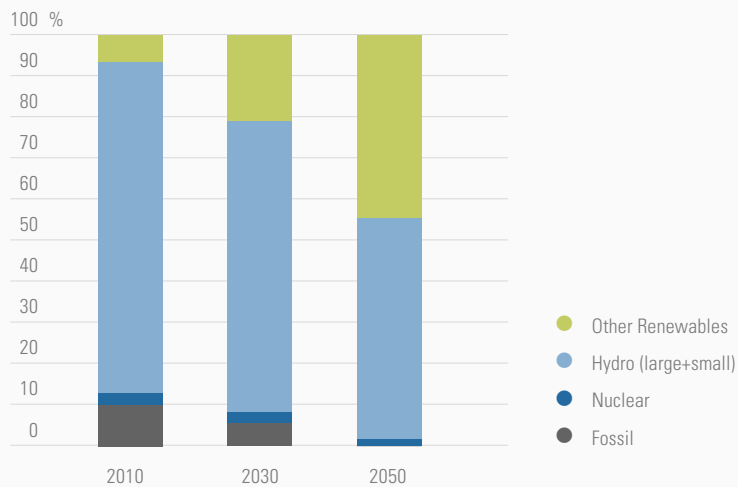
¹ A small hydropower plant is defined as a facility with between 1 and 30 MW of installed capacity and a reservoir area no larger than 3 square kilometers.

Table SM 1. Brazil. Hydro power potential per basin*

Stage/Basin	Eastern Atlantic	Northern/Northeastern Atlantic	South-eastern Atlantic	Amazon river	Paraná river	Sao Francisco river	Tocantins river	Uruguai river	Total per stage
Remaining	767	525	941	17 584	3 414	694	1 780	12	25 717
Individualized	655	182	1 090	15 391	2 296	867	128	404	21 013
Estimated total	1 423	707	2 031	32 976	5 710	1 561	1 908	416	46 730
Inventory	5 567	1 183	1 756	38 164	9 275	3 883	7 897	4 017	71 743
Viability	725	408	2 218	774	1 760	6 140	3 738	292	16 055
Basic Project	852	55	366	2 156	2 593	289	134	598	7 043
Construction			25	13 458	32				13 515
Operation	5 393	587	3 709	8 882	43 335	10 724	13 193	6 333	92 156
Total	13 960	2 941	10 105	96 410	62 705	22 596	26 869	11 656	247 242

* December 2014

Source: SIPOT/Eletronbras (2015)

Figure SM 5. Brazil. Deep Decarbonization Pathway: Power generation sources

in electricity production (multiplied by 3.6 over 2010-2050) when a sizable share of the overall potential is already deployed in 2010 (installed hydropower capacity can reach only 180GW, or a multiplication of “only” 2.6 over the same period). Nonetheless, hydropower remains the major source of electricity even in 2050, demonstrating the crucial role this energy will keep on playing over the coming decades, even when taking deployment constraints into account. Therefore, the development of hydropower is a necessary but not sufficient condition for deep decarbonization, the main difference lying in the development of other renewables (wind and solar) which account for the rest production under the DDP (see [Figure SM 5](#)).

The importance that hydro energy has had in supporting economic development in Brazil is unquestionable. Nevertheless, these ventures sometimes have significant impacts on other uses of the water resource. The negative outcomes of the construction of dams in the Amazon region are primarily due to the effect of reservoir flooding, displaced flora and fauna (bi-

odiversity), water quality deterioration, and the loss of terrestrial and aquatic ecosystems services (Tundisi et al., 2006). The related greenhouse gases emissions from vegetable decomposition, mainly methane, are also estimated to be significant in several instances (Abe et al, 2005). Reconciling electricity generation with other river uses such as waterways, irrigation, fishery and tourism may also pose a challenge, as do the needs to assure respect for the rights of indigenous populations and other traditional communities, such as the *ribeirinhos*, who rely strongly on the available natural resources. New power plants address some of these issues by using a “run-of-river” design, with smaller and reservoirs. However, their operational efficiency may be compromised.

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5

Country Case Study China

Production Profiles/Industry

As a main sector driving economic growth, industry accounted for almost 69% of final energy consumption and 72% of total energy-related CO₂ emissions in 2010.

Since the 1990's, China has made great strides in improving industrial energy efficiency by vigorously eliminating backward production capacity and promoting advanced energy-saving technologies. This has permitted a significant reduction in energy consumption per unit output in most major industrial activities during the 11th Five-Year-Planning period 2006-2010 (see [Table SM 2](#))

Over a longer period, from 1990 to 2012, the steel and cement sector have in particular experienced large efficiency improvements, with the highest decrease rate among several main countries. As a result, in 2012, the energy consumption per ton of clinker production in China was lower than world average, EU 28, United

States and Germany and the energy consumption per ton of crude steel in China is around the world average (see [Figure SM 6](#)).

These energy efficiency improvements are driven by a combination of factors, notably industrial structure optimization, energy efficiency technology investment and innovation, and energy consumption control and management. In recent years, innovating development pathway and solving environmental pollution have had an important role in driving energy efficiency improvement. In September 2013, the Chinese government promulgated the Air Pollution Prevention and Control Action Plan, which put big pressure on many industry-dominant regions to accelerate the elimination of backward facilities and control low efficiency and total coal consumption.

In June 2015, the Chinese government submitted its Intended Nationally Determined Contribu-

Table SM 2. China. Variation of energy consumption per unit output 2006-2010*

crude steel	cement	electrolytic aluminum	aluminum oxide	copper smelting	petroleum refining	ethylene	synthesis ammonia
-12%	-28.6%	-3.9%	-36.7%	-52.3%	-7.9%	-11.3%	-4%

* Center for Industrial Energy Efficiency. Report of China's Industrial Energy Saving Progress 2011.

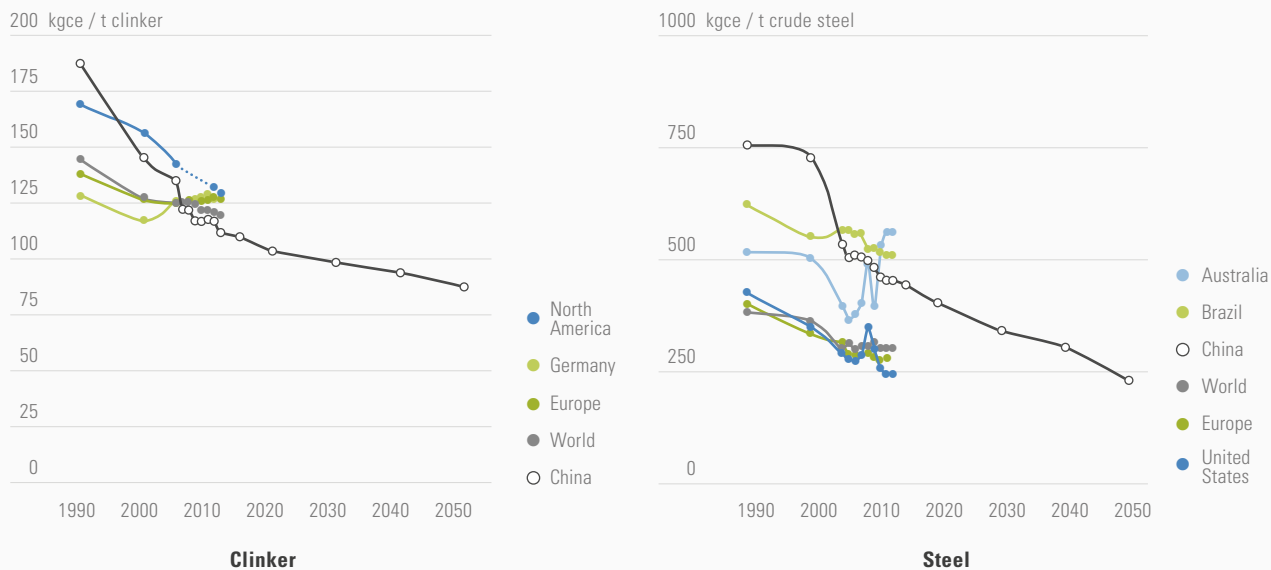
tion, which requires China to seek an innovative new path of development and upgrade its growth model to a “new normal”. As the industry sector accounts for around 70% of total energy-related CO₂ emissions, the achievement of a carbon emission peaking target means that industrial carbon emissions should peak earlier, which would enhance the requirement for further improvement of energy efficiency in the industry sector within 10-20 years.

Nevertheless, it should be noted that, in total, Chinese industry remains significantly more energy intensive than developed countries, notably because of the large share of the most energy-intensive sectors in Chinese industrial structure. Indeed, energy consumption per unit of indus-

trial added value is 0.516 kgce/\$ in China¹ in 2012, which is about 2 times the world average (and 3.7, 4.4 and 5.5 times the level in US, EU and Japan respectively). Further improvement of energy efficiency faces challenges, however. First, because policies and measures offering the most potential (such as eliminating backward production capacity and retrofitting old facilities to increase technological efficiency) have already been largely implemented over the last two decades. Second, because of specific characteristics, like the variability of the scale of enterprises, the coexistence of advanced and backward technologies and the dominant role of coal. Third, because China is still a developing

¹ Calculated by data from World Energy Outlook 2014 (IEA, 2014), CO₂ Emissions from Fuel Combustion (IEA, 2014) and World Development Indicators (access in 2015)

Figure SM 6. China. Energy consumption per ton in each region over time

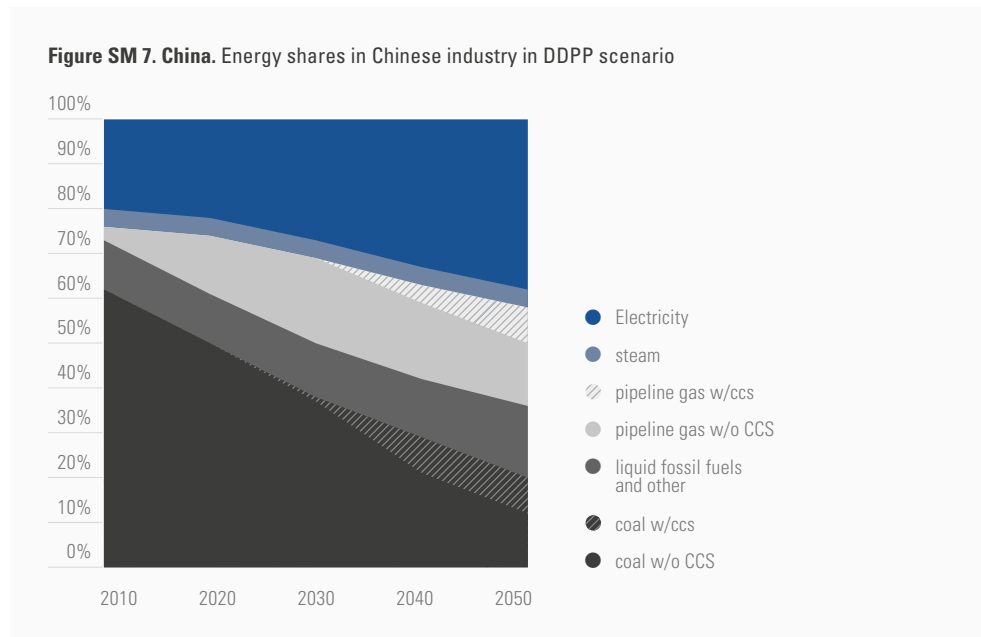


a - Data before 2012 is from World Business Council for Sustainable Development, Cement Sustainability Initiative, GNR PROJECT.

Predicted value is consistent with DDPP of China.

b- Data before 2012 is from World Energy Council, Energy Efficiency Indicator, Enerdata.

Predicted value is consistent with DDPP of China



country facing financial and technological constraints, which affect the potential for improving energy efficiency and management. Therefore, it is very crucial for China to use more innovative and broader approaches to improve the overall efficiency of the industry sector, especially giving more attention to adjusting and optimizing the industry and product structure in the future. Meanwhile, from a long-term perspective, China still has potential to adopt more advanced low-carbon technologies and optimize the energy-use structure to increase energy efficiency. In the deep decarbonization scenario, the CO₂ emissions from fuel combustion in the industry sector peaks around 2025 with about 7.2 GtCO₂. While the energy use of the industry sector reaches 1588 Mtoe in 2050 (+24% from 2010 level), CO₂ emissions decrease to less than 2.6 GtCO₂, nearly 60% of the 2010 level. This is reached by a combination of measures. Energy efficiency is improved significantly, as measured by a 75% decrease in energy consumption per value added of the industry sector from 2010 to 2050 (reaching the average current

level in the European Union). This is permitted by the application of energy saving technologies, high-efficiency waste heat recycling technologies, and high-efficiency boilers and motors in the industrial sector. In particular, the energy consumption per unit of product output of energy-intensive industries are significantly reduced between 2010 and 2050 (-53%, -26%, -20% and -19% in iron and steel, cement, synthesis ammonia and ethylene production, respectively). In addition, structural change brings additional potential for energy efficiency at the sectoral level given the decrease of energy-intensive secondary production (which drops from 46.5% of GDP in 2010 to 32.5% in 2050) substituted by the development of tertiary industry (which grows from 43.7% of total GDP in 2010 to about 65% at 2050). Notably, the output of some high energy-intensive industry products (notably, cement and crude steel) are anticipated to peak by 2020.

Fuel switching is also a crucial strategy for deep decarbonization. In particular, the share of coal can be significantly reduced from 62% in 2010

to 22% in 2050, by promoting the transformation of coal-fired boilers to gas and enhancing the use of electricity (Figure SM 7). Gas plays a crucial bridging role in the short-term, whereas electricity takes over after 2030, once the decarbonization of electricity generation allows direct electricity use to be less carbon-intensive than direct coal use. The large-scale deployment of CCS after 2030 is also key in industry sectors, notably for the most energy-intensive sectors (cement, iron and steel, chemicals and petrochemicals). CCS captures ~25% of total sectoral CO₂ emissions in 2050. In total, these changes allow a 70% reduction of CO₂ emissions per unit energy consumption of the industry sector, reaching half of current European Union level.

6

Country Case Study France

Building Sector

In 2010 the residential sector in France was responsible for 30% of final-energy consumption, two-thirds of which was for heating. This is a key issue for energy demand policy and decarbonization in France but also in many other developed countries. In countries with mature infrastructure, the core of the building stock was built several decades ago with low concern for energy conservation, leading to the energy efficiency of the current building stock being low. In France, the first thermal regulation was introduced in

1975 and 55% of the 2010 building stock are older than that. Average final-energy consumption in existing dwellings is 190 kWh per sqm, with thermal energy (heating and hot water) accounting for nearly 80% of energy consumption. Given its very long lifetime, around 70% of the building stock that will exist in 2050 has already been built so that standards on new construction, even if ambitious, will be insufficient to trigger a significant improvement in energy efficiency. Instead, deep thermal retrofitting of

Figure SM 8. France. Evolution of energy labels in current buildings

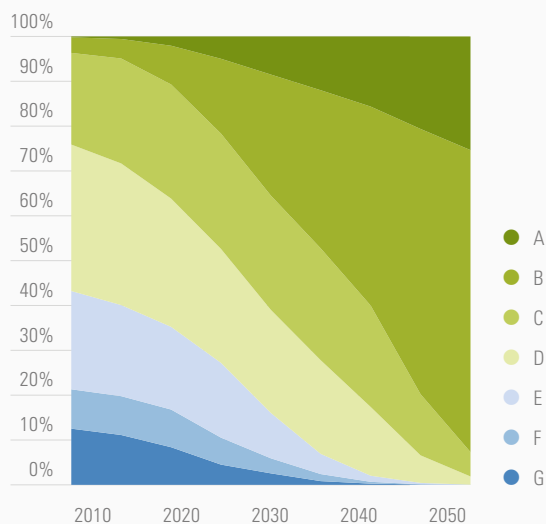
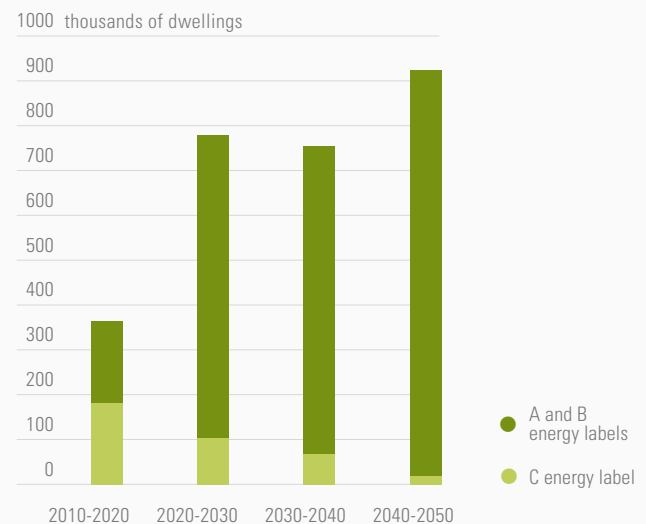


Figure SM 9. France. Housing retrofits per year (thousands of dwellings)



an important part or even of the entire existing buildings would be a central strategy to address energy consumption and carbon emissions from the residential sector. If the entire building stock were to be retrofitted, then the number of dwellings heavily rehabilitated each year would need to increase steeply, reaching 2% of total building stock each year (Figure SM8).

Experience shows that thermal retrofit of buildings is in most cases justified on a standard economic calculation basis, but that at the same time such operations are often difficult to trigger in real life, due to substantial transaction costs, funding difficulties, and the short return-on-investment – and consequently high implicit discount rate – demanded by building owners. The ‘landlord-tenant dilemma’ is also a major issue: the landlord is supposed to commission the operation but as he does not pay for energy consumption, he has little incentive to invest in the energy efficiency of the dwelling. All these factors relate to the well identified “energy-efficiency gap”. While investment costs for a deep retrofit will indeed be recovered by an annual savings over the lifetime of the building, owners usually require much shorter payback times, often of 3 to 5 years.

Various types of policies may be deployed to narrow the gap between collective and individual rationales, in particular subsidies to reduce the cost of investment, such as tax credits or energy price increases through environmental taxes. The first option may be hampered by the constraints weighing on public finance; the second is certainly worth considering, but inevitably has an impact on household budgets, particularly the least well-off populations. It should consequently be supplemented by structural policies designed to extend the timeframe of decision (i.e. lower the discount rate): provision of suitable funding packages, reduction of the uncertainties and various transaction costs entailed by the project. In scenarios which require a substantial drop in

energy demand, the capacity to gradually ramp up deep thermal retrofit programs for the building stock will thus depend to a large extent on the government’s ability to frame policies articulating energy prices, suitable funding, lower transaction costs and adequate business structure to make the operations happen at a very large scale (including formation).

7

Country Case Study UK

Electrification of passenger road transport

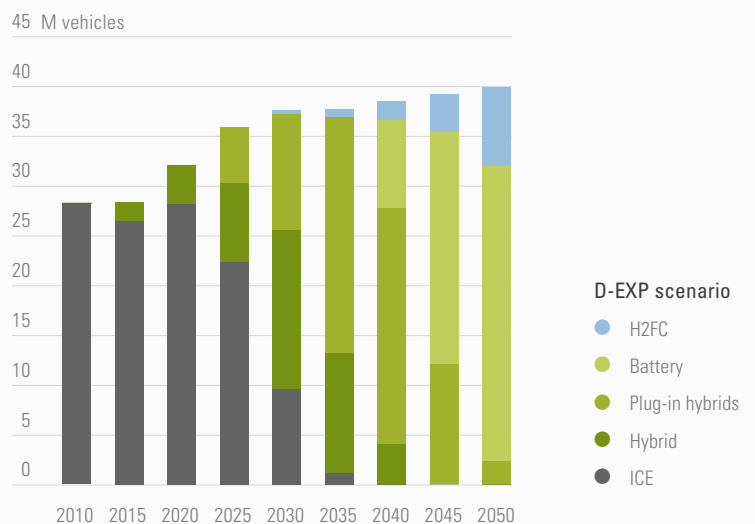
An important decarbonisation pathway for passenger vehicles relies on a switch to higher efficiency ICEs through increasing drivetrain hybridisation, and a shift to plug-in vehicles, including plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs), collectively known as EVs. The increasing penetration of such vehicles in the UK system under the D-EXP scenario (in which electrification is the dominant decarbonization strategy) is shown in **Figure SM 10** below. The scenario shows a strong growth in market share of such vehicles during the 2020s, with strong market dominance by 2035. It is important to note that there will be some earlier adoption of EVs prior to 2025, at lower levels, and that the relative shares of PHEVs and BEVs by 2030 could differ depending on the evolution of BEV costs and battery range. A decline in share of EVs post 2040 reflects some limited penetration of hydrogen fuel cell vehicles.

The key question is how can this radical shift be realised, and what barriers need to be overcome? Firstly, there is the barrier of a vehicle price premium of EVs. For PHEVs, there is currently a 60% premium over an equivalent ICE, and 140% for a BEV. These are projected to drop to 10% and 25% respectively by 2030 due to learning pro-

cesses bringing costs down along with R&D and market diffusion. Other key barriers include lack of consumer choice in vehicle models, insufficient range and long charging times, and low levels of awareness and acceptance.¹

¹ Element Energy (2013). Pathways to high penetration of electric vehicles. December 2013. http://www.theccc.org.uk/wp-content/uploads/2013/12/CCC-EV-pathways_FINAL-REPORT_17-12-13-Final.pdf

Figure SM 10. UK. Penetration of hybrid and electric vehicles in the passenger car fleet



The regulatory and policy environment is going to be particularly important in incentivising further R&D by manufacturers to drive down costs, and making the technologies more attractive to consumers. The EU targets on emissions from new light duty vehicles will help to increase the uptake of EVs, as will a number of domestic policy factors, including continued support for EVs via the Office of Low Emission Vehicles (OLEV), growth in urban charging infrastructure, and fiscal measures to encourage uptake. Unfortunately, since the publication of the UK report, one such fiscal measure, vehicle excise duty, has been changed and payment is no longer structured based on vehicle emissions. This reinforces the concern raised in a recent UKERC report, which highlighted the need to ensure that consumers are confident of ongoing support to reduce costs of ownership for low-carbon vehicles.²

Given the price premium of EVs, and observations from effective roll-out in other countries, it is clear that equivalent value support is needed. Currently there is a plug in car grant of 35% off the price of an EV; however, as uptake increases, such support may be unsustainable. Alternative approaches that may provide the requisite support include low cost financing (low interest rates and long payback periods), making EVs much more competitive, spreading the investment and allowing consumers to benefit from lower running costs.³ Strong growth in the EV market globally will also have significant implications for costs of such vehicles in the UK market. There are of course the wider system implications of strong transport sector electrification.

Clearly there will be increased demand on local distribution networks, with challenges for grid capacity expansion and network reinforcement. There will also be opportunities for EVs to play a role in developing smarter systems, including ensuring demand is outside of peak periods, and providing distributed storage on an increasingly intermittent system.

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- 2 Watson, J., Gross, R., Ketsopoulou, I. and Winskel, M. (2014). UK Energy Strategies Under Uncertainty - Synthesis Report (UKERC: London). Ref. UKERC/RR/FG/2014/002. <http://www.ukerc.ac.uk/publications/uk-energy-strategies-under-uncertainty.html>
- 3 CCC (2015). Meeting Carbon Budgets – 2015 Progress Report to Parliament. The Committee on Climate Change. June 2015. http://www.theccc.org.uk/wp-content/uploads/2015/06/6.737_CCC-BOOK_WEB_030715_RFS.pdf

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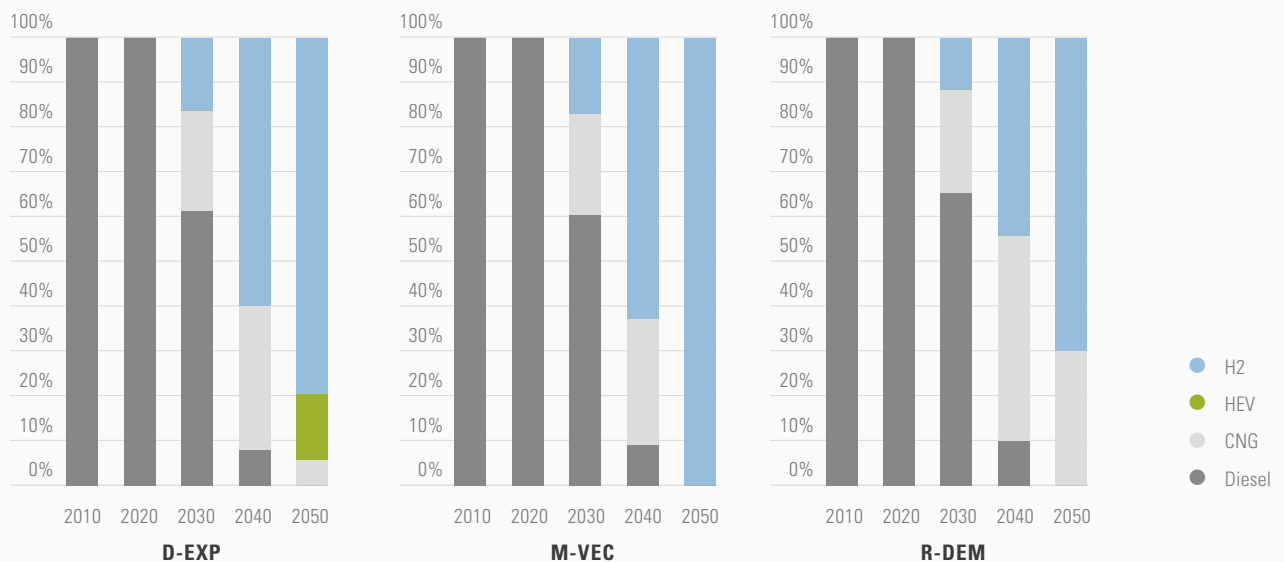
Country Case Study UK

Decarbonising road freight: growing demand and fuel-technology uncertainty

Road freight in the UK currently accounts for 24% of total transport emissions, split between heavy (HGV) and light (LGV) goods vehicles (61% and 39% respectively). While LGVs can potentially follow decarbonisation pathways similar to those for passenger cars (electric vehicles and biofuels), the pathways for HGVs are much less certain.

Demand for HGVs is projected to increase, based on National Transport Model forecasts, by over 70% in 2050 relative to current levels. This is driven by continued growth in the economy, which grows over the same time period by just under 160%. There is therefore some lowering of the freight demand per unit of GDP; however, the increases in overall vehicle fleet necessitate

Figure SM 11. UK. Shares of Heavy Goods Vehicles by technology under UK DDPP scenarios



strong action for decarbonization combining efficiency gains, switching to low emission technology-fuels, and increased use of lower carbon fuel supplies.

In all UK scenarios, the decarbonisation of HGVs is primarily based on a shift to hydrogen-fueled vehicles in the long-term, with compressed natural gas (CNG) vehicles playing an important transitioning role. For conventional ICE vehicles, which still represent around 60% in 2030, fuel efficiency per vkm has improved by 30%. Post 2030, hydrogen vehicles dominate in all cases but the mix of technologies depends on the context. Notably, in the R-DEM scenario featuring lower demand (and emissions) CNG remains part of the mix even in 2050; under the M-VEC scenario focusing on the development of hydrogen systems, the whole HGV fleet uses hydrogen; finally, under D-EXP scenario which puts the emphasis on the switch to decarbonized electricity, a small share of electric HEV appears in 2050 (but remains marginal given the poor applicability of this technology for long haulage). For more extensive description of the different scenarios, see UK country report available at <http://deepdecarbonization.org/>

There are strong challenges associated with the application of fuel cells in HGVs due to the associated cost, lower density of fuel meaning lower ranges, and the necessary infrastructure to allow for strong uptake. If hydrogen does play a role, it will be in the longer term, and will be dependent on a strategic decision to pursue this pathway, given the necessary infrastructure.

In fact, most of the current discussion to 2030 is focused on improved efficiency, the role of biofuels and the potential of CNG as the key routes to decarbonisation. In the UK scenarios, biofuels plays a limited role due to the system level limits on bioenergy, and the cost-effective use of that bioenergy in other sectors. CNG is being actively considered as an alternative fuel

for HGVs,¹ although its potential in a deeply decarbonised system is limited due to it being a fossil fuel; hence its role as a transition fuel in the UK scenarios. Non-technical improvements also offer potential; recent analysis suggests a 6.5% reduction in vkm by 2030 through supply chain rationalisation, better vehicle utilisation and some modal shift to rail and water.²

There are undoubtedly strong challenges to the decarbonisation of this sector. In addition to uncertainty about the role of specific alternative drivetrains, there is no overarching EU legislation (as for passenger cars) to reduce emissions. This is essentially because there is such heterogeneity across the HGV fleet, making standardisation of emission levels problematic. The lack of a strong single decarbonisation pathway necessitates a push across all possible options for decarbonisation.

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- 1 Low Emission HGV Task Force Recommendations on the use of methane and biomethane in HGVs. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/287528/taskforce-recommendations.pdf
 - 2 CCC (2015). Meeting Carbon Budgets – 2015 Progress Report to Parliament. The Committee on Climate Change. June 2015. http://www.theccc.org.uk/wp-content/uploads/2015/06/6.737_CCC-BOOK_WEB_030715_RFS.pdf

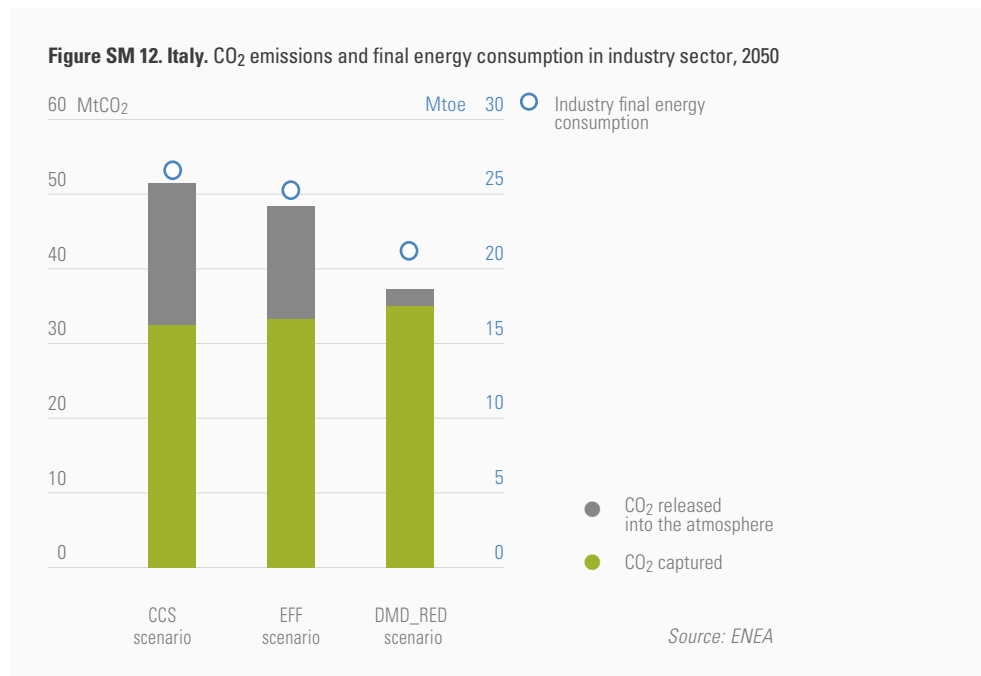
9

Country Case Study Italy

CCS Role in Industrial Sector

The degree of CCS availability is the main difference in assumptions between the three deep decarbonization pathways considered in the Italian study (which all reach similar levels of national emissions). In all scenarios, the industrial sector features significant emission reductions reaching between 50% to 55% lower sectoral emissions than 2010 levels, or an emission differential of 33-36 Mt CO₂ with respect to the Reference Scenario. This is permitted notably by energy efficiency and electrification, but the

availability of CCS proves to be a crucial factor driving the amount and nature of these sectoral emission reductions. This technology is notably used in industrial sectors to capture and store CO₂ process emissions, hence allowing greater consumption of fossil fuels and less efficiency improvements for the same emission outcome. The results of the DDP analysis measure the potential contribution of CCS to emissions reductions in industry and its link with energy efficiency requirements (Figure SM 12). In the CCS



scenario, a widespread use of this technology was assumed especially for industrial processes, particularly in the iron & steel and cement industry, leading to almost 19 million tons of captured CO₂ in 2050. In this scenario, the more optimistic regarding CCS deployment, industry needs to reduce energy demand only by 18% compared to the Reference Scenario; under more constrained CCS deployment, energy reductions must reach 22% in the EFF Scenario and as much as 34% in the DMD_RED Scenario to ensure required emission reductions. In this latter case, energy demand reduction is essentially driven by the decrease of activity levels in energy-intensive industrial end-use sectors, required to meet the carbon constraint. This illustrates that the availability of commercial scale CCS could make the difference whether deep decarbonization can be compatible with the preservation of a significant portion of activity in energy intensive sectors like cement production or iron and steel. In other words, CCS may allow a global choice to consume more cement and iron and steel in a decarbonized world.

The diffusion of CCS implies a reasonably cost competitive capture technology, the existence of suitable storage sites, transport infrastructure, and social acceptance. In Italy, storage capacity potential is estimated to be around 20-40 Gt CO₂, partly in aquifers and partly in exhausted oil and gas wells. But a big uncertainty lies also in the attitude towards the CCS technology by the local populations around storage sites, and the ease of navigating authorization procedures.

10

Country Case Study Germany

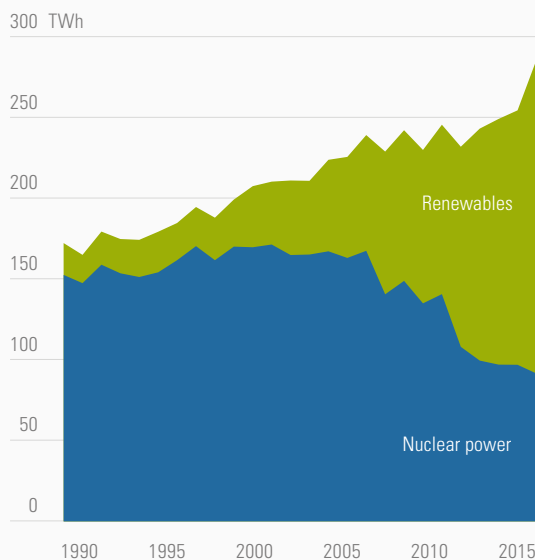
Decarbonizing electricity supply while phasing out nuclear power

As part of its energy concept of 2010 the German government announced that the country's existing nuclear power plants would be allowed to run longer than previously planned – some of them more than a decade longer, until at least the mid-2030s. This controversial decision was revoked a year later following the Fukushima accident and pressure from the German public to

accelerate the phase-out. In the summer of 2011, the German government announced a nuclear phase-out by 2022, largely reverting back to the original schedule devised in the early 2000s. Waiving nuclear power (as well as CCS power plants, which also lack public acceptance in Germany) obviously limits the options available for decarbonizing electricity supply. How-

Figure SM 13. Germany. Role of renewables in electricity generation

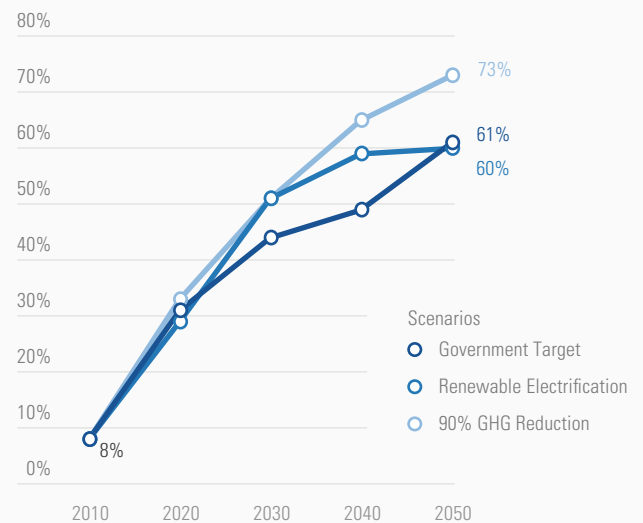
Carbon-free electricity generation in Germany from 1990 to 2014



Source: Own figure based on data from AG Energiebilanzen 2015.

Share of fluctuating sources* in total electricity supply

*(defined as domestic solar PV, onshore and offshore wind)



Source: Own figure based on Schlesinger et al. 2014, Repenning et al. 2014, Nitsch 2014.

ever, there are indications that Germany can decarbonize its electricity supply in the coming decades by relying only on renewable energy sources.

The share of renewables in gross electricity consumption has increased from 6.5% in the year 2000 to 32.5% in 2015 (AG Energiebilanzen 2015). The three mitigation scenarios analyzed in the German DDPP country report, as well as a large number of other recent studies, suggest that reaching the German government's target of at least 80% of renewables in gross electricity production by 2050 is technologically and economically feasible.

A crucial challenge lies in the management of the transition. But, despite this increase in carbon-free electricity generation, power sector CO₂ emissions increased by 9% between 2009 and 2013. This increase is due to strong growth in net electricity exports and a switch in fossil fuel power generation from natural gas to coal and lignite, triggered by relatively high natural gas prices and low CO₂ allowance prices.

Germany's anticipated future electricity supply mix brings along several challenges. Most importantly, Germany will need to rely largely on fluctuating renewable energy sources. (Scenarios expect the combined share of wind and solar PV in electricity generation to reach at least 60 to 70% by 2050.) Such high shares of fluctuating renewables requires a high degree of system flexibility to maintain a stable supply. Options to help achieve this flexibility include grid extensions, flexibly operating gas power plants, demand side management (in combination with an increased use of heat pumps and electric vehicles), more storage capacity and in the longer run also power-to-X technologies. However, Germany will need to make sure to not only address technological issues, but also regulatory and social issues, like devising an adequate power market design to incentivize the required investments and dealing adequately with public opposition against grid extensions or new wind power plants.

11

Country Case Study Japan

Decarbonization of power sector with nuclear phase-out or less CCS deployment

Japan faces a combination of specific constraints and challenges regarding the decarbonization of power generation. Indeed, the three solutions that can be deployed are associated with specific important uncertainties in the Japanese context: the restart of nuclear plants after Fukushima, the scale and stability of CO₂ storage in seismic areas and the potential for intermittent renewables given the issue of building interconnections between areas of large renewable potential (Hokkaido and Tohoku) and areas of demand. This is why the Japan DDPP analysis considers three variants of the future of power generation, all consistent with identical levels of national emissions reduction.

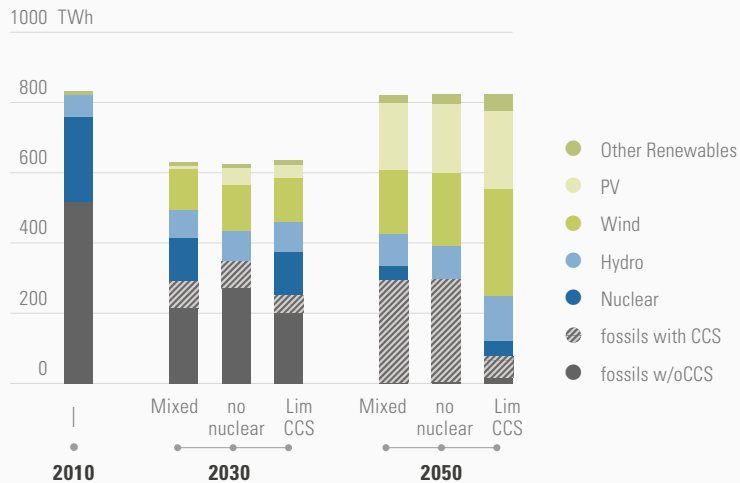
The central scenario ('Mixed') considers a partial phase-out of nuclear (all plants are operated no more than 40 years) which still represents 19% of electricity generation in 2030 and 5% in 2050. In this case, CCS must be deployed at large scale to provide up to 35% of electricity in 2050, and renewables represent almost 50% of electricity generation in 2050, essentially from solar PV and wind.

A complete phase-out of nuclear power ('No-Nuclear' Scenario) does not imply a drastic change of the long-term power generation mix, but entails significant challenges in the transition. Notably, to compensate for the gap caused by the phase-out of nuclear, on the one hand, intermittent renewables must be deployed more rapidly by 2030 (they represent 31% of 2030 electricity production vs 21% in the previous case) causing higher short-term investments towards the energy supply sector. On the other hand, higher carbon intensity of electricity is experienced during the transition period because additional fossil fuels without CCS must be maintained, making electrification of end-uses a less attractive option as a decarbonization pathway.

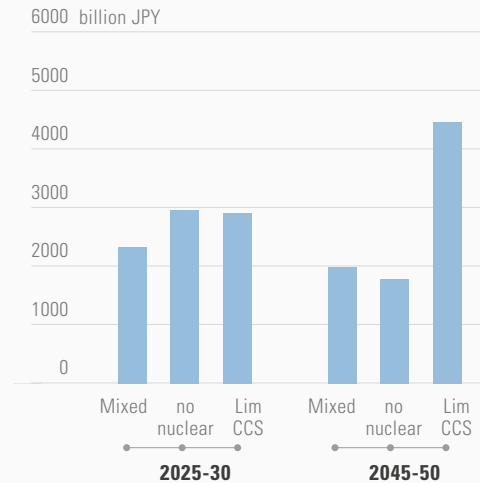
These two scenarios assume an important contribution of CCS with annual CO₂ storage volume increasing up to 200 Mt-CO₂/year in 2050. Although this value is not inconsistent with current estimate, it means that around 5 Gt-CO₂ must be stored by 2050, representing about half of the more optimistic assessment of storage capacity by that time.

Figure SM 14. Japan. Electricity supply and investments in energy transformation

Annual electricity supply in 2010 and 2050



Average additional investments in energy transformation compared to Reference Scenario



In the case of more limited scale of CO₂ storage potential, achieving long-term electricity decarbonization still proves to be feasible but requires a substantial increase in intermittent renewable energy, particularly solar PV and wind power, which account for about 64% in electricity generation in 2050. This in turn poses the twofold challenge that i) the development of renewables at this scale requires significant investment in energy transformation even in the long-term, ii) the integration of such a large amount of intermittent energy requires extensive grid development as well as specific management strategies, including on the demand side.



12

Country Case Study UK

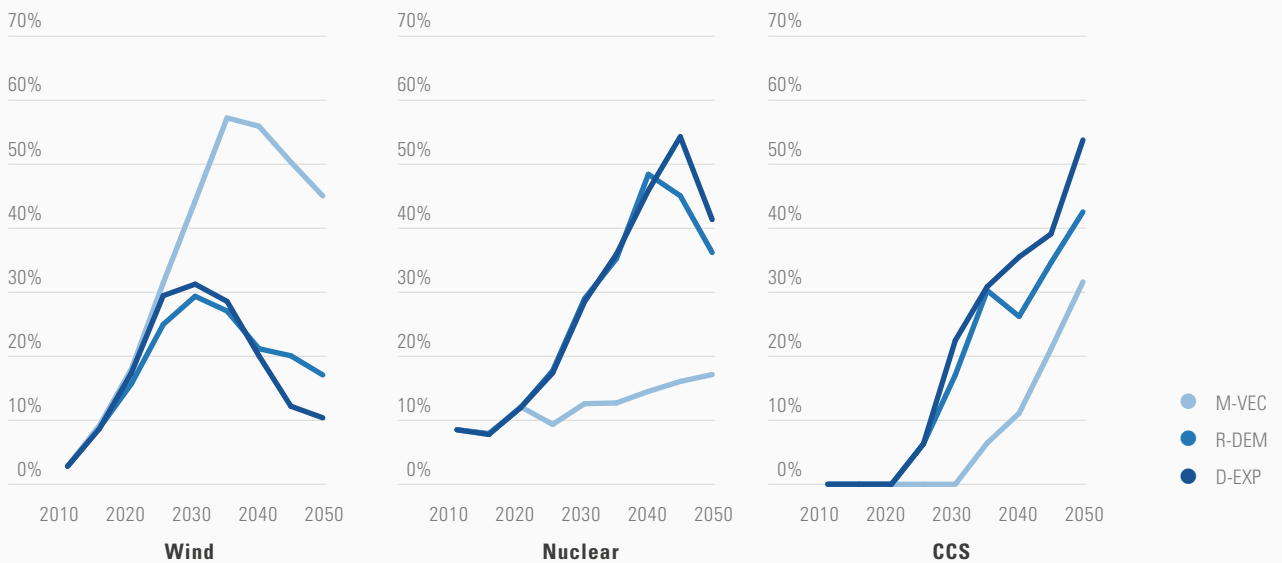
Multiple power sector decarbonisation pathways

All of the pathways featured in the UK DDPP report suggest strong decarbonisation of the power sector by 2030, with carbon intensity reductions of between 85-90%. This near term effort to transform the generation system to one that is low carbon reflects a requirement to meet the interim 4th carbon budget, a near 60% reduction

relative to 1990 levels, and to allow for system expansion to generate low carbon electricity for increased supply to end use sectors.

There are three key groups of technologies that enable this transformation, as shown in [Figure SM 15](#). If cost-effective and scalable, CCS plays a critical role in the post 2030 sys-

Figure SM 15. UK. Power generation shares by technology under UK DDPP scenarios



tem, as shown on the right. In these scenario, that means a build of between 5-10 GW in the system by 2030. This is ambitious and will require a strong domestic policy push, ensuring then rapid implementation of the CCS demonstration programme, and effective international cooperation.

An alternative pathway could see a stronger role out of wind generation, for which the UK has excellent resources. The M-VEC scenario shows a system with higher levels of wind generation, reaching a capacity of over 90 GW by 2050, mainly driven by offshore deployment. Key system operation challenges emerge under such a high renewable-based system, with the need for effective demand-side response, inter-connection, and balancing generation. The third technology is nuclear, providing generation that is neither subject to intermittency (like wind) nor reliant on fossil fuels (as for CCS). However, while cost-effective in the analysis, current attempts to kick start a nuclear programme, at Hinckley C, have been subject to a range of barriers, both financial, technical and political.

In summary, the UK has multiple decarbonisation pathways it can go down, but it is clear that this sector must decarbonise rapidly. This means policy makers taking strong action to support all three technologies, with their relative contribution determined by a range of factors in future years. Taking strong action will allow for key uncertainties to be addressed, around issues such as technical performance, financing and public acceptability.

Country Case Study Canada

Freight Transport

Introduction

In the Canadian DDPPs the heavy freight sector almost completely decarbonizes, going from over 100 Mt today to 5 Mt in 2050, despite almost a doubling in demand. In this case study we discuss total activity, mode switching, energy intensity and fuel switching. Then we summarize what happened to the sector on a more discrete technological basis under the DDPP scenario 2016-2050. Finally, we discuss what was not included in the analysis. The reader should keep in mind the results and commentary in this section are primarily about long haul heavy road freight, not urban light and medium freight. We found “daily return to base” light and medium road freight to be much more amenable to plug in hybridization and pure electrification, similar to the personal transport fleet in our modelling.

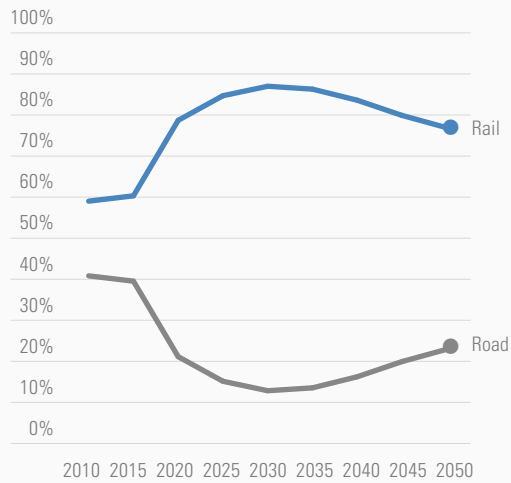
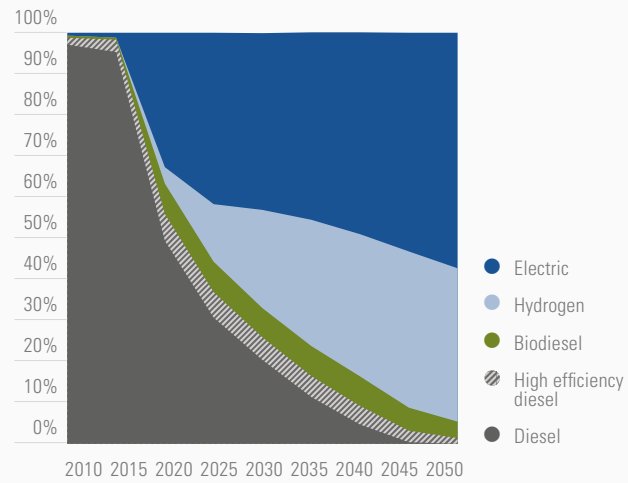
Total freight demand

Total freight volume (tonne/kilometres) was held constant in our capital stock turnover model (CIMS), upon which these results are based. Total “tonne/kilometers”, or tonnes moved a kilometer by all modes, rise from 874 billion to 1610 billion per year by 2050. This assumption was tested in our macroeconomic modelling first. This modelling, which allowed freight transport activity to vary, supported our assumption in that it showed a consistent picture of transport activity roughly

doubling in both the reference and DDPP scenarios 2016-2050, despite a relative 20-35% rise in real sector prices by 2050 (20% in the low oil price case with decarbonization, 35% in the high oil price case). In other words, demand showed itself to be somewhat inelastic.

Mode shifting

Figure SM 16 shows how mode shifting between road and rail long haul heavy freight develops over the life of the DDPP scenario; marine's share was held constant. Starting in 2016 when the policy starts, the model immediately starts shifting to rail, which is a much more energy efficient technology measured on a per tonne moved basis. It is also, to a certain degree, easier to electrify the rail sector with dual fuel electric-(bio) diesel or electric-hydrogen fuel cell locomotives. Looking at **Figure SM 17**, at maximum there is a 75% shift to rail from road freight. The mode shifting dynamics in the model have been tested with stakeholders and reflect the Canadian reality, which includes a mix of dense industrial urban corridors (e.g. Windsor to Québec City), and very long hauls between urban centers (e.g. Vancouver to Toronto). There is a shift back once biofuel heavy trucks become more economic. Our mode shift if driven by very strong climate policy, the equivalent of several hundred \$/tonne carbon prices, but done as a combination of regulations and carbon pricing. A more gradual shift

Figure SM 16. Canada. Land freight mode shares**Figure SM 17. Canada. Canada. Rail energy source mix**

is more likely given political constraints, perhaps by 2030-35. For this to occur some extra rail infrastructure may also be required at choke points in the system (e.g. rail yards, switching systems, computer network monitoring, etc.), and extra rolling stock would be required.

Energy intensity & fuel switching

Heavy road freight energy intensity improves about 25% over the DDPP scenario. At the beginning of the period the sector is operating on fossil fuel diesel, but steadily through the period this is replaced with biodiesel sourced from non-food feedstocks until the mix is over 90%, implying market takeover by biodiesel. Hydrogen was included as a competitive option in our technology competitions, but was not economic on a cost basis against biodiesel sourced from woody biomass or switchgrass. This assumption is grounded in Canada's large feedstock base for making biofuels - for other more dense nations feedstocks could be an issue, and hydrogen or more rail mixed with electric light and medium freight may be more attractive (see comments at the end).

In our scenario rail energy intensity almost halves 2016-2050, but this is a mixture of energy efficiency and fuel switching to electricity and hydrogen (locomotives would electric dual source motors, driven by either overhead wires or fuel cells). Trains are less vulnerable than trucks to network build out costs for hydrogen, as they are more efficient and can carry large amounts of fuel with them. Almost half the rail tonne kilometres are electric by 2050, mostly in dense corridors (e.g. Windsor to Québec City) where it is economic to erect electric wiring. Hydrogen driving fuel cells would be used on long hauls (e.g. across the Prairies). For this scenario to occur there would need to be significant retrofitting of Canada's denser rail corridors with electric high wiring.

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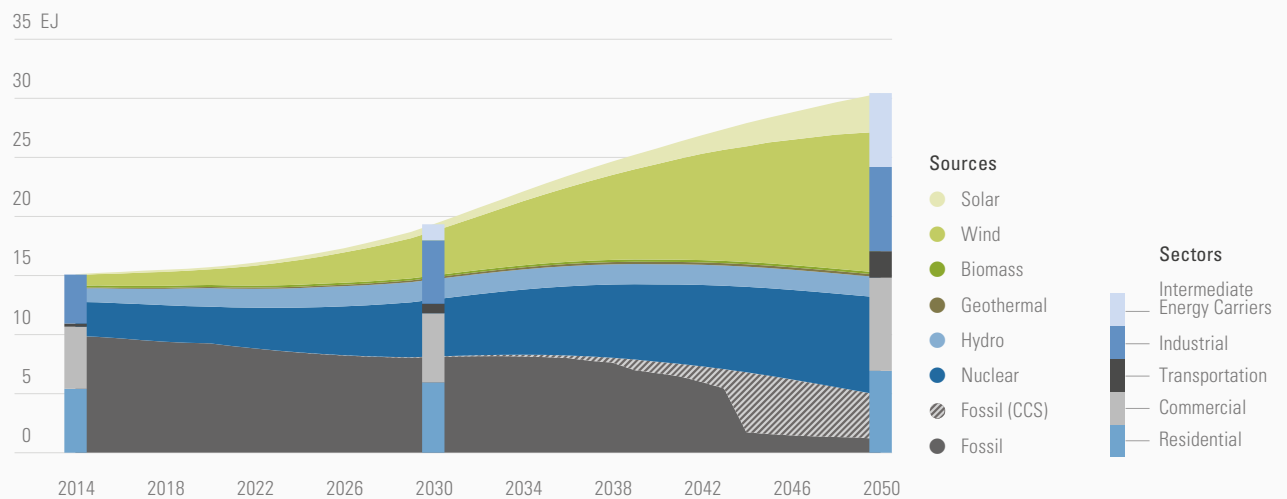
Country Case Study USA

Decarbonization of power generation and electricity dispatch

The US decarbonization analysis distinguishes four main scenarios for decarbonization of electricity, and case names are indicative of final 2050 generation mixes (Figure SM 18). The High Nuclear, High CCS, and High Renewables Cases have the highest amount of each respective type

of generation, though they do not exclusively rely on this type of generation, and the Mixed Case includes a more balanced expansion of low-carbon sources. CO₂ emission factors fall precipitously in all decarbonization cases, from 329 gCO₂/kWh in the Reference Case to at most

Figure SM 18. USA. Mixed Case Electric Sector Supply and Demand



54 CO₂/kWh (High CCS) and at least 14 gCO₂/kWh (Mixed).

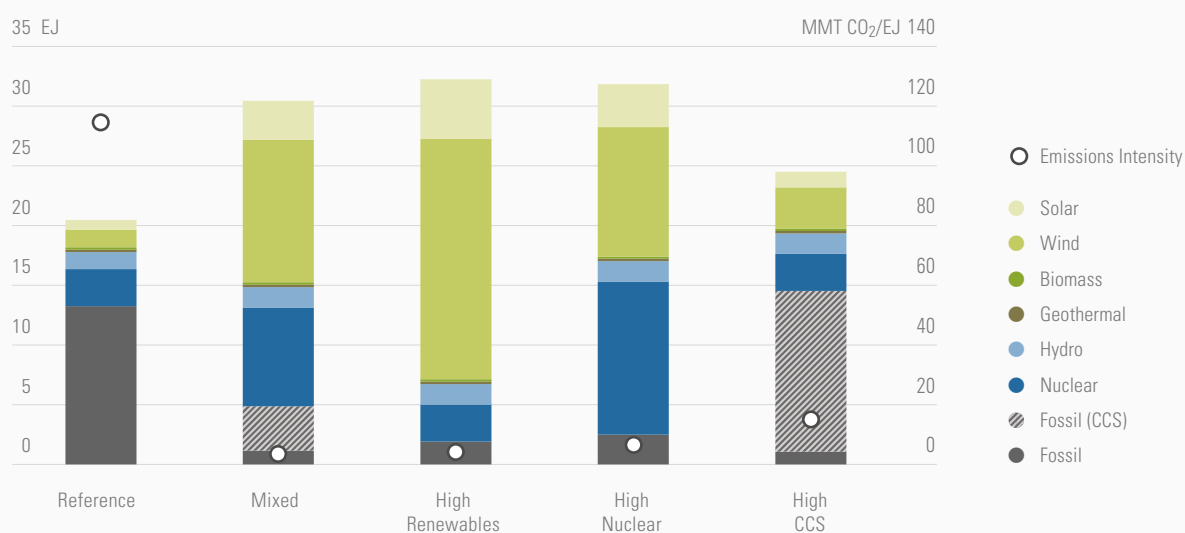
The Mixed Case illustrates the interaction between supply decarbonization and end use electrification that occurs, to different extents, in all of the decarbonization cases (Figure SM 19). In the Mixed Case, end use electrification doubles demand for electricity by 2050, with particularly rapid growth after 2030. Some of this growth occurs as a result of the electrification of end uses, such as electric water heating or vehicles, but a large portion results from the electrification of fuels, such as hydrogen produced through electrolysis (“Intermediate Energy Carriers” in Figure SM 18). Fossil fuel generation declines gradually over 2014-2050, and the only remaining uncontrolled fossil fuel generation in 2050 is a small amount of gas generation that operates as a peaking resource. Much of the increase in demand for electricity after 2030 is met by significant increases in wind, nuclear, and solar power output.

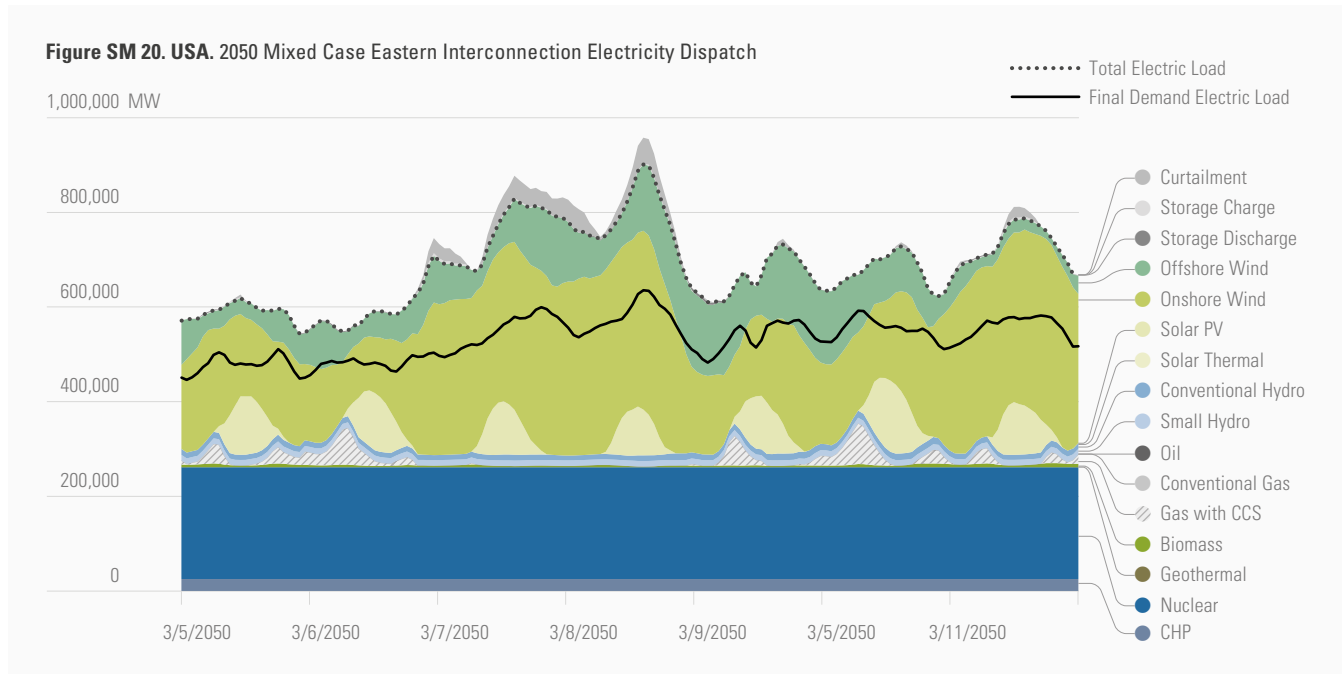
Large penetrations of non dispatchable decarbonized resources (wind, solar, nuclear) present

challenges for balancing electricity supply and demand (load). Due to the lack of coincidence between these generation sources and conventional loads, high penetrations require supporting low-carbon dispatchable generation (electricity storage facilities or gas power plants with carbon capture) or greater flexibility in load (as permitted by newly electrified loads like water heating, space heating, and electric vehicles). Much of the balancing on the load side comes in the form of electric fuel production—hydrogen and synthetic natural gas (SNG)—which may be inefficient from a primary energy perspective, but help to reduce curtailment by their ability to operate flexibly, which can provide significant value as a component of an integrated energy system, despite its potentially high cost when viewed in isolation.

Figure SM 20 illustrates these challenges, showing dispatch in the Mixed Case for a week in March 2050 in the Eastern Interconnect. The coincidence of significant nuclear generation online and large wind power output means that total electric load (the solid red line) exceeds

Figure SM 19. USA. 2050 Electric Generation by Resource Type





final demand for electricity (the dotted red line). The majority of the difference is absorbed by facilities producing electric fuels, and a small amount of wind output is curtailed. The use of flexible loads for balancing, as in this case, would represent a new paradigm in power system operations, as system operators have traditionally relied on the flexibility of supply, rather than the flexibility of demand, to address load resource imbalances. The High CCS Case, which has lower penetrations of non dispatchable resources, has a more traditional generation dispatch where nuclear and coal with CCS operate as base load resources and gas CCS operates as a load following resource to balance modest penetrations of wind and solar.



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Country Case Study China

Air quality co-benefits of deep decarbonization strategies

Since 2013, a total of 74 cities in key regions, municipalities and provincial capital cities such as the Beijing-Tianjin-Hebei region, Yangtze River delta and Pearl River delta have conducted monitoring according to the new air quality standard (GB 3095-2012), which requires monitoring of six pollutants, namely SO_2 , NO_2 , PM_{10} , $\text{PM}_{2.5}$, O_3 and CO. Monitoring results showed that only three cities, or 4.1%, of the 74 cities subject to air quality standards met the national standard for good air quality in 2013. All cities in the Beijing-Tianjin-Hebei region and Pearl River delta failed to meet the national standard. Days with up-to-standard air quality in the 74 cities accounted for 60.5% on average, with remainder classified as polluted. The percentage of cities which attained air quality standard for SO_2 , NO_2 , PM_{10} , $\text{PM}_{2.5}$, CO and O_3 is 86.5%, 39.2%, 14.9%, 4.1%, 77.0% and 85.1%, respectively. PM_{10} and fine particles $\text{PM}_{2.5}$ are also an increasing problem.

Coal is an important emission source of China's $\text{PM}_{2.5}$ and smog precursors. It accounts for 53% of $\text{PM}_{2.5}$ emissions in China, 91% of SO_2 emissions, 68% of NO_x emissions and 16% of VOC emissions. NO_x emissions are 68% from coal combustion and 28% from oil combustion. $\text{PM}_{2.5}$ emissions are 53% from coal combustion, 27% from biomass and 16% industrial processes. VOC emissions are mainly from non-energy use (54%). Under the Chinese DDP scenario, various measures for further energy-saving are taken, including

changing the mode of economic development and lifestyle and strengthening the application of advanced technologies. Due to the optimization of economic structure, emerging and tertiary industries develop rapidly, and advanced more efficient technologies are widely used. The fuel mix structure in the DDP scenario is further improved – a coal consumption cap policy is implemented, and the share of coal in energy consumption is reduced to nearly 50% in 2030, and the share of natural gas and non-fossil fuels increased to more than 35%. Energy-intensive industries will be curbed, mainly to meet domestic demand. The production of energy-intensive products will peak near 2020. The utilization of coal and natural gas will be optimized together with coal consumption cap. Coal consumption will be concentrated in electricity and heating sector with advanced end-of-pipe control, and those from small coal-fired facilities will be limited. The use of increased natural gas will be prioritized in the residential sector or as a substitute to coal.

In the DDP scenario which includes further optimization of energy and industrial structure on the basis of the End-Of-Pipe scenario, SO_2 , NO_x , $\text{PM}_{2.5}$, VOC and NH_3 emissions will be reduced by 78%, 77%, 79%, 52% and 42%, respectively, from the 2010 levels. Air quality modeling results show that the comprehensive structure adjustment measures will enable the major cities to achieve air quality standards.

Country Case Study India

Sustainable Deep Decarbonization and Air Quality Benefits

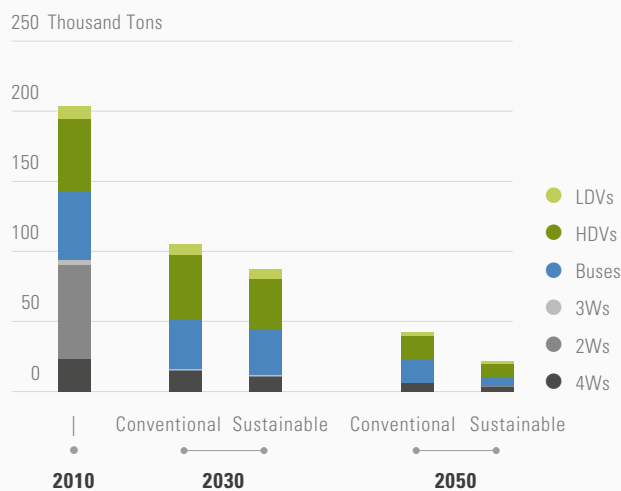
Deep decarbonization can bring air quality improvements, but different decarbonization pathways deliver different types and levels of air quality benefits. Compared to 'Conventional' decarbonization scenarios that focus solely on carbon mitigation, the 'Sustainable' decarbonization scenario aiming at long-term sustainable

development goals including carbon mitigation delivers greater air quality benefits.

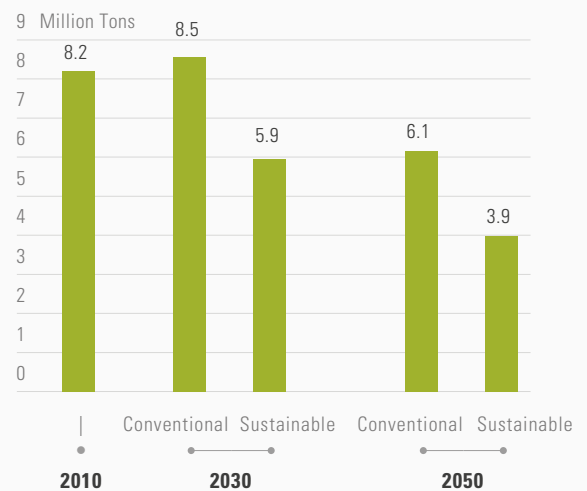
On the national policy landscape, air pollution mitigation policies preceded the decarbonization agenda. The Government of India has instituted numerous policies for air pollution linked to fossil fuels. Two focal areas of air

Figure SM 21. India. Air quality, PM2.5 and SO₂ Emissions

PM2.5 Emissions from Road Transport



SO₂ Emissions



pollution policies have been: i) vehicle technology and fuel improvement aimed to meet urban air quality standards, and ii) control of air pollutants from coal burning in industry and plants generating electricity. In the wake of rapidly rising fossil energy consumption, this conventional air quality control policymaking approach succeeded, albeit partially, in abating air pollution but contributed little to carbon dioxide emissions mitigation.

Decarbonization and air pollution abatement actions are naturally linked since they both originate from fossil fuel combustion. The contemporary global policy focus on sustainable development goals and a climate stabilization target has created an opportunity to align actions on both fronts. The analysis of such a sustainable deep decarbonization pathway shows that same CO₂ emissions seen in the conventional scenario can be achieved with sizable air pollution reductions by aligning sustainable development and deep decarbonization actions.

Sustainability actions deliver these conjoint benefits by reducing end-use demand, shifting consumption to cleaner modes and technologies and raising the clean energy fraction of the energy supply-mix. Conventional approaches to air pollution focus on the end-of-the-pipe technology and fuel related interventions like catalytic converters in vehicles or desulfurization equipment in case of coal combustion in industry. The levers of air pollution control in the sustainable scenario are very different compared to the conventional track. For instance, the key mitigation actions in road transport would include urban design and planning to reduce travel, investments in infrastructure that facilitate modal shift to public transport and non-motorized transport and support for innovations of alternate technologies (e.g. electric vehicles, and energy storage devices). Implementation of targeted demand reduction measures can potentially reduce travel demand in 2050 by half in the sustainable sce-

nario compared to the conventional scenario. Lower travel demand translates into reduced energy demand and lower travel time. In addition, market based incentives for cleaner low carbon fuels like natural gas and bio-fuels deliver sizable CO₂ emissions mitigation as well as mitigation of PM_{2.5} (Figure SM21 left).

SO₂ emissions in India come mainly from industry and power generation. Conventionally, SO₂ emission mitigation relies on a shift away from coal towards low carbon sources. Advanced technologies, dematerialization, recycling and sustainable behavior differentiate the demand for industrial products in the sustainable scenario from the conventional scenario. The fuel mix shifts to cleaner fuels. A simultaneous implementation of targeted environmental policies including desulphurization of coal, process efficiency, emission norms, and cleaner fuels is assumed. The sustainable scenario therefore delivers higher SO₂ reductions compared to the conventional deep decarbonization scenario (Figure SM22 right).

The analysis of 'Deep Decarbonization Scenarios' for India shows that 1. Both decarbonization scenarios make a positive contribution to air pollution mitigation in the long run, 2. Compared to the conventional 'climate centric' deep decarbonization approach, the sustainable scenario will deliver substantial air quality benefits 3. The benefits are greater when deep decarbonization measures and air pollution mitigation measures are crafted to align with the national sustainable development goals.

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Country Case Study Japan

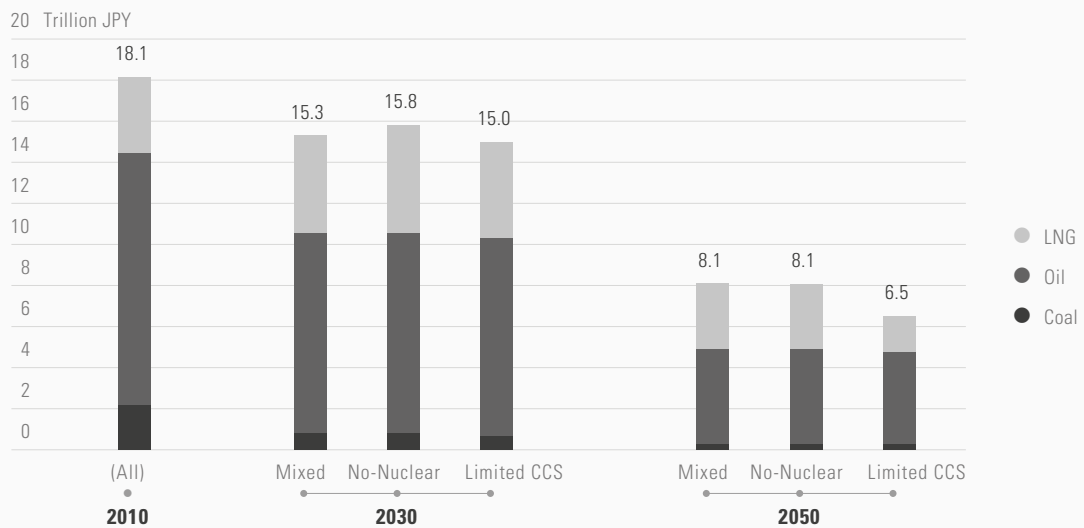
Avoiding dependency on imported fossil fuels

In all the DDP scenarios examined for Japan, dependency on imported fossil fuels is reduced substantially by 2050 compared to 2010. This is achieved thanks to a combined drastic reduction in energy demand plus by deploying non-fossil options, especially renewable energy on the supply-side. Nuclear power supply is also drastically reduced from its 2010 level under all the DDP scenarios considered. In 2050, under every DDP

scenarios, fossil fuel consumption falls by approximately 60% compared to 2010

The structure of Japan's energy supply varies significantly, however, across the DDP scenarios. The share of renewable energy in primary energy, including hydropower, increases significantly in all scenarios, yet the magnitude of change varies. Renewables account for approximately 33%-35% of total primary energy supply in 2050

Figure SM 22. Japan. Fuel import costs in DDPP scenarios



in the Mixed and No-Nuclear Scenarios. Renewables account for an even larger share of total primary energy supply (49%) in the Limited CCS Scenario, to compensate for the hypothesized constraints on CCS (carbon capture and sequestration) in the decarbonization of electricity.

Natural gas, oil and some coal (including for non-energy use) remain in use in Japan in 2050 under the DDP scenarios mainly in the industrial and freight transport sectors. Coal, however, almost completely phases out (excluding in the heavy-industry sector) thanks to a switch to renewables and natural gas. Japan's natural gas supply increases, particularly in the medium-term due to the construction of new LNG power plants, which substitute for oil- and coal-fired power plants because of their lower carbon intensity. But natural gas supply then falls to its 2010 level by 2050, in tandem with an overall reduction in energy demand reduction and the large-scale deployment of renewable energy.

Thanks to a reduction in fossil fuel dependency, fuel import costs fall below 2010 levels by 2030 and substantially decrease in 2050 in all scenarios. Particularly in the Limited CCS Scenario, fuel import costs in 2050 are lower than in the other two scenarios due to the additional deployment of renewable energies in place of fossil fuel, mainly in the electricity sector.

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Country Case Study India

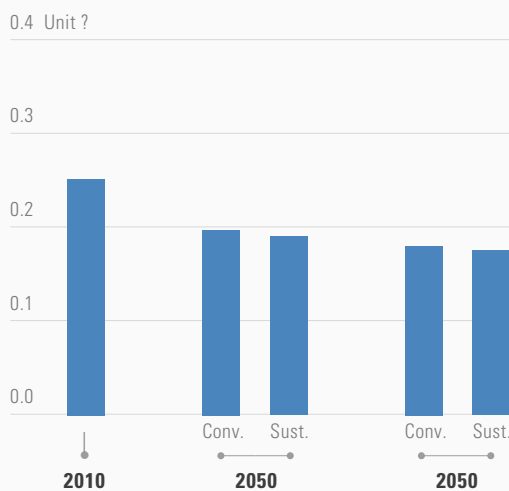
Deep decarbonization and energy security

Energy resource endowments, technology stocks and demand for energy vary across nations. India is endowed with sizeable coal resources, as well as good solar and wind energy potential. India lacks oil and gas, however. The Indian DDPP team's assessment of future energy demand

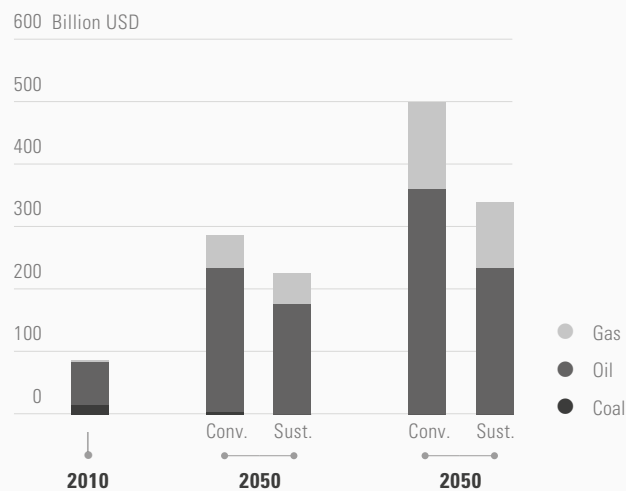
under a deep decarbonization pathway (DDP) shows rising imports of oil and gas in India. Over 80% of the country's oil demand is currently met through imports and by 2050 a significant proportion of the country's primary energy will come from imports. This raises concerns vis-a-vis

Figure SM 23. India. Energy Security Indices

Net Energy Import Dependence



Value of Energy Imports



the four dimensions of energy security (Kruyt, 2009¹), namely the availability, accessibility, affordability and acceptability of energy.

The analysis of two deep decarbonization pathways for India, each following distinct development paradigms but targeting identical CO₂ emissions budgets from now to the year 2050, results in very different energy security risk profiles. The 'conventional' climate-centric decarbonization approach delivers mitigation by altering the energy supply mix with enhanced investments in renewable, nuclear and CCS technologies. The alternate 'sustainable' approach aligns decarbonization and sustainable development actions. It, at first, focuses on demand-side technological and behavioral interventions which significantly reduce end-use demands and eventually uses low carbon energy supply options to the extent needed to keep cumulative CO₂ emissions within the budget.

The diversity of fuel increases with time in both scenarios and fuel-mix shifts towards lower carbon content. The lower end-use demands in the sustainable DDP results in higher percentage of domestic renewable energy contribution. The sustainable DDP therefore fares better compared to the conventional DDP on the energy security indices: a) Net Energy Import Dependence (Figure SM 23 left), and b) Total value of fuel import which are 30% lower in 2050 in the sustainable DDP (Figure SM 24 right).

The energy mix in the conventional DDP has high shares of nuclear and CCS. Risks associated with these technologies would require to be mitigated. Both DDPs have high renewable electricity content and would require mitigating risks associated with the stability of transmission grid. The energy security benefits from nuclear and renewables will accrue, provided these technologies are indigenized. DDP, implemented with

actions aligned to domestic sustainability goals, can improve the resilience of national economies to international conditions.

¹ Kruyt B., vanVuuren D.P., deVries H.J.M., Groenenberg H. (2009). Indicators for energy security. *Energy Policy* 37 2166–2181

Country Case Study UK

Addressing fuel poverty through energy efficiency

Fuel poverty, often referred to as energy poverty in other European countries, was first recognized in UK legislation under The Warm Homes and Energy Conservation Act 2000 (WHECA), which stated that a person is to be regarded as living 'in fuel poverty' if he is a member of a household living on a lower income in a home which cannot be kept warm at reasonable cost.¹ This situation is largely affected by three drivers – i) thermal efficiency of homes, ii) income levels, and iii) energy prices.

This issue matters from a number of perspectives; firstly, if a household is not adequately heated, this can lead to both direct and indirect health impacts. The Marmot Team Review (2011) highlighted the strong relationship between colder homes and excess winter deaths, and the increased incidence of other health problems.²

Secondly, poverty can be further entrenched if a disproportionate share of income needs to be spent on energy costs. Thirdly, fuel poor households in the UK tend to have poorer thermal efficiency, but affordability concerns make it difficult to realize the potential for energy and carbon emission reductions.

In England, fuel poverty is measured by the Low Income, High Cost (LHIC) indicator, as recommended by John Hills.³ This measures fuel poverty based on annual income being below the poverty line (after fuel costs) and energy costs being higher than typical (above the median level).⁴ It also measures the 'fuel poverty gap', defined as the extent to which assessed energy needs of fuel poor households exceed the threshold for reasonable costs. In 2013, 10.4% of households, or

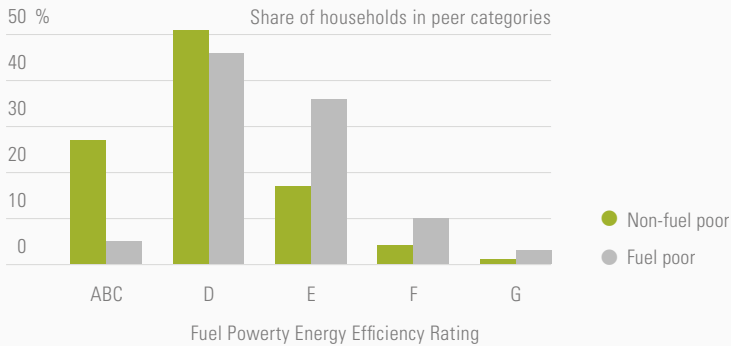
1 Legislation can be found at <http://www.legislation.gov.uk/ukpga/2000/31/introduction>

2 Marmot Review Team (2011). Health impacts of fuel poverty and cold housing. On behalf of Friends of the Earth (FOE). <http://www.instituteofhealthequity.org/projects/the-health-impacts-of-cold-homes-and-fuel-poverty>

3 Hills, J. (2012). Getting the measure of fuel poverty: Final Report of the Fuel Poverty Review. CASE report 72. ISSN 1465-3001. March 2012. <http://sticerd.lse.ac.uk/dps/case/cr/CASEREport72.pdf>

4 Other UK constituent countries have retained the previous 10% definition, where a household needs to spend more than 10% of its income (measured before housing costs) on energy in the home.

Figure SM 24. UK. Share of households in fuel poverty (FP) and not in fuel poverty (NFP) by FPEER efficiency rating



2.35 million, were fuel poor, with an estimated fuel poverty gap of £877 million.⁵

Energy efficiency measures are critical to addressing this problem. The Government has proposed a target to ensure that as many fuel poor homes as is reasonably practicable achieve a minimum energy efficiency standard of Band C, by 2030.⁶ As shown below in **Figure SM 24**, only 5% of fuel poor households currently meet this standard (compared to 27% of non-fuel poor households), while almost 50% are rated at Band E or less (compared to 22% of non-fuel poor households).⁷

There are strong synergies between tackling fuel poverty and reducing CO₂ emissions, based on energy efficiency action. However, there are also concerns that as well as being an opportunity for efficiency improvements, policies to address climate change could increase energy costs, impacting on low income households. Recent anal-

ysis has shown that targeted energy efficiency interventions can offset any increases in energy costs.⁸ The CSE analysis highlighted the need for targeted energy efficiency interventions and careful policy design to ensure pass-through costs to energy bills did not unduly burden low income households. The analysis illustrated that if effectively designed, policies to deliver the 2030 level of reduction in the UK DDPs could also lead to a fall in fuel poor households from 2.86 million in 2013 to 1.18 million by 2030.

⁸ Centre for Sustainable Energy (2014). Research on fuel poverty: The implications of meeting the fourth carbon budget. Report to the Committee on Climate Change. November 2014. http://www.theccc.org.uk/wp-content/uploads/2014/11/CCC_FinalReportOnFuelPoverty_Nov20141.pdf

⁵ 2013 UK Fuel Poverty Statistics. <https://www.gov.uk/government/collections/fuel-poverty-statistics>

⁶ DECC (2015). Cutting the cost of keeping warm – a fuel poverty strategy for England. March 2015. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/408644/cutting_the_cost_of_keeping_warm.pdf

⁷ 2013 UK Fuel Poverty Statistics. <https://www.gov.uk/government/collections/fuel-poverty-statistics>

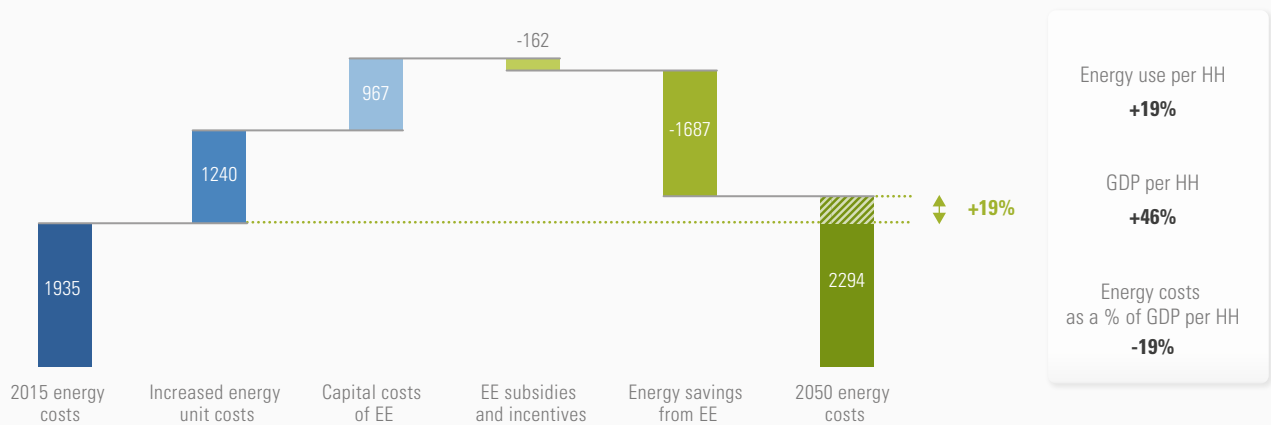
Country Case Study France

Retrofitting of heating systems and the risks of an “energy poverty trap”

Housing retrofits, which constitute a crucial dimension of deep decarbonization for France and many other industrialized countries with a mature building stock, lead to significant energy savings for households when implemented. Even if total energy related expenditures increase in absolute terms, they decrease as a share of income.

This is a significant result because most countries, even industrialized ones, experience increasing levels of energy poverty: more than 6% of the French population is below the threshold defining fuel poverty (expenditures on energy in housing representing more than 10% of income). For instance, low-income households living in rural areas or in small towns spend on average

Figure SM 25. France. House energy costs per household (€/HH)



15% of their income on energy, both for housing and transport. Nevertheless, borrowing capacity for this part of the population can be extremely limited, whatever the ambition of energy efficiency incentives. There is thus a real need for governments to propose specific energy poverty alleviation programs that could lead to financing of the investment required for retrofitting the buildings of energy-poor households.

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Country Case Study South Africa

Decreasing energy poverty and increased access to electricity is compatible with Deep Decarbonization



With 49% of South Africans living below the official poverty level in 2010, energy poverty takes three main forms. First, inadequate energy services for basic needs such as cooking, lighting, refrigeration and heating lead to lower

quality of life and social and economic exclusion, including malnutrition, lack of sufficient light to read, do schoolwork, and conduct nighttime social activities. Second, health and safety problems with indoor air-pollution

Figure SM 26. South Africa. Household income and electricity access

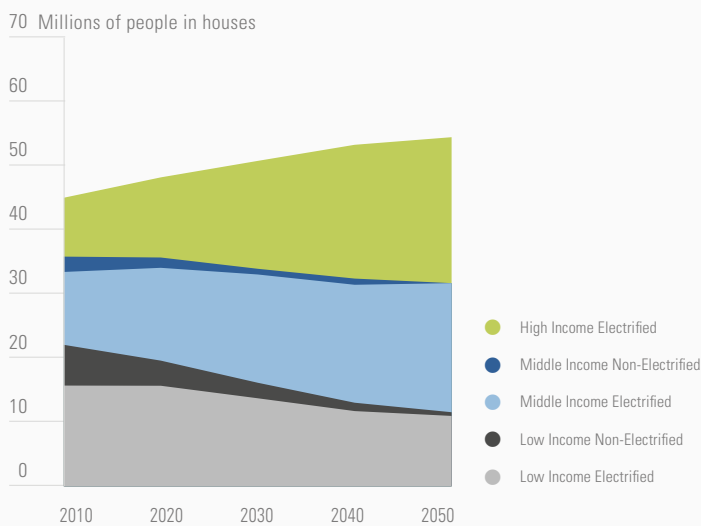
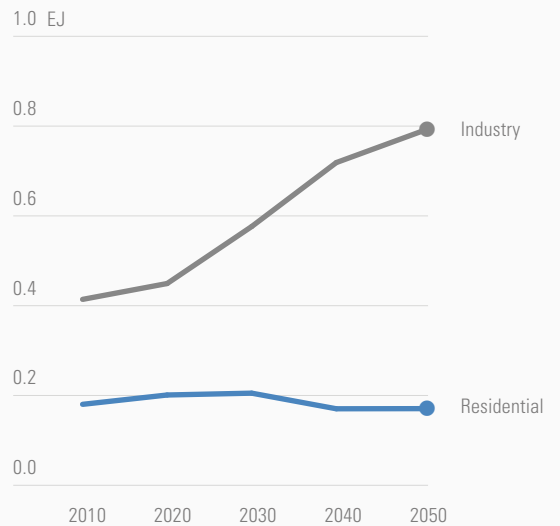


Figure SM 27. South Africa. Final electricity consumption (EJ)



from widespread indoor use of coal and wood, as well as ingestion of paraffin. Third, energy service costs place undue strain on already meager household budgets.

The solutions to these problems rely first on increasing household incomes, which the South African modeling shows is compatible with deep decarbonisation in that while achieving its emissions reduction goals South Africa can also significantly reduce the number of people living below the poverty line from 49% to 18% in 2050. This will decrease energy poverty on the demand side by facilitating affordability of adequate and safe energy services to those that move into the middle income category. On the supply side, just about all households will be connected to electricity by 2050 (1% remain unconnected). While levelized costs of electricity generation double from 2010 to 2050, much of this increase is inevitable, owing to South African need to add capacity for industry and replace the existing coal fleet by 2050. Households only make up .17 EJ in 2050 compared with 0.79 EJ for industry. Households do not drive the capacity increase: total consumption in fact decreases, despite increased energy service delivery to more households, owing to significant improvements in appliance efficiency, especially lighting and household thermal performance. Also, generation costs only make up less than half of household retail tariffs¹, and those with lower consumption pay lower tariffs. The much smaller proportion of households below the poverty line will improve the sustainability of existing subsidized tariffs and the minimum free electricity provided for basic needs (mainly lighting and refrigeration).

¹ Trollip, H., Walsh, V., Mahomed, S., Jones, B., Potential impact on municipal revenue of small scale own generation and energy efficiency.

Country Case Study South Africa

DD can be achieved in parallel with improved income distribution, poverty and unemployment

For decades, South Africa has experienced persistent very high levels of income poverty, inequality and unemployment. In 2011 45.5% of the population were living below the Upper-bound Poverty Level¹, the income share of the lowest 40% was some 7%, the Gini coefficient deteriorated from 59 to 64 from 1993, and the employed population as a percentage of population over 15 years old has deteriorated from 45% in 1995 to less than 40% in 2015. Also, results of the education system indicate persistent problems in improving educational outcomes and skills shortages are a major limit on economic growth. The history and persistence of these features of the South African socio-economy present special challenges to formulating pathways that credibly demonstrate changes that will effectively address these features significantly. Based on a review of research on the issue and by consulting eminent economists, was decided

¹ ZAR577 per month in 2009 prices, roughly some 60 US\$ 2015 at ZAR13/\$US (SStatsSA MDG Goals Report, 2013, South Africa Millennium Development Goals Country Report to the President of the Republic

to present two economic pathways to illustrate what might be possible. Working with one assumption, namely that the South African labour force skills profile will not improve significantly, the one economic pathway (economic structure)

Figure SM 28. South Africa. Unemployment rate over time as calculated from the quantity of labour demanded in the e-SAGE CGE model

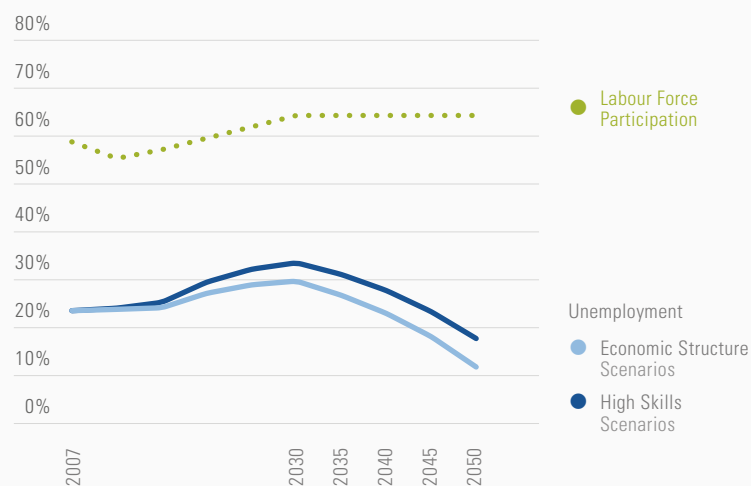
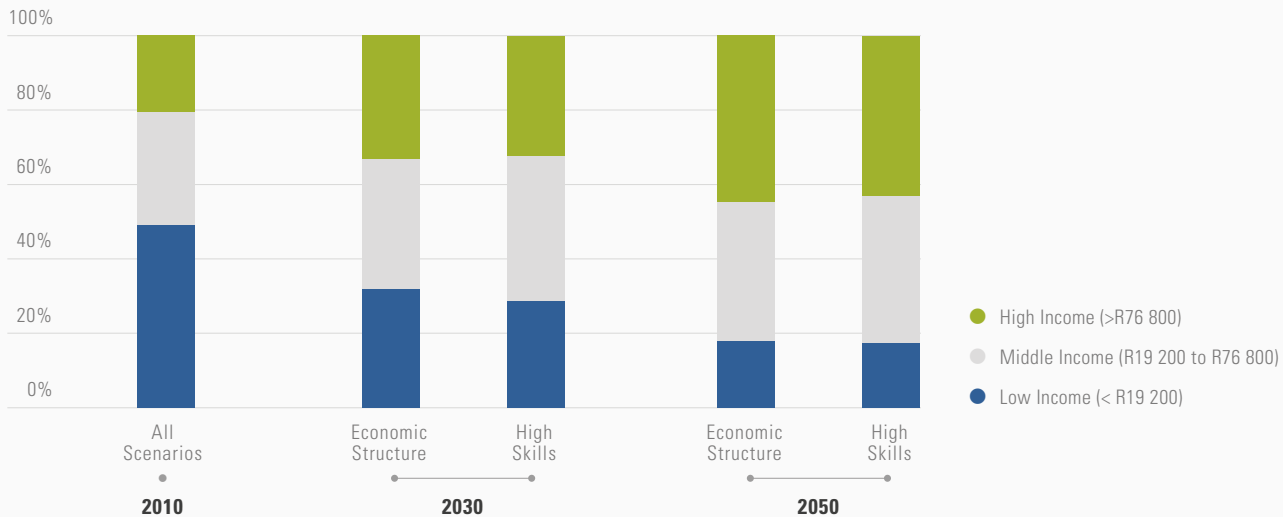


Figure SM 29. South Africa. The percentage of the population in the low , middle and high income groups as defined by SATIM

centers on a change in the structure of the economy, promoting sectors that are relatively higher low-skill labour absorbers and lower marginal GHG emitters. The other pathway (high skills) assumes success in improving the education system and skills availability to the economy. Note that these are illustrative and in actual futures combined elements of these and other factors are possible. The objective was to illustrate interesting features of what might be possible.

The modeling of these economic pathways, done with a CGE model, is linked to an energy system model and the results are that there can be significant improvements in the indicators. The unemployment rate drops from 25% in 2015 to between 12% (economic structure pathway) and 18% (high skills), and the percentage low-income households drops from 49% in 2010 to 18% in 2050. Whilst these are not ideal, they represent significant improvements. These results are achieved within a GHG budget of 14Gt for the South African, energy sector an amount assessed within DDPP methodology to be fair for the country circumstances.

Country Case Study France

Deep decarbonization can successfully be combined with social and economic priorities

The medium- and long-term impact of climate policies on growth and employment depends on their interplay with each country's economic system, including the inertia of technical systems, imperfect foresight and rigidities outside the technological sphere (notably in the labour market) limiting flexibility of adjustments in the energy transition. Such constraints lead to investment decisions that may not be adapted to future economic conditions (particularly rising energy prices) and create risk of expensive fossil fuel intensive lock-ins.

Climate policies can contribute to the correction of these imperfections and lead to more economic growth and employment. For example early carbon pricing rising gradually according to pre-established rates can help short-sighted decision-makers to internalize constraints on fossil fuels and accelerate the adoption of less fossil-intensive consumption and production patterns. The resulting reduction of energy costs in production and household budgets despite the introduction of a carbon price can implement a virtuous circle,

Table SM 3. France. Average GDP growth rates and policy packages in France

Scenario name	Description of the policy package	2010-15	2010-20	2020-30	2030-40	2040-50	2010-50
REF	Reference	0.77	0.83	1.09	1.47	0.85	1.06
SC1	Sectoral climate policies + carbon tax + recycling through annual lump-sum refund to households	0.69	0.86	1.32	1.32	0.87	1.09
SC2	P&M +carbon tax + recycling through annual lump-sum refund to households and through lower payroll taxes	0.81	0.96	1.37	1.34	0.88	1.14
SC3	P&M +carbon tax + recycling through annual lump-sum refund to households and through lower payroll taxes + carbon finance	0.87	1	1.46	1.5	0.97	1.23

boosting household purchasing power, final demand for non-energy goods, and consequently production, leading to higher employment and an additional increase in household purchasing power through higher wages.

In France, the economic assessment of the deep decarbonization pathways (conducted with the general equilibrium model *Imaclim-R France*) shows that a combination of sectoral climate policies mixed with a carbon tax with revenues of the tax recycled to households in a lump-sum manner (see scenario SC1 in the French analysis) would lead to higher average GDP growth rate than under a reference scenario (REF) over 2010-50 (1.09% vs 1.06%).

Such positive effects should be seen in perspective for two reasons. First, climate policies could exacerbate labour market distortions if long term expectations are not clear. The deep decarbonization transition requires a big change in labour market training programs, to develop new skills at a very large scale and reorient workers from declining activities (e.g., from coal intensive industry to building retrofitting). Credible answers for job switching are needed in order to avoid further labour-market inflexibility, which would create the risk of delay in the effectiveness of energy efficiency improvements and trigger additional economic costs.

Second, SC1 leads to a decline in growth and employment during the first five years, (0.69% in SC1 compared to 0.77 in REF). Although small in absolute terms, this difference can represent a significant effect for specific social groups (low income, people in old houses, or those who are car dependent because they live in rural areas or suburbs) or coal intensive industries (steel, non-ferrous, cement, petrochemical), creating the risk of undermining the acceptability of the energy.

These adjustment costs can be addressed through adequate recycling schemes for the carbon tax revenues. Scenario 2 (Sc 2) considers a recycling scheme where carbon revenues are shared be-

tween a lump-sum "green check" for households (to limit the purchasing power losses), and a reduction of payroll taxes (to prevent the increase of production costs in industry of non-energy goods). This scenario shows a significant positive effect in the short term (0.81% growth rate compared to 0.69% in SC1 and 0.77% in REF) but might not be sufficient to discourage this opposition of diverse set of interests, including low-income populations (car-dependent workers in suburbs, farmers in mountain areas, fishers, truck drivers...) and energy-intensive industries. A second element is the implementation of a large scale 'carbon finance' scheme to reduce the investment risks in low carbon technologies and infrastructures given their high upfront costs, therefore helping to avoid lock-ins in fossil fuel intensive infrastructures and lowering adjustment costs.¹ Such scheme is tested in Scenario 3 (Sc 3), which displays significant gains both in the short-term (0.87% during the first five years, against 0.69% and 0.77% in SC1 and REF), respectively and the long-term (1.23% growth in SC3 between 2010 and 2050, against 1.09 in SC1 and 1.06% in REF).

¹ Such 'carbon finance' scheme could consist in a public guarantee covering, at a predetermined notional value carbon, carbon certificates representing carbon emissions reduction expected from a type of project. The loans would be reimbursed in carbon certificates instead of in cash.

Country Case Study Brazil

Macroeconomic and Social Implications of a Deep Decarbonization Pathway

Brazil is an “upper middle income” country according to World Bank, with very important macroeconomic challenges over the medium-term, including growth, employment and trade. But the main socio-economic challenge is the reduction of inequality, since Brazil is recognized as one of the most unequal countries in the world where, even though the Gini Index has experienced an important decrease during the last decade, this indicator still reached 0.53 in year 2010, one of the highest values worldwide. In the DDPP analysis, the limitation of GHG emissions is achieved through implementation of a carbon tax, growing linearly from 0 US\$/tCO₂e in 2015 to 100 US\$ in 2030, and then to 150 US\$ in 2050. This carbon tax stimulates the introduction of a number of mitigation measures that compose the deep decarbonization scenario. The CGE simulations with the IMACLIM-BR show that these measures trigger additional investments summing up 2.5 trillion US\$ (2010) from 2015 to 2050, causing a deep reduction in GHG emissions and good macroeconomic performance.

The DDP scenario shows a significant reduction of total emissions, from 1,214 Mt CO₂e in 2010 to around 1,009 Mt CO₂e in 2030, and 367 Mt CO₂e in 2050, while energy emissions related

grow from 326 Mt CO₂e in 2010 to 483 Mt CO₂e in 2030, and 262 Mt CO₂e in 2050, thanks to the low-carbon investments and implementation of mitigation measures along with the carbon tax.

Table SM 4 presents some selected macroeconomic and social indicators related to the deep decarbonization pathway.

Table SM 4. Brazil. XXXXX Title XXXXX

	2010	DDPP-2030	DDPP-2050
Population (millions)	191	223	221
GDP (trillion 2010 US\$ dollars)	2,14	4,53	8,64
GDP growth per year		3.81%	3.28%
Investment rate (% of GDP)	19,50%	20.84%	25.16%
Total investments (Trillion 2010 US\$)	0.14	0.94	2,17
Number of full time jobs (million)	94.1	128.0	115.9
Unemployment rate (%)	6.70%	3.81%	5.49%
GDP per Capita(Thousand 2010 US\$)	11.2	20.3	39.1
GINI	0.53	0.42	0.33
Price index		1.174	1.314
Trade Balance (Billion 2010 US\$)	20.3	35.9	44.6
Trade Balance (% GDP)	0,95%	0.79%	0.52%
Carbon tax (US\$/tCO ₂ e)	0	100	150
Energy-related CO ₂ emissions	326	483	262
Energy-related CO ₂ emissions per capita (t CO ₂ e)	1.7	2.2	1.2
Total GHG Emissions (MtCO ₂ e)	1,214	1,009	367
Total GHG Emissions per capita (t CO ₂ e)	6.4	4.6	1.7

The DDPP is characterized by an important decoupling between GDP growth and GHG emissions for Brazil from 2005 to 2050 in the deep decarbonization scenario. Indeed, the drop in emissions happens in parallel with an average GDP growth of 3.5% per year from 2010 to 2050, leading to a multiplication by almost four of GDP per capita, from 11.2 k US\$ (2010) in 2010 to 39.1 k US\$ (2010) in 2050. This increase of wealth happens along with a significant reduction in inequality, as measured by a drop in the GINI index to 0.33.

Energy related GHG emissions per capita will be strongly reduced in the period, coming from 1.7 t CO₂e per capita in 2005, 2.2 t CO₂e per capita in 2030 and reaching 1.2 t CO₂e per capita in 2050.



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Country Case Study India

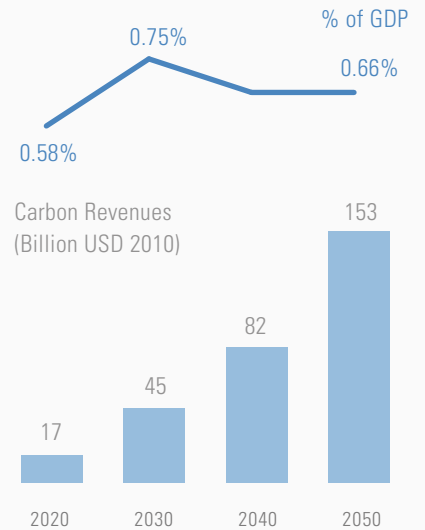
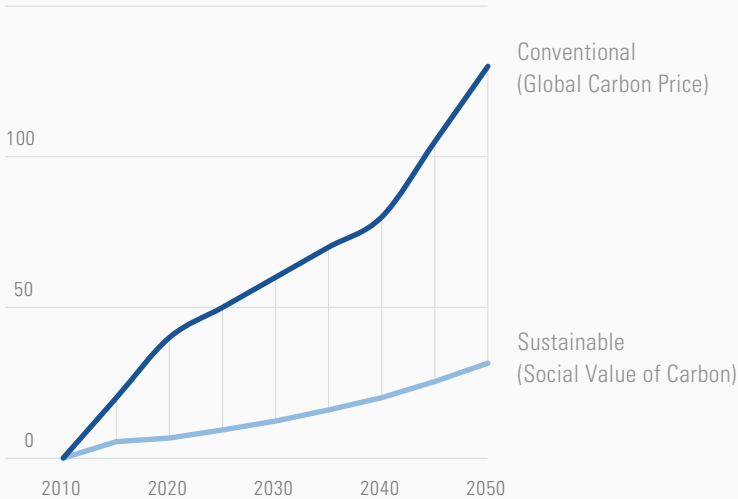
Deep Decarbonization with Least Social Cost of Carbon

In India's case, fundamental transitions in demography, income, urbanization and industrialization are expected to alter the key drivers of future greenhouse gas emissions. These multiple transitions bring opportunities and challenges regarding the twin challenges of development and decarbonization. The scale and diversity of resources endowments, institutions and socio-economic dynamics annul any attempt to

find a 'one-size-fits-all' solution package and instead encourage a scan of the entire policy spectrum in order to holistically address the national and sub-national goals of economic development, environmental integrity and social justice. India's National Action Plan on Climate Change (NAPCC) envisions addressing the different objectives simultaneously by adopting national policies (on inclusive growth, smart urbaniza-

Figure SM 30. India. Social Value of Carbon

150 CO₂ Price (US \$ per tCO₂)



tion, balanced regional development, sustainable mobility and building codes, to name a few) aiming at structural and behavioral shifts that alter market dynamics towards lower resource intensities and environmental externalities.

The Indian DDPP analysis considers two deep decarbonization pathways, which rest on distinct approaches to the policy package. The 'conventional scenario' envisions deep decarbonization as a commitment to apply a global carbon price trajectory that is consistent with 20C temperature stabilization, while other socio-economic policies continue to follow an autonomous track. In contrast, the 'sustainable scenario' places deep decarbonization within the bouquet of national sustainable development goals. In an integrated approach across diverse sectors, geographical scales and dimensions of sustainable development, this scenario considers a multitude of local, bottom-up and sectoral policies and measures targeting various objectives like SDGs, share of renewable energy, air quality standards, energy access and energy efficiency, waste reduction, dematerialization and resources conservation. The prominent measures include the choice of urban form, investments in low carbon infrastructures, energy efficient building codes, fuel-economy standards, air quality standards, waste recovery mandates, water conservation policies, regional agreements for sharing rivers & infrastructures, and the wise use of common property resources. The conventional scenario overlooks these opportunities as the carbon price alone does not provide the adequate anchor for the market to pull these options

The conceptual bifurcation underlying the two scenarios is the treatment of the '*social cost (or value) of carbon*'. The starting point is the assumption of identical *carbon budget over 2010-2050* in the two scenarios. In the conventional scenario, the *social cost of carbon* is same as the global carbon price trajectory, whereas, in the sustainable scenario, the *shadow price of carbon*

corresponding to the carbon budget constraint is the surrogate for social cost of carbon.

The sustainable scenario has a much lower social cost of carbon (Figure SM 30 left) compared to the conventional scenario, which measures the joint benefits of sustainability actions since incremental investments in actions aimed to achieve sustainability targets, in most cases, also generate lower carbon emissions. The conjoint benefits of targeted sustainability programs are sizable, especially in developing countries, due to pre-existing market distortions, weak institutions, uneven socio-economic development and geo-political risks. The incremental costs of sustainability programs are offset by lower social costs and reduced risks. Notably, deep decarbonization as implemented in the 'conventional scenario' would enhance risks from higher use of nuclear and CCS; in the sustainable scenario, primary energy demand is substantially lower and therefore also the need for high risk technologies.

Another scenario would be where even under the sustainable scenario India participates in global carbon markets where the carbon would be priced at the same level as in the conventional scenario. In this case, the carbon budget in the sustainable scenario would be underutilized and the excess emissions credits could be monetized at the prevailing global carbon price, generating sizable revenues, around 0.7% of India's GDP (Figure SM 30 right), which could partly pay back the economic cost from decarbonization actions. Under both interpretations, scenarios analysis for India shows that aligning national sustainable development and decarbonization policies lowers the social cost of carbon. *Least social cost of carbon can be made an explicit goal, aiming to minimize external costs and risks from decarbonization.* To this end, the policies, measure and actions to attain SDGs and deep decarbonization target can be interwoven, everywhere, into least social cost of carbon.

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Country Case Study Australia

Deep Decarbonization lowers net energy costs for households



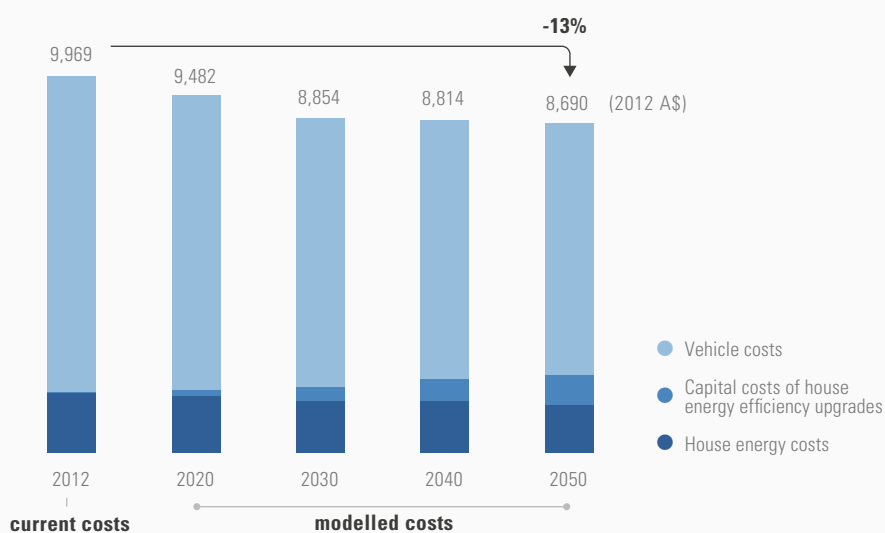
By undertaking ambitious energy efficiency while decarbonizing energy use in residential buildings and personal transport, the Australian DDP finds that substantial emissions reductions can be achieved while also reducing the net cost of energy for households.

As a result of energy efficiency in the home and car, the costs of energy and transport for households could be reduced by 13% per

household as shown in **Figure SM 31** below, despite increased capital costs and electricity prices. As income is expected to increase by over 50 percent over this period, this reduction in costs would represent a near halving in the energy and transport spend as a proportion of household income.¹

¹ this assumes household income increases in line with GDP per household

Figure SM 31. Australia. Average annual energy and personal transport costs per household, 2012 A\$



Energy and transport costs per households
-13%

GDP per households
+55%

Energy costs as a % of GDP per households
-44%

For homes, significant energy savings are available in residential buildings which can contribute to offset the increase in the unit costs of electricity from a decarbonized electricity sector. Appliances using direct energy such as gas can also be replaced to run on decarbonized electricity to improve efficiency while eliminating direct emissions. This combination of energy efficiency, fuel switching and decarbonization of electricity reduces overall emissions from residential buildings by 97%. Many houses are able to emit no greenhouse gasses at all by running on electricity from a 100% renewable grid or rooftop PV.

These emissions reductions can be achieved without increasing the costs of energy as a proportion of income per household. The Australian county team modelling results show that the cost of energy per household decreases by 22% even with an increase in unit costs of electricity. When the capital costs to improve the efficiency of buildings, appliances and equipment are considered, the overall costs to households increase by nearly 30%, although these energy costs fall by 17% as a proportion of income per household. For cars, the costs of owning and running vehicles can be reduced by 21% by employing more advanced efficient technology such as electric and plug in hybrid drivetrains with an overall trend to shift to smaller vehicles.

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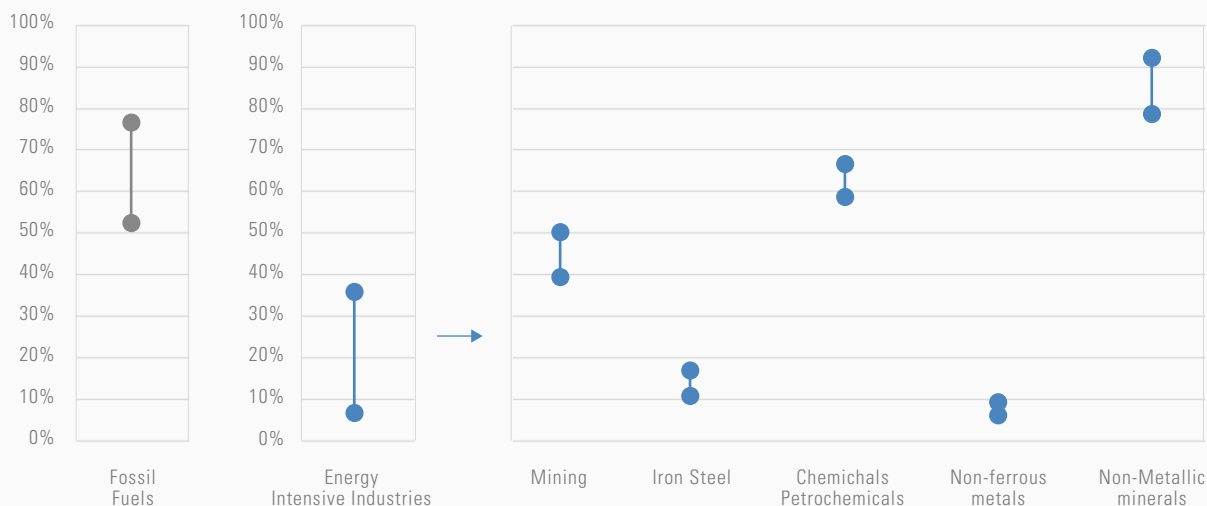
Country Case Study Italy

Trade balance

Currently, Italy imports 80% of its energy requirements, in particular coal and gas, and it is also a net importer of energy intensive commodities. Deep decarbonization pathways will move the energy and economic system away from fossil fuels and reduce the dependence of Italy on imported fossil fuels, and on imported energy-intensive goods.

In a framework of decarbonization efforts shared by all countries, macroeconomic effects on Italy's trade balance will produce positive outcomes in terms of either increased net exports or lower net imports, depending on the sector. The impact will be particularly strong in terms of reduced fossil fuel imports through increased reliance on domestic renewable sources, thus

Figure SM 32. Italy. Impact of DDPs on the Italian trade balance to 2050



Percentage change relative to the Reference scenario as a range for three DDPs. Positive changes represent improvements in the trade balance (reductions in deficits or increases in surplus or both). Ranges in results show the variation across models (ICES and GDyn-E) and scenarios. Results on the individual energy intensive industries are from the GDyn-E model.

lowering energy dependence. In the decarbonization pathways renewable energy sources would account for between 60% and 70% of the energy mix.

Figure SM32 shows the trade balance change in the DDPs in 2050 for fossil fuels and energy intensive sectors in 2050, compared to the reference scenario, taking into account recent pledges made by countries to limit CO₂ emissions. The trade balance change in the graph is normalized as the difference of net exports between the DDP and Reference scenario, divided by the absolute value of net exports in the Reference scenario. Positive changes in this graph represent improvements in the trade balance, which can be caused by reductions in deficits or increases in surplus or both, with respect to the reference scenario. The trade balance positive effects can be caused by a contraction of imports, as in the case of fossil fuels, or an expansion of exports as for the energy intensive industries, or due to both effects combined. Imports of primary fossil fuels in the three DDPPs would be reduced between 55% and 76% while imports from energy intensive industries as a whole would decrease between 7% and 13%. The trade balance for energy intensive products remains negative but is reduced in all decarbonization scenarios.

For these industries and compared to the reference scenario, the most important trade deficit reductions would come from non-metallic minerals, chemicals and petrochemicals and iron and steel. However, in a low carbon world economy, Italy would become a net importer of refined oil products, instead of a net exporter.

In conclusion the policy-induced structural adjustment would improve the resilience of the Italian economy to fluctuations in international energy markets and their repercussions on energy intensive industries.

Country Case Study Russia

Deep decarbonization can improve the resilience of national economies to international conditions

The Russian economy currently relies heavily on the export of natural resources. Primary energy contributes around 70% to total export revenue, and when including minerals and metals the percentage goes up to 90%. Russia's abundance of natural resources provides tremendous benefits and opportunities, but also creates risks, as clearly demonstrated during the current economic slowdown that has followed the fall of oil prices. The obvious conclusion is that Russia's natural resource export-led growth model is not sustainable. Export-led growth dominated by raw materials has exhausted its potential and cannot provide the economic backbone to meet the social and environmental challenges of long-term development.¹

Russian authorities have officially recognized that the modernization and diversification of the economy is an essential component of long run economic development. In 2009, President Medvedev initiated a set of modernization pro-

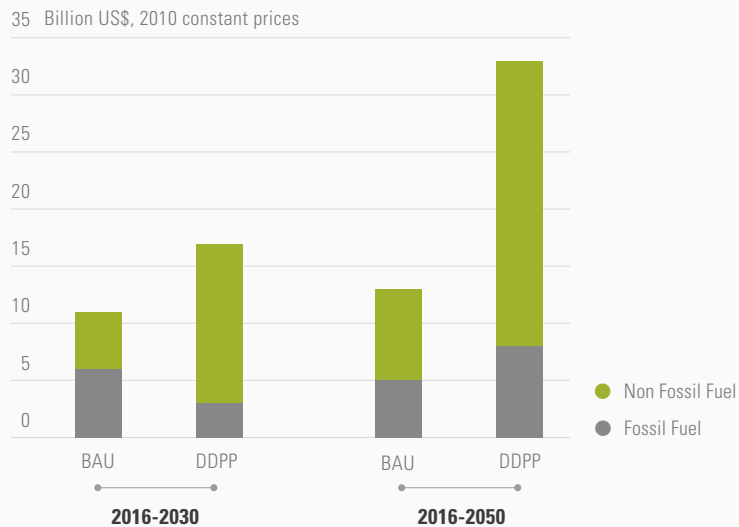
grams.² Their targets include decreasing the country's dependency on oil and gas revenues, and creating a diversified economy based on high technology and innovation. The programs formulate five top priorities for technological development: energy efficiency/resource conservation, nuclear technology, and information technology and communications among them. At the turn of 2010-2011, at the request of President Vladimir Putin, a blueprint³ through to 2020 and beyond was defined to chart the direction for the reforms required, to form the basis for new sources of long-term growth and sustainable development. Priority was given to qualitative rather than quantitative growth. The economy can no longer rely on the export of raw materials, which not only creates instability, but fosters technological and institutional backwardness, high macroeconomic risks, and vulnerability to external shocks beyond the control

¹ For discussion see Lugovoy, Mau (2015) "La Russie en quête d'un nouveau modèle de croissance" / A Planet for Life 2015 - Building the Future We Want (in French).

² For list of projects see <http://www.i-russia.ru/> (in Russian).

³ Mau, Valadimir (ed), Kuzminov, Yaroslav (ed), (2013) Strategy 2020: New model of growth – new social policy. Moscow: RANEP, vol. 1-2 (in Russian).

Figure SM 33. Russia. Average annual investments in power generation from 2016 to 2030, and 2016-2050 by types.



of the authorities. The new growth model must stimulate supply by improving the business environment, and promoting investments in R&D and human capital.

A decarbonization strategy is fully consistent with the officially announced long-term goals of modernization and reducing the Russian economy's dependence on energy and raw-materials exports. This is true in two ways: First, the deep decarbonization scenarios we have considered assume that as greater demand for energy innovations unfold, on the supply and demand sides, significant investments will be made in energy efficiency and clean-energy technologies, creating room for large-scale economic impact. Second, based on our estimates, deep decarbonization leading to a 25% reduction in carbon emissions by mid-2030 versus 2010 would be linked to an additional cumulative investment of \$200-\$250 billion (in constant 2010 dollars, depending on the decarbonization strategy), creating important business opportunities. In addition, deep decarbonization would permit a

net reduction of \$30-\$50 billion in total energy expenditures by 2030. Third, decarbonization aligns with the modernization of the energy sector and energy independence in the changes it would catalyze in the structure of investments. Decarbonization demands the more efficient utilization of resources and the decarbonization of electricity generation. **Figure SM 33** demonstrates the structure of investments under current business-as-usual policies (BAU) and under a DDPP scenario. The DDPP scenario requires investing about 60% more in the power industry by 2030, and investing more than 2.5 times more by 2050 than BAU, with a significant shift towards non-fossil generation. Notably, this higher level of investment will not lift electric generation costs, because of fuel savings and the longer lifespan of some generation capacities (such as hydro- and nuclear power plants). Sectors besides power generation will have to invest in energy efficiency and fuel switching as well; this shift assumes higher demand for industrial manufactured products and information and communication technology products and services, all of which are more labor intensive and have higher potential for long-term growth, thus stimulating more R&D.

We estimate the volume and quality growth in investment, plus the positive energy-bill savings, can add in average from 0.5% to 1.2% to Russia's annual GDP growth vs. BAU, and a net gain in jobs from 0.2% to 0.6% a year, with higher demand for skilled labor.

Besides the direct economic impact, adopting real measures to limit greenhouse gas emissions can greatly strengthen Russia's position in the global competition for investments, provide incentives for modernization, and unlock opportunities for cooperation in the field of clean energy.

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Country Case Study South Africa

The development of CSP with Storage

The power generation sector in South Africa faces the twofold challenge of a significant increase in electricity demand (consistent with development priorities regarding access to energy services) and strong constraints on CCS, which requires a shift away from coal, which currently represents 92% of 2010 power generation. CCS

is not considered as a feasible option in South Africa mainly because the coal mines are located very far from potential storage sites. Despite these constraints, the electricity sector undergoes almost complete decarbonization in the two DDPP scenarios, with the generation emissions factor decreasing from 1065 to 35 and 38

Figure SM 34. South Africa. Electricity generation

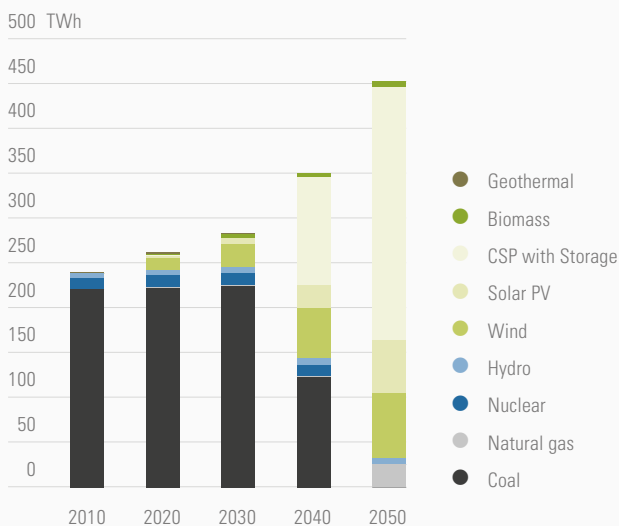
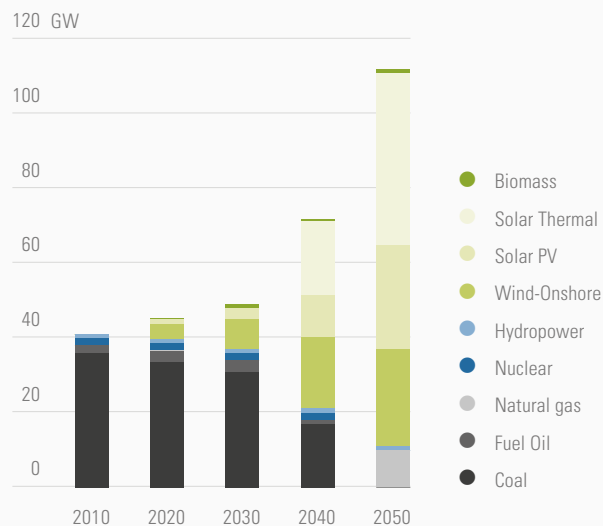


Figure SM 35. South Africa. Power generation capacity



g/kWh from 2010 to 2050 in Scenario 1 and 2 respectively. The differences between the two scenarios are minor, especially as compared to the dramatic changes that happen over time. We focus here on scenario 1 only.

The decarbonization of power generation is primarily achieved through the end-of-life retirement of coal-fired power stations. Solar PV and wind start to contribute to electricity generation by 2020 with wind increasing significantly by 2030. In the long-term, only small amounts of gas contribute to the final generation mix, but gas does not become a significant electricity source as CSP is cheaper than LNG; indeed, although solar CSP does not make a large contribution until 2040, it then becomes the dominant source of electricity by 2050. Non-fossil fuel technologies account for 89% of generation capacity by 2050 with solar PV and CSP with storage dominating at 63% of total capacity, and wind accounting for another 23%.

The wide-spread use of solar PV on commercial and residential properties and, even more importantly, the additional CSP capacity are plausible given South Africa's vast solar radiation resources (Fluri et al., 2009 and references therein). But, the underlying assumption is that cost declines will make these technologies affordable, notably compared to alternatives like nuclear, gas and wind technologies with which the cost tradeoffs are small. This means that this particular technology mix could be exchanged for one with more wind or nuclear, without changing the fundamental result, which is decarbonization of the electricity supply mix in a manner that does not hamper economic growth as investment costs are of a similar magnitude. However, CSP with storage, if available at affordable cost, offers certainly a particularly interesting solution for South Africa in that it makes the best use of an abundant domestic sustainable resource, i.e. solar radiation. Conversely, it must be noted in turn that the important market potential offered by South

Africa according to the DDPP scenarios (20 GW in 2040, 46 GW in 2050) could be crucial even from a global perspective. Indeed, the CSP option requires specific conditions of solar radiation, it only uses direct sunlight and is suited for desert and arid areas, where the direct normal insolation is high. This means that the market potential will remain limited and that any opportunity to expand the global market for this technology, thus enabling costs decreases, can play an important role in creating incentives for research and development. This chicken-and-egg issue (South Africa can adopt CSP only if costs decrease globally, but cost decreases depend on diffusion of the technology in South Africa) can be solved only through adequate policy schemes to encourage CSP uptake, without creating economic distortions in terms of investment costs or the price of electricity.



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Country Case Study Australia

Investment analysis including buildings and industry as well as sensitivity tests on different pathways

The transition to a decarbonized economy will require investment in new low carbon capital assets across the economy, particularly in transportation, electricity generation, industrial equipment, and buildings. In many instances this investment can reduce expenses such as fuel costs and reduce overall operating costs in the economy.

The Australian modeling results suggest that while the overall investment in electricity, road transport and energy efficiency in industry and buildings grows significantly over time, it remains fairly consistent throughout the pathway as a proportion of GDP. As shown in **Figure SM36** below, investment levels vary by only 0.1% of GDP for each decade between 2012 and 2050. Investment levels in those sectors in recent years is likely to have been about 0.3% or 0.4% of GDP lower. This is a very small variation when considering the overall level of investment in the economy, which in 2012 amounted to 27.1% of GDP.

Investment levels vary significantly within sub-sectors, with in particular investment in energy efficiency and electricity generation increasing strongly, while investment in road transport equipment grows at a smaller pace than GDP. The decrease in road transport investment per \$ GDP occurs despite investment in technologies

Figure SM 36. Australia. Average annual capital investment in electricity generation, road transport and energy efficiency in industry and buildings, \$b

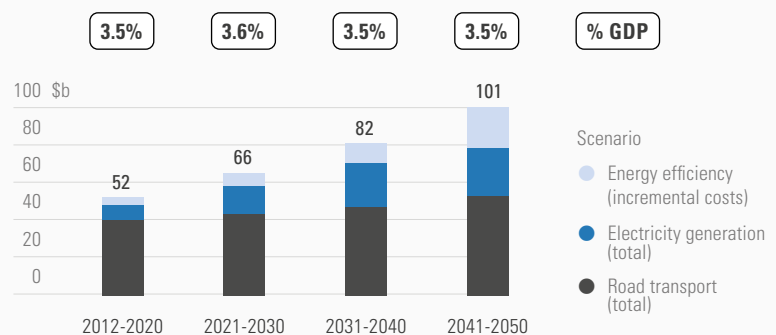
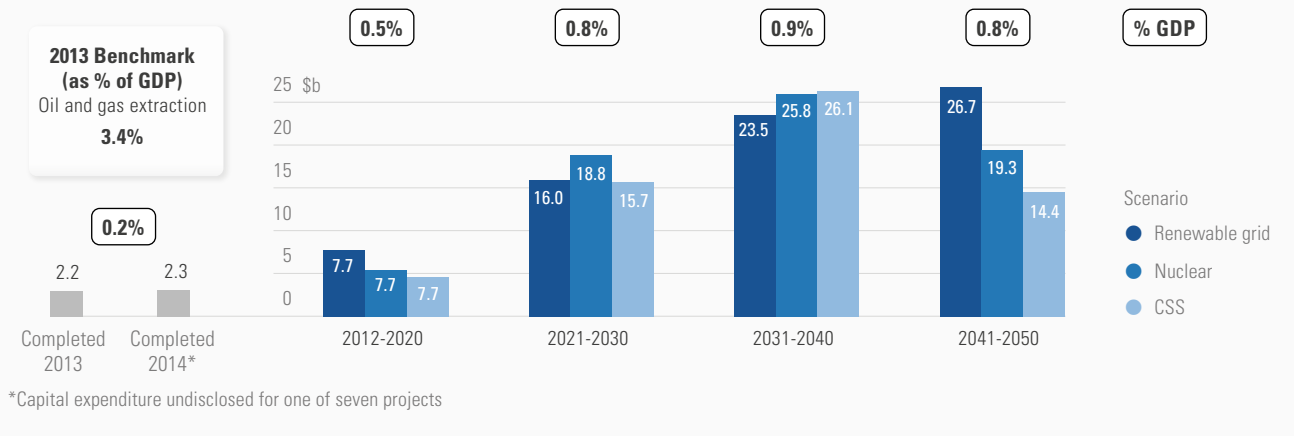


Figure SM 37. Australia. Average annual capital investment modelled in DDPP scenarios compared to current value of completed generation projects

such as electric and hybrid vehicles. A continued trend towards smaller vehicles, increased urban density driving some shift to public transport and telecommuting, as well as operational improvements in road freight leading to increased vehicle utilization drives this decrease which also results in a significant reduction in fuel use. The increase in capital investment required for decarbonization is strongest in the electricity generation sector. Overall investment in electricity generation in Australia has been low in recent years due to falling electricity demand and as political uncertainty has stalled investment in renewable energy. In 2013 and 2014 there was \$A 2.2 billion and \$A 2.3 billion in completed projects respectively (BREE 2014) with around 2GW of capacity added in mostly wind and gas generation.

As part of the Australian DDPP, three electricity generation pathways were modelled (100% renewable grid, nuclear and CCS). In each of these modelled pathways, average annual investment in electricity generation increases to over 10 times current investment, although this level of investment as a proportion of GDP remains below one percent.

While this is a significant increase, experience shows that it can be achieved if the right financial incentives are in place. Larger increases in investment have been achieved in the energy sector in Australia over shorter periods of time. Indeed from 2009 to 2013 investment in oil and gas extraction increased from 0.5% of GDP to 3.4% from the development of several major Liquefied Natural Gas (LNG) projects.

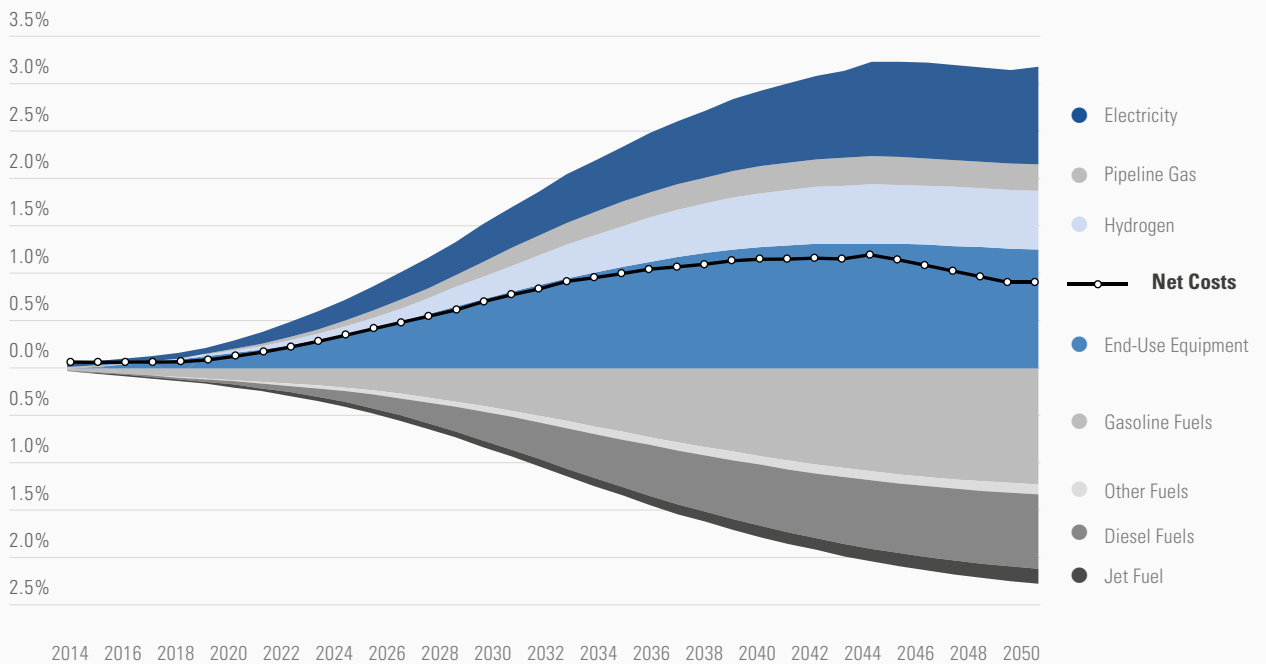
Country Case Study USA

Energy system costs in the US DDPP pathway

The United States deep decarbonization analysis employed a bottom-up modeling framework that tracked infrastructure related to the production, delivery, conversion, and final consumption

of energy in the U.S. economy. This accounting framework allowed for a detailed investigation of energy system costs and benefits to society from deep decarbonization, and also the chang-

Figure SM 38. USA. Net energy system cost (% GDP)



ing structure of energy costs over time. Here, the findings of the U.S. cost analysis are consistent with the findings of the DDPP global investment analysis. Across all U.S. deep decarbonization scenarios, the net cost of energy supply and use increases slightly, on the order of 1% of GDP in 2050, with a wide uncertainty range. However, as the economy expands, overall energy spending actually declines as a percentage of GDP. The principal impact of deep decarbonization on the energy economy is thus not an overall increase in spending, but a fundamental shift in the direction of that spending. Instead of consumers and businesses continuing to expend vast sums on refined fossil fuels at the pump, spending is instead directed toward investment in low carbon technologies on both the supply and demand sides of the energy system. [Figure SM38](#) shows the levelized cost impacts of these changes compared to a reference fossil fuel-based future.

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Country Case Study Australia

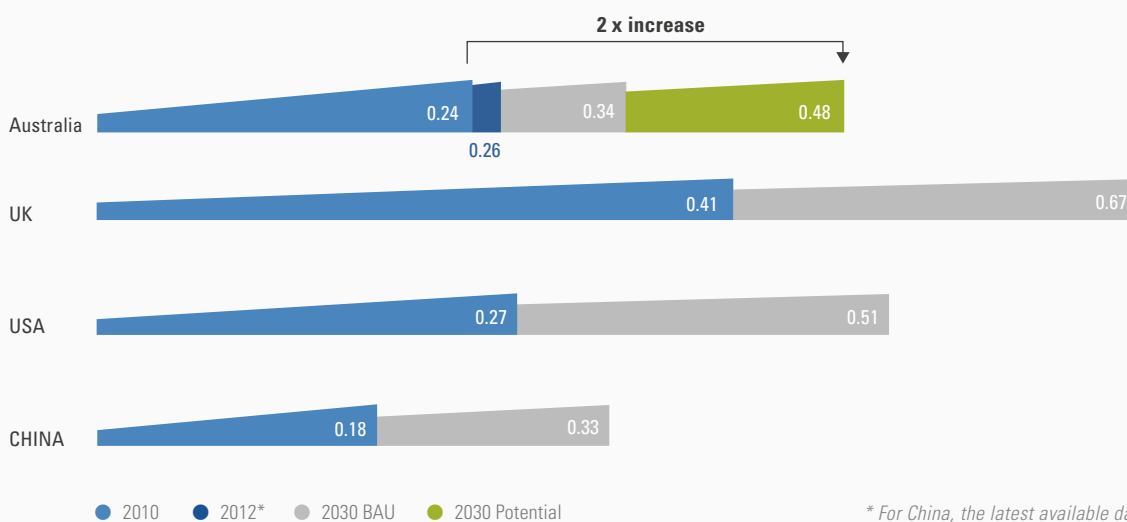
Deep decarbonization as a booster for energy productivity



Like many other countries, Australia has experienced substantial increases in energy costs in recent years. Over the past decade, energy costs have grown by 67 per cent, and are now equivalent to 8.2 per cent of total GDP. Reducing these costs through improved energy productivity is becoming an increasingly important consideration for countries seeking to improve resilience to rising or fluctuating energy prices, and economic competitiveness.

Many of the activities that reduce greenhouse gas emissions can also improve energy productivity. For example, Australia currently lags behind its peers in energy productivity, and would fall further behind if current trends continued (see chart below). However, implementing the deep decarbonization pathway would deliver a doubling of Australia's energy productivity by 2030 compared to 2010 levels, bringing it back in line with the US.

Figure SM 39. Australia. Australia's energy productivity compared, \$GDP / MJ primary energy



Like labor and capital inputs, energy inputs are essential for economic activity, driving our office buildings, our homes, our factories and transportation systems. Energy productivity refers to the amount of economic activity that is generated for each unit of energy consumed. Energy productivity can be improved through improvements in the effi-

ciency with which energy is produced, transported and consumed.

All three pillars of decarbonization would contribute to the modelled improvement in energy productivity, with energy efficiency providing the largest contribution (see chart below).

Figure SM 40. Australia. The role of energy productivity for economic activity

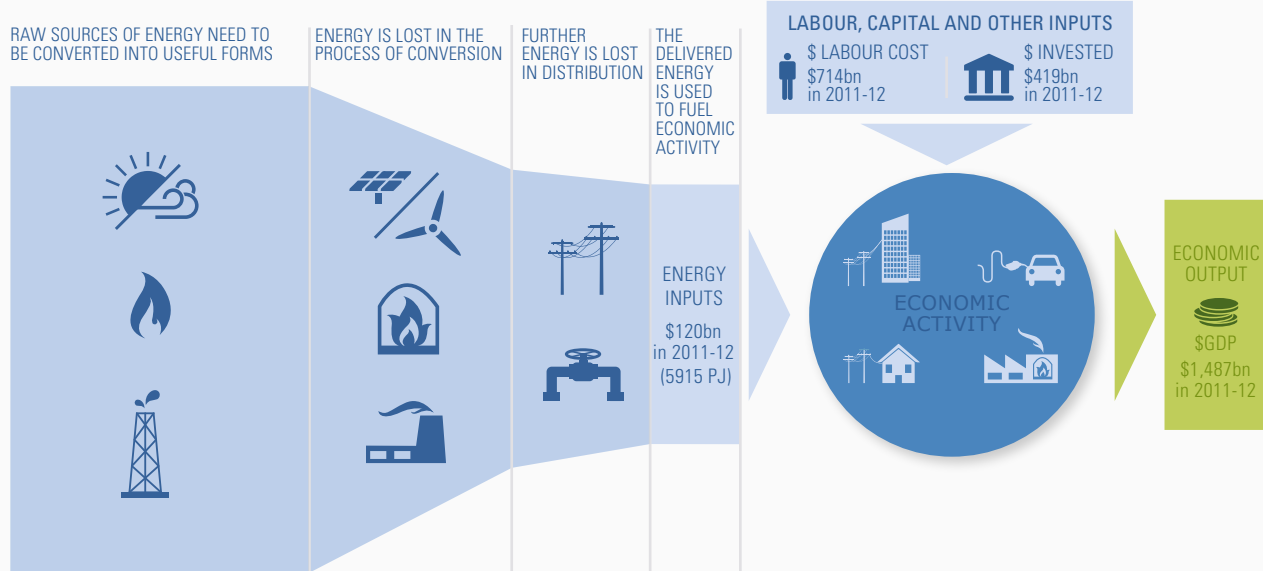
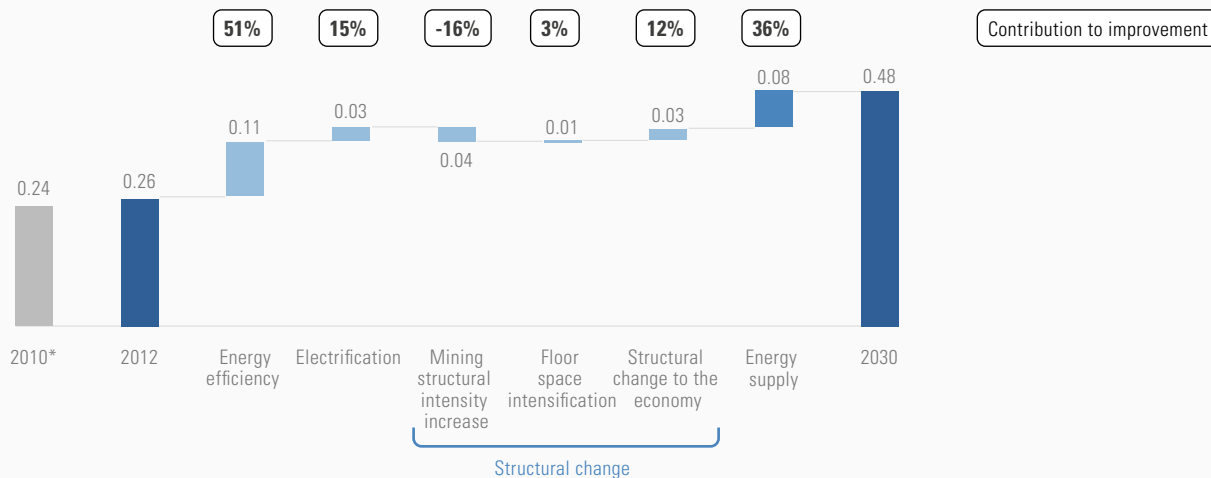


Figure SM 41. Australia. Factors contributing to improvements in energy productivity to 2030 in the Pathways to Deep Decarbonization modelling, \$GDP / MJ primary energy



Country Case Study France

Adaptive and dynamic management of the transition to accommodate uncertainties

Strong uncertainties and inertias characterizing the building blocks of the deep decarbonization transformation. This makes sequential decision-making necessary in the course of the transition, to build upon continual learning and permit the adaptation of policies in response to experience and increasing information over time (Dewey, 1927). In such a context, an important role is played by policies that make the transformation more robust, (i.e. suited to very different economic or technological environments, at the domestic and international level) and resilient (i.e. that swiftly recover their balance and functionality in the event of crises, accidents or acute instability). These include:

- Policies and Measures that are common to all pathways, in the sense that deep decarbonization becomes increasingly challenging if they are not implemented, at least during the initial launching phase.
- Policies and Measures that are constrained by severe inertia and delays in response or de-

ployment, and for which near-term action is required in order to make possible their gradual deployment at scale over the course of the transition;

- Policies and Measures which preserve future freedom of choice by encouraging the extended use of existing facilities and/or systems (avoiding lock-ins), thus leaving time to get more information, reduce uncertainty and broaden the scope of possible future outcomes.

With this kind of perspective, policies must be reviewed and re-appraised at regular intervals. According to a 'rule of seven'¹, the deep decarbonization to 2050 would require a revision of policies every five years. Combined with a precise monitoring process, this revision would pro-

¹ This rule recommends to divide the timeframe of a policy scenario by seven as a simple way to organize its design, implementation and recurrent review. It is notably recommended by Ged Davis (*former head of SHELL's Group Planning, now World Economic Forum and World Energy Council*)

vide the basis for dynamic management of the transition corresponding to a new paradigm for policy design in a context of strong uncertainty. Policymakers would create a strategic vision of the future, commit to short term actions and establish a framework to monitor the results and adapt decisions in a flexible manner. This analysis argues in favor of setting up in every country an institutional management system for low-carbon energy transition, comprising:

- Imperatives, i.e. objectives which must be achieved regardless of the strategy (long-term emission target but also socio-economic targets);
- Short-term goals consistent with the long-term objective, against which the performance of the transformation can be assessed;
- Timely decisions for large programs or infrastructures that involves a significant degree of inertia.

Country Case Study UK

Case Studies, Institutional capacity for delivering DDPs

DDPs require both a strong policy package to start moving towards deep decarbonisation but also the development of institutional capacity. Drawing from the UK example, there are a number of principles that provide a basis for establishing this institutional capacity:

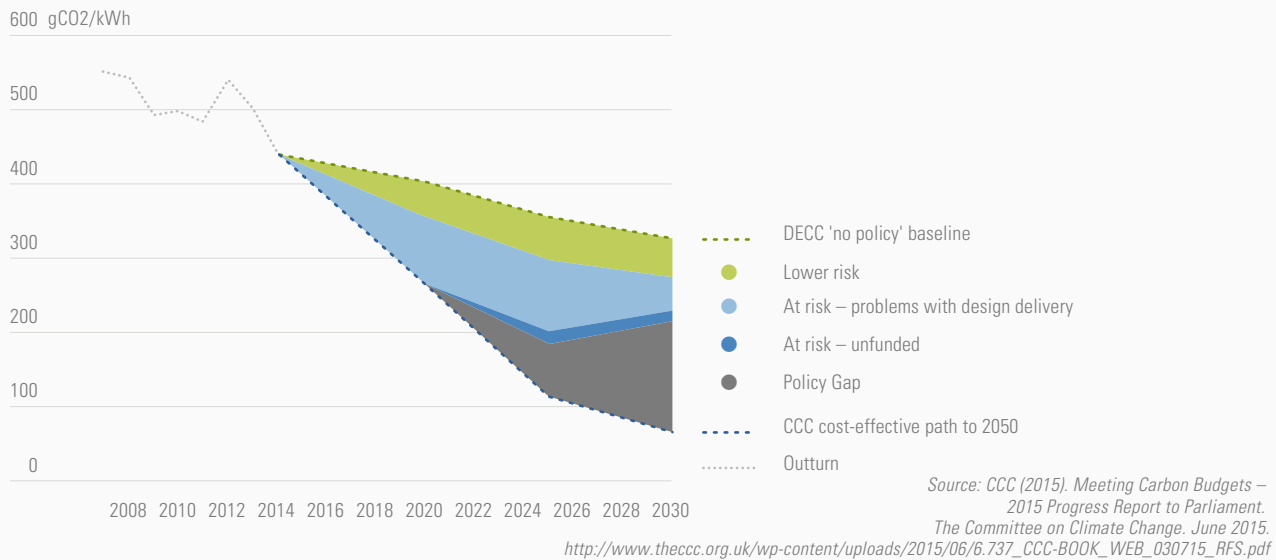
1. A long term framework in legislation but with interim goals. The Climate Change Act 2008 established that Government must *ensure that the net UK carbon account for the year 2050 is at least 80% lower than the 1990 baseline*.¹ Legislation ensures two things; that Government should be legally accountable to its citizens, and that action should not be bounded by the electoral cycle. The Act also required interim 5 yearly carbon budgets to be established, to focus mid-term action to ensure progress to the longer term 2050 target.
2. De-politicisation of the process through independent advice. The Government has independent advisors, the Committee on Climate Change (CCC), who are mandated under the Climate Change Act 2008 to provide advice

relating to the setting of carbon budgets, and monitoring progress. While this guidance may or may not be taken, the Government is required to respond to such advice.

3. Transparency of advisory and policy process, and accountability. In addition to de-politicising the setting of ambition levels, advice can also be a basis for transparency in providing guidance, and if rigorous, engender greater levels of public trust. The CCC and Government, through the lead department, DECC, publish much of the supporting evidence that helps formulate the advice and policies.² Accountability is also critical. The annual reporting by the CCC of progress is also an independent check on Government action across all sectors, against a range of indicators. **Figure SM 42** illustrates the recent assessment of the policy gap and policy delivery at risk in meeting the ambition level to 2030 for power sector decarbonisation.

¹ Climate Change Act 2008, <http://www.legislation.gov.uk/ukpga/2008/27/contents>

² The modelling framework used in the UK DDPP report is also being used in the 5th Carbon Budget process, to determine the 5 year budget between 2028-2032. Through a joint DECC-UCL collaboration, this model will be published online as an open access resource, with full documentation.

Figure SM 42. UK. Assessment of current and planned policies: power sector

4. Strong and diverse analytical capacity. A strong basis for analytical capacity provides both independent advisors, the CCC, and DECC, the necessary support to provide advice and make evidence-based policies, respectively. Different tools are needed for different objectives, the capacity for which cannot be held solely by Government.

In summary, it is worth noting that policies still need to be developed by governments within political realities. However, establishing a long term framework, provision of independent advice, ensuring transparency and accountability, and developing analytical capacity to help decision making, are all important principles that should aid the development and implementation of DDPs.

Country Case Study Australia

Implementation framework towards different groups of stakeholders



The Deep Decarbonization Pathways developed for Australia have identified that achieving zero net emissions by 2050 is technically feasible in Australia, and can be achieved in tandem with ongoing economic prosperity. In order to help facilitate this transition, a framework which translates the pathways into actions to be taken by key decision makers across business, government and the investment community has been developed. The actions can be broken into three broad categories:

- Accelerate actions now to increase deployment of profitable technologies, reduce cost of demonstrated technologies and facilitate exit of emission intensive technologies;
- Avoid lock-in of emissions from long lived assets by providing long-term signals and ensure compatibility of new assets;
- Prepare for the future through increased R&D, building supply chains and capabilities and undertaking appropriate planning.

For businesses, this means taking a strategic approach to emission reductions through iden-

tifying opportunities, setting targets and implementing a portfolio of opportunities that meet internal hurdle rates. Implementing an internal price on carbon will also assist in driving investment decisions, and review of exposure and opportunities in a decarbonized future will help ensure decisions are made in the appropriate context.

Within Australia, ClimateWorks has briefed a range of businesses on the implications of decarbonization, and continues to work with businesses to understand their risks and opportunities and develop decarbonization strategies.

For government, this means establishing policy to drive uptake of energy efficiency and low carbon energy. In the short term it also requires a leadership role in terms of government's own procurement and operation, for example low carbon electricity procurement, vehicle fleet management and office energy performance. To avoid lock-in of emissions government can implement energy efficiency standards for buildings and vehicles, place more stringent requirements

Table SM 5. Australia. Key actions to be taken by business, government and investors to implement the Deep Decarbonization Pathway

	Key actions	Business tools examples	Central government tools examples	Investors tools examples
Accelerate action now to reduce emissions	<ul style="list-style-type: none"> Deploy profitable technologies Accelerate cost reduction of demonstrated technologies Accelerate exit of emissions intensive technologies 	<ul style="list-style-type: none"> Set internal emissions reduction targets Develop a strategy for emissions reductions Make sure hurdle rates for energy efficiency and renewable energy are appropriate and implement all cost-effective opportunities 	<ul style="list-style-type: none"> National targets for EE and RE Incentives for EE & RE (subsidies, tax rebates, feed-in-tariffs, reverse auctions, carbon pricing/ETS) Information (disclosure of building energy performance at sale/lease, info & audits for HH & SMEs) Government leadership in procurement (buildings, vehicles) 	<ul style="list-style-type: none"> Quantify carbon risk and opportunity in existing portfolio and redirect investment from highly exposed assets to low-carbon assets Engage with companies in portfolio to reduce their carbon exposure
Avoid lock in of emissions intensive technologies	<ul style="list-style-type: none"> Establish clear long-term signals to inform investment decisions Ensure new assets are compatible with the long-term pathway 	<ul style="list-style-type: none"> Implement internal carbon price reflecting long term goal to drive investment decisions Develop deep decarbonisation pathways for company Pilot / test new low-carbon technologies and identify those profitable to implement 	<ul style="list-style-type: none"> Minimum standards for long-lived assets (buildings, cars, industrial plant, infrastructure, generators) Planning and other approvals reflect long-term goal (eg. mining licences; forestry licenses) Develop supporting infrastructure (eg. public transport, EV charging) 	<ul style="list-style-type: none"> Encourage companies in portfolio to implement internal carbon price and develop deep decarbonisation pathways Do not invest funds in new assets incompatible with two degrees target
Prepare for the future	<ul style="list-style-type: none"> Accelerate R&D Build the supply chains, skills and capabilities Plan transition 	<ul style="list-style-type: none"> Identify potential growth sectors and invest in R&D, etc. Develop business models which could facilitate uptake of new low carbon technologies 	<ul style="list-style-type: none"> Tax breaks for innovation/research; grants for pilots & capacity building Ongoing national decarbonisation planning for green growth (eg. biorefineries with local feedstocks) and transition 	<ul style="list-style-type: none"> Invest in promising low-carbon technologies and enabling sectors

Note: EE = Energy Efficiency, RE = Renewable Energy, HH = Households, SME = Small and Medium-sized Enterprises, ETS = Emissions Trading Scheme, EV= Electric Vehicles, R&D = Research and Development

on environmental and planning approvals, and invest in infrastructure such as public transport. To assist in preparing for the future governments can provide incentives for innovation and R&D, and support capacity building of key supply chains such as bioenergy.

ClimateWorks and ANU have worked across both national and state governments in Australia, to translate the research undertaken for the Deep Decarbonization Pathway into suitable material to inform policy development. This has included identifying the potential for improvements to energy productivity (see [Case Study 32](#)), and identifying the potential post-2020 emission reductions that are feasible within Australia. It has also led to the development of projects to help upgrade Australia's commercial building code to improve energy efficiency, and develop light vehicle emission standards for Australia.

For investors, the focus is on quantifying the potential exposure to decarbonization in their existing portfolio and investing in low carbon assets into the future. In order to avoid lock-in, investors can work with businesses they invest in to mitigate their exposure, and support the development of new technologies through investing in early stage R&D.

ClimateWorks has begun working with the investment community in Australia, and internationally. This work is focused on increasing awareness amongst the investment community of the risks decarbonization can present, and also working to help the investment community understand the potential financial benefits energy efficiency can provide.

Country Case Study Germany

Participation process

After Germany experienced strong opposition against nuclear power plants in the past, today the generally welcomed energy transition is--on a micro level--also facing opposition, particularly against wind power and new transmission lines. The arguments citizens raise are mainly for aesthetic and health reasons. Furthermore, some citizens suspect a hidden agenda with most decisions on the 'Energiewende' being made behind closed doors, and with interests not being transparent.

Although such public conflicts exist, a joint federal initiative to increase acceptance through participation has long been lacking in Germa-

ny¹. However, the number of public participation projects has increased sharply in recent years as decision makers realized that participation can be a useful instrument when communicating information is not enough. Rather, concerns need to be integrated, local knowledge needs to be gathered, conflicts need to be resolved and shared recommendations need to be produced. Participation does not produce acceptance, but

¹ The German government now initiated a participation process aiming at generating inputs for a national Climate Protection Plan. Similar to the process in North-Rhine Westphalia, it should constitute a roadmap to achieve GHG mitigation targets.

Figure SM 43. Germany. Schematic description of the NRW climate protection plan process



Source: German DDP report, IFOK 2013 (personal communication, July 13, 2015)

it does enable citizens to become owners of a process and encourages tolerance of the policy. A broad participatory process was e.g. conducted by the state of North Rhine-Westphalia (NRW), the German state with the highest amount of fossil fuel-fired power plants and energy-intensive industries. The process was based on NRW's climate protection law (Climate Protection Act) where concrete GHG emission mitigation goals have been fixed for 2020 (-25% vs. 1990) and 2050 (-80%). The output of the participation process constitutes the basis for the so-called 'Klimaschutzplan' (Climate Protection Plan), the road map containing strategies and measures for achieving NRW's mitigation targets.

In an effort to develop inputs for the 'Klimaschutzplan', politicians engaged in discussions with more than 400 different stakeholders along six sectoral working groups (cf. [Figure SM 43](#)). They debated in a systematic process over a period of two years e.g. on appropriate technologies to obtain the decarbonization targets, the integration of these technologies into consistent pathways, possible impacts of the pathways and appropriate policy instruments supporting the process.

With the participation process, the NRW government decided to intensively engage relevant stakeholders already in the development of the 'Klimaschutzplan'. After two years several added values could be detected:

- Specification of relevant stakeholders for ambitious climate protection policy in NRW
- Significantly improved knowledge about mitigation potentials and scenarios in NRW
- Stakeholder assessment of mitigation measures
- Buildup of highly productive discussion culture among stakeholders
- Increased awareness for different perspectives among stakeholders
- Confidence building between stakeholders and ministries

- Better chance to implement mitigation measures due to joint development with stakeholders

- Starting point for further dialog structures with stakeholders (e.g. dialogue with industry)

Generally, evaluations of participation processes tend to show that although not all projects are successful in terms of implementing a specific infrastructure (e.g. a windmill), they do reach important goals such as knowledge creation, conflict resolution etc.

Country Case Study Canada

The Canadian policy package

To reach deep decarbonization, the DDPP Canadian scenario relies on a combination of policies and measures, among which the main elements are

1. Best-in-class mandatory energy and GHG intensity regulations requiring the use of zero or near-zero emission technologies in the buildings, transport and electricity sectors, applied to all new installations and retrofits:
 - In buildings, regulations would trend down to require net-zero-energy residential buildings after 2025, and commercial buildings after 2035. This would be enabled by highly efficient building shells, electric space and water heaters with heat pumps for continuous load devices, solar hot water heaters and eventually solar photovoltaic (PV) as costs fall. Community heating opportunities identified through energy mapping is also an option.
 - In transport, personal vehicles and light freight, because they have several options (efficiency, electrification, bio fuels, hydrogen and mode shifting), would be on a rolling 5-year schedule, with the announced long-run goal being for all new vehicles to decarbonize in the early 2030s. Heavy freight vehicles that have more limited options (including some rail-based mode shifting, efficiency, biofuels and hydrogen—batteries are not sufficiently power dense for freight) would be on a schedule to decarbonize by 2040.
2. Mandatory 99 per cent controls for all landfill and industrial methane sources (landfill, pipelines, etc.). Any remaining emissions would be charged as per the following policy.
3. A hybrid carbon-pricing policy, differentiated by heavy industry and the rest of the economy:
 - A tradable GHG performance standard for heavy industry (including electricity), evolving from -25 per cent from 2005 in 2020 to -90 per cent before 2050, using output-based allocations to address competitiveness concerns. If desired, an absolute cap and trade system could be implemented instead with mostly similar effects.
 - A flexible carbon price, either a carbon tax or an upstream cap and trade, covering the rest of the economy, rising to CDN \$50 by 2020 and then in \$10 annual increments to 2050.³ The funds are recycled half to lower personal income taxes and half to lower corporate income taxes. The charge would be flexible based on progress, notably on technologies.
4. A land-use policy package that values the net carbon flows of large parcels of land. The

policy would provide standardized valuation and accounting for net carbon flows on agricultural, forested, brownfield and wild private lands. Government lands would be managed including net carbon flows in the mandate.

Country Case Study Indonesia

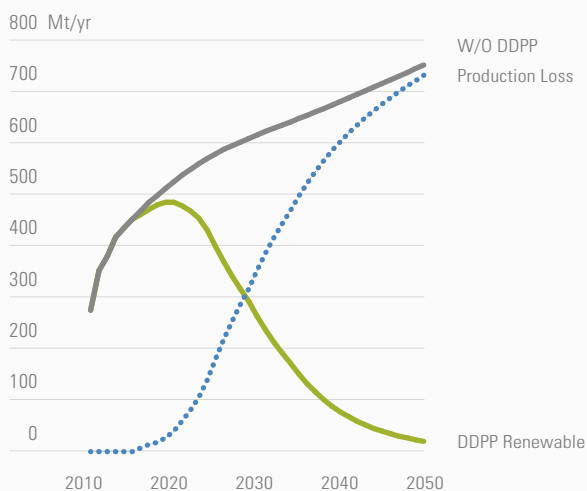
Unrecovered resource: the case of Indonesia coal

Global deep decarbonization through deep reduction in fossil fuel use means a considerable amount of fossil energy resources must remain in the ground. This will have economic implications for fossil energy exporting countries.

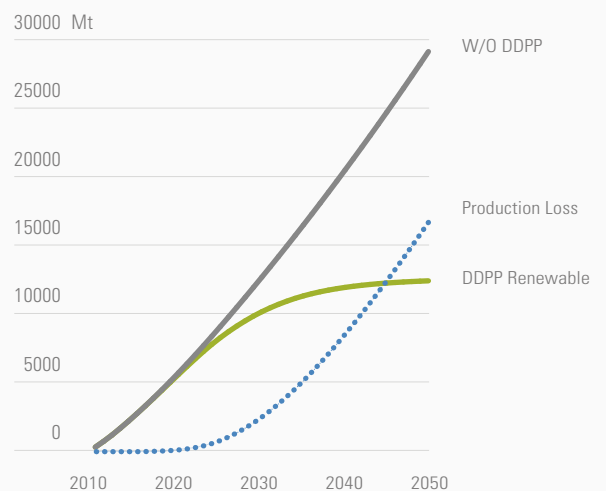
As an illustration, we take Indonesian coal as a case study. Indonesia, with a total coal reserve and resource of 29 and 115 billion tonnes, is a

major coal producer and one of the world's top coal exporters. In 2014, Indonesia coal production amounted to 435 million tonnes, of which around 359 million tonnes is for export. In the past 10 years coal production has been increasing steadily at an average growth of 12% per year, from 132 million tonnes in 2004 to 435 million tonnes in 2014. In the past two years, however,

Figure SM 44. Indonesia. Future coal production
Annual Production



Cumulative Production



growth has slowed to 3% per year. Based on this historical trend and coal resource endowment, Indonesia coal production is forecasted to reach around 725 million tonnes in 2050, whereas global deep decarbonization means instead a sharp decline to only around 20 million tonnes in 2050 (Figure SM44). The cumulative loss of production opportunity from 2016 to 2050 caused by deep decarbonization is around 14 billion tonnes. To give an order of magnitude, using the current value of Indonesian coal at \$60/tonne, this leads to a cumulative production loss of 840 billion US\$. In addition, there will be other losses associated with this loss of production, notably stranded assets in coal production capacity and associated losses of employment. It must be noted, however, that Indonesia's deep decarbonization pathway would include substitution of coal by renewables and nuclear and gain some positive economic impact from the creation of domestic renewable energy industry.

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