POLICY LESSONS ON DEEP DECARBONIZATION **in large emerging economies**

Brazil, India, Indonesia and South Africa

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Contact

Henri Waisman, henri.waisman@iddri.org

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Layout: Ivan Pharabod.

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Introduction

Marta Torres Gunfaus, Anna Perez Catala, Hilton Trollip, Henri Waisman.

The world has agreed to prevent the irreversible damages to human and natural ecosystems caused by anthropogenic global warming by limiting the rise of global temperature to well below 2°C and to pursue efforts to limit it to 1.5°C. To implement this, the Paris Agreement grounds this goal in terms of global emission trajectories and the need to embed them in the in the context of sustainable development and efforts to eradicate poverty. Subsequently science (IPCC SR1.5) further specifies that global neutrality concerning carbon dioxide specifically should happen between 2050 (for 1.5°C) and 2075 (for 2°C). It also points out the necessity of minding non-CO_2 forcers to maintain the global objective. To reach this scale of emission reductions, the scientific assessment concludes that rapid and far-reaching transformations, far beyond what has been observed in the past, are required in all components of the economic system, i.e. in energy, urban and infrastructure, industry and land and ecosystems. Such drastic transitions in turn require profound changes in technologies but also in social, economic, institutional and policy conditions. Science shows that the changes required by climate objectives can be compatible with broader sustainable development objectives if action is implemented without delay, is guided by strategic visions of transformations informing the design of well-designed policy packages and the cooperation among actors and is enabled by effective international cooperation. With these framework conditions at hand, countries are set to explore national pathways to explain how the rapid and far-reaching transitions required globally can happen in each country context.

National deep decarbonisation of large emerging economies has been largely explored from a techno-economic perspective, resulting in viable sets of long-term pathways under a number of conditions. Existing analysis shows that the national transition can mostly been initiated using existing technologies and market instruments at low and often net negative financial cost and that, usually, these transformations can have associated large overall net economic benefits when external economic and environmental costs and benefits are factored in. However, similar to most parts of the world, most major necessary decarbonisation transformations are either not happening or happening at a slower pace than necessary. This gap between existing evidence and concrete action highlights that the carbon neutral transition is not only a matter of techno-economic feasibility but essentially a question of political economy. Actual implementation requires clarity about the choices to be made in the transition, about the concrete policies and actions that can be envisaged, about those who can be winners and those who may lose and the measures adopted to manage the socio-economic costs of the transition. Scientific assessments should therefore be seen less as an instrument to illustrate transition pathways in a normative manner than as a way to determine the inclusive whole-of-society conversation that would be required to make the transition effective and acceptable.

The DDP community behind this report has committed to this vision of the role of scenario analysis in the public debate. The body of knowledge emerging from this community aims at ensuring that the features of the techno-economic deep decarbonisation transformations are contextualized in the diversity of country circumstances and described with sufficient details and granularity to inform decisions required to drive these transformations. Key challenges to date, which are critical to increase ambition and accelerate action, include: connecting the scenarios analysis and the diversity of policies and actions to implementation in the real world; revealing the critical conditions that are outside the control of national authorities, where international cooperation must play a role, and ensuring ownership of the insights emerging from the scenarios by a diversity of actors to empower them in the public debates .

The DDP approach underlying this report's research is established with these key challenges in mind. It is fundamentally a country-driven exploration, back casting from the mid-century emission and socio-economic objectives to inform the short-term decisions within and across systems. Sectoral deep dives allow for an in-depth investigation of all levers, opportunities and challenges suited to inform domestic stakeholder debate in highly complicated sectors, such as transport, industry, or agriculture/land-use, which are traditionally represented poorly in existing long-term roadmaps. The stakeholder engagement approach to the development of the scenarios and emanating policy insights is an essential means for these scientific assessments to serve an action agenda.

This report presents a synthesis of the results of the assessments conducted in Brazil, India, Indonesia and South Africa. For each of the countries chapters, Part I describes the main features of the economy-wide Deep Decarbonization Scenario(s) (DDS), including a description of key national-scale socio-economic aspects and an explicit characterisation of the emission objective and trajectory. To realise the necessary changes to get on track to this path, a description of the Current Policy Scenario (CPS) is also presented, including a description of the main policies and actions considered. Scenario results include an in-depth description at sector level for the deep dives selected by each country. Part II of the country chapters focuses on key policy lessons, which can serve as direct inputs into policy conversations at the country level. It includes a description of the main synergies and trade-offs with country non-climate objectives, priority short-term policies and actions, with a focus on where shifts from current paths are critically required, investments patterns and key international enablers and accelerators of domestic transitions.

BRAZIL

Emilio L. La Rovere
Carolina B.S. Dubeux
William Wills
Michele K. C. Walter
Giovanna Naspolini
Otto Hebeda
Daniel N. S. Gonçalvez
George V. Goes
Márcio D'Agosto
Erika C. Nogueira
Sérgio H. F. da Cunha
Cláudio Gesteira
Gaëlle Le Treut
Giovanna Cavalcanti
Mark Bermanzon

Center for Integrated Studies on Climate Change and the Environment (CENTRO CLIMA) at COPPE/UFRJ – Institute for Research and Graduate Studies of Engineering, Federal University of Rio de Janeiro.

The Brazilian NDC has an economy-wide goal of 37% GHG emission reduction, by 2025 and 43% reduction by 2030, compared with 2005 as the base year. Brazil also made voluntary commitments of emission reductions in 2009 during COP15 (Copenhagen) linked to its NAMAs, corresponding to keep emissions below a cap of roughly 2 Gt CO_2eq in 2020. More recently, the Brazilian President announced at the Climate Leader Summit organized by US President on 22 April 2021 the country's commitment to reach climate neutrality by 2050.

This study simulates two GHG emissions scenarios in Brazil until 2050. It provides a framework for an analysis of economy-wide and sectoral indicators of a decarbonization pathway aligned with the general objective of the Paris Agreement (net-zero GHG emissions in 2050). The Current Policies Scenario (CPS) follows the trend of ongoing mitigation actions. Its emissions are of 1.65 Gt CO_2eq in 2030, with no increase in ambition between 2030 and 2050. The CPS nearly meets the country's target for 2030 under the "new first NDC" but is above the figure (1.4 Gt CO_2eq) of a revised target when the 2005 base year emissions are updated according to the new 4th national emissions inventory. The Deep Decarbonization Scenario (DDS) reaches 1.0 Gt CO_2eq in 2030, going beyond the NDC target and following a GHG emissions trajectory compatible with the global objective of 1.5ºC, achieving net-zero emissions in 2050.

The sectoral mitigation measures considered in CPS are based on national plans and policies. DDS incorporates more ambitious actions and other available technologies. DDS's main features are a radical reduction in deforestation rates and an increase of carbon sinks. Carbon pricing from 2021 is assumed for a significant share of the emissions (Energy and IPPU), with sectors introducing mitigation actions with costs under the carbon price in each period, starting with the most cost-effective. Carbon prices are introduced through a cap-and trade system in Industry, and a carbon tax on GHG emissions from the combustion of fossil fuels in other sectors. They will grow linearly, reaching 25 USD/tCO_2eq in 2030 and 65 USD/tCO_2eq in 2050. Carbon pricing will be neutral from a fiscal perspective, with 100% of its revenues recycled back into the economy through labour charges reduction aiming to foster employment, and to compensate low-income households for the average price level increase.

Population size increases from 210 million inhabitants in 2019 to about 233 million inhabitants in 2050. In this period, the urban population share grows from 86% to 89%. Following the sharp downturn in the economy from 2015 to 2020 due to a political-economic crisis and the COVID-19 pandemic, Brazilian economy economic recovery is assumed to start on 2021: annual average GDP growth rates would be of 3,5% in 2021; 2,5% from 2021 to 2030; 2,25% from 2031 to 2040; and 2% from 2041 to 2050 (with linear growth assumed within each decade). After the drawback in the 2015-2020 period, Gini index starts to decrease again, but slower than the 2000-2015 record. Household size is projected to decrease slowly while household disposable income as a % of GDP is projected to increase. Trade will become more important to Brazil during the scenario timeframe, and import taxes and protectionism will be reduced, following the global trend.

We use an integrated modelling approach, where a set of six sectoral models is linked to a CGE model (IMACLIM-BR). The sectoral models consist of four energy demand models (transport, industry, buildings, and agriculture energy demand), an agriculture, forestry and other land use (AFOLU) model and an energy supply model (MATRIZ). GHG emission estimates from Waste complete the picture.

PART 1: SCENARIO RESULTS

EMISSION PROFILES

GHG emissions reach 17 Mt CO_2eq in DDS and 1889 in CPS by 2050. Comparing 2050 in both scenarios with 2020 values, DDS is 99% lower, while CPS is 27% higher. **Table 1** presents the figures by sector.

Most GHG emission reductions come from land use change and forestry. Compared to CPS, in 2050 DDS emissions from deforestation are 93% lower, a reduction of 953 Mt CO_2eq. On the top of that, carbon removals increase 76%, equivalent to 451 Mt CO_2eq, thanks to increased forested and protected areas (indigenous lands and conservation units). Transport is the second most relevant sector, with an emission reduction of 126 Mt CO_2eq (53%), followed by the waste sector with a reduction of 120 MtCO_2eq (65%), and livestock activities with 116 Mt CO_2eq (22%). Finally, in industry the reduction is of 84 Mt CO_2eq (31%), and in energy supply added to other energy consumption sectors of 27 Mt CO_2eq (23%). The only activity with a small increase in emissions is cropping, with 4 Mt CO_2eq (4%) more emissions in DDS due to higher biofuels production.

In DDS, only two sectors have higher GHG emissions in 2050 than in the base year 2019: cropping activities increase emissions by 29%; and industry by 14%. In these cases, under the assumption of no major breakthroughs or disruptive technologies, the improvement of technologies currently in use was not sufficient to compensate for the higher production levels.

MITIGATION ACTIONS AND COSTS

In DDS, besides the huge effort to curb down deforestation and increase removals, the carbon pricing policy supplies the complementary mitigation actions in other sectors required to reach net-zero emissions in 2050. **Table 2** presents the cumulative avoided GHG emissions per decade (Mt CO_2eq).

Table 1 – Total GHG Emissions per Sector, 2005-2050, under CPS and DDS (Mt CO_2eq)

MtCO_2eq		2005	2010	2019	2020	2030	2005-2030	2040	2050	CPS-DDS (2050)
Land Use Change (LUC) – gross emissions	CPS	2,171	668	948	1,018	1,024	-53%	1,024	1,024	-93%
	DDS					614	-72%	201	71	
Removals (LUC, Forest, Protected Areas and Other)	CPS	-249	-313	-574	-591	-556	123%	-576	-593	76%
	DDS					-695	179%	-794	-1042	
Agriculture (crops + energy)	CPS	146	161	92	92	97	-34%	101	115	4%
	DDS					99	-32%	106	119	
Livestock	CPS	329	329	433	432	466	42%	485	529	-22%
	DDS					453	38%	444	413	
Transport	CPS	139	173	196	175	209	50%	220	240	-53%
	DDS					167	20%	139	114	
Industry (energy + IPPU)	CPS	139	162	162	166	194	40%	232	268	-31%
	DDS					172	23%	180	184	
Energy (supply + demand from households and services)	CPS	100	111	121	95	127	27%	115	120	-23%
	DDS					120	21%	100	93	
Waste	CPS	61	69	100	102	105	71%	145	186	-65%
	DDS					76	25%	78	65	
Total	CPS	2,837	1,361	1,479	1,488	1,665	-41%	1,745	1,889	-99%
	DDS					1,005	-65%	454	17	

Command and control policies combined with constraining the access of farmers and ranchers to public credits (subject to conformity with environmental laws and regulations) achieve 59% of total cumulative GHG emission reductions up to 2050, through the sharp reduction of annual deforestation rate. The 2004-2012 record has already shown the potential of these measures that can be successfully adopted again. Command-and-control measures also allow to avoid deforestation through the increase of the number and the surface of conservation areas (e.g., permanent preservation areas, indigenous land demarcation, and other legal reserves).

The carbon pricing policy can supply 30% of total cumulative avoided emissions up to 2050 in different sectors: AFOLU (18%), Transport (6.5%), Industry (4%), and Energy supply (1%).

Native vegetation restoration in public and private areas have a significant abatement potential and lower costs than the other sectors. It allows to remove 2,647 Mt CO_2eq up to 2050, when native vegetation restoration will reach 30.18 million ha. Private areas present more attractive costs in comparison with public areas (7 versus 17 USD/t CO_2eq in 2021, 8 versus 28 in 2031, and 9 versus 31 in 2041). Considering the enforcement of Forest Code compliance, private areas provide higher cumulative avoided emissions in 2021-2030 (121 versus 38 Mt CO_2eq) and in 2031-2040 (322 versus 302 Mt CO_2eq) than public areas. However, in the last decade, the bulk of removals will come from public areas thanks to a better cost-effectiveness, and thus its contribution to cumulative avoided GHG emissions throughout the whole 2020-2050 period will be of 1,6311 against 1,015 Mt CO_2eq from private areas.

The abatement cost assessment indicates the pathway of carbon prices. Costs for a given mitigation option may vary throughout the three decades

Table 2. Cumulative avoided emissions (CPS-DDS) per mitigation actions, per decade (Mt CO_2eq)

Cumulative avoided emissions per decade (Mt CO_2eq)			Decades
	2021 – 2030	2031 – 2040	2041 – 2050
Total Mitigation Actions	3,629	10,069	16,103
Carbon Pricing Policy	1,013	2,618	5,254
AFOLU	619	1,483	3,281
Native forest restoration in public areas (through government concession)	38	302	1,291
Native forest restoration in private areas (offsets)	121	322	572
Planted forests (homogeneous and integrated crop-livestock- forest systems)	196	244	275
Agriculture	39	76	38
Livestock (restoration of degraded pastures, intensification, other)	225	538	1,105
Transport (freight and passenger)	233	639	1,064
Modal shift	132	169	271
Electromobility	-	346	520
Biofuels	98	124	273
Industry	126	387	694
Energy intensive industries	86	257	451
Light industry (rest of industry)	40	129	243
Energy Supply	35	110	216
Power generation	8	42	107
Self-consumption and fugitive emissions	28	68	109
Other Mitigation Policies	2,616	7,451	10,849
AFOLU	2,461	6,957	9,887
Reducing annual deforestation rate	2,252	6,367	8,940
Increasing conservation units, indigenous lands and other protected areas	209	590	947
Waste	155	494	963

Source: the authors.

due to increasing economies of scale and variations in cost assumptions (e.g., decreasing costs for electric vehicles and renewable electricity). **Table 3** presents the cumulative avoided emissions per mitigation cost range (US$/t CO_2eq) in each decade.

A significant share of avoided emissions can be obtained at negative costs. Modal shifts in the freight transport sector (e.g., from roads to railways and waterways), a wide range of energy efficiency measures in industry and sustainable agricultural practices (e.g., no-till systems, biological fixation of nitrogen) can be implemented at negative costs up to 2050. In the last decade, this share is reduced to 13%.

A pathway towards net-zero GHG emissions in 2050 can be reached with a carbon price of 25, 45 and 65 USD/t CO_2eq, respectively, in each decade. AFOLU remains the key sector to this end, since it presents the largest mitigation potential with a low cost per avoided GHG emission. Energy efficiency measures in industry, and electromobility in passenger transport also provide relevant contributions. The identified portfolio of mitigation actions presents a significant decline of marginal returns after 35 USD/t CO_2eq. Therefore, a much more cost-effective trajectory of carbon prices (such as 25, 30 and 35 USD/t CO_2eq in each decade, for example) can deliver an ambitious mitigation target in 2050, not ensuring but getting close to climate neutrality, as it would provide 100%, 87% and 94% of the DDS cumulative avoided emissions in each decade. This is mainly due to the underlying assumption of counting upon available technologies only. It illustrates the huge mitigation potential ready to be tapped at low costs in Brazil even before the deployment of new disruptive technologies expected to come on stream up to 2050.

MACROECONOMIC AND SOCIAL IMPLICATIONS

DDS allows to reach carbon neutrality while keeping slightly better economic and social development results than in CPS. Throughout the period up to 2050, GDP and GDP per capita are slightly higher, unemployment rate is slightly lower and the average disposable income for the poorest household income class is slightly higher, compared to CPS. Tables 4 and 5 compare the macroeconomic and social results of the two scenarios.

The carbon pricing scheme leads to higher domestic price levels, contributing to deteriorating terms of trade and affecting trade balance results. The ratio trade balance deficit / GDP is higher in DDS than in CPS, throughout the period up to 2050, although lower than in 2020 (but higher than in 2015).

Table 3–Cumulative avoided GHG emissions (CPS-DDS) per cost range of mitigation actions, per decade

Mitigation action cost ranges (USD / t CO_2eq)	2021 – 2030		2031 – 2040		2041 - 2050	
	Mt CO_2eq	% Mt CO_2eq / period	Mt CO_2eq	% Mt CO_2eq / period	Mt CO_2eq	% Mt CO_2eq / period
up to 0	167	16%	478	18%	661	13%
up to 5	198	20%	582	22%	986	19%
up to 10	659	65%	1,613	62%	2,236	43%
up to 15	659	65%	1,613	62%	3,299	63%
up to 20	963	95%	1,619	62%	3,299	63%
up to 25	1,013	100%	1,619	62%	3,299	63%
up to 30			2,282	87%	3,308	63%
up to 35			2,309	88%	4,916	94%
up to 40			2,319	89%	4,916	94%
up to 45			2,618	100%	4,916	94%
up to 65					5,254	100%

Note: costs in present value of the first year of each decade (at 8% discount rate).

Source: the authors.

A smart recycling of carbon pricing revenues can be socially friendly. Carbon revenues are distributed back to the economy, keeping the government net lending evolution identical in DDS and CPS, under the following rules: i) part of the carbon revenues are transferred back from the government to households to neutralize the effect of the carbon price on purchasing power; ii) the rest of the carbon revenues is used to reduce labor charges. The latter decreases distortions on the economy and is key to creating additional 150 thousand jobs in DDS compared to CPS. These jobs are created mainly in the services, transport, forest, and biofuels sectors. The carbon price penalizes in a higher proportion carbon-intensive sectors, and recycling carbon revenues favors more labor-intensive sectors and poorer household classes.

The higher employment and wage levels in DDS improve income distribution. The positive impact on households' income levels is particularly relevant in HH1 and HH_2 groups (bottom 60%), which depend more on labor income. HH1 (the 20% poorest households, most of which were under the extreme poverty line in the base year) benefit even more from the DDS scenario due to the direct transfers of collected carbon revenues from the government.

DDS allows neutralizing GHG emissions in 2050 while mitigates the adverse effects of carbon taxation on poor households. Disposable income gains in DDS are significant compared to CPS, thanks to higher activity levels, lower labor charges, and increased transfers from the government, which are reflected in more jobs and higher income. DDS is also progressive in terms of income distribution throughout the period up to 2050, as lower income household classes show higher disposable income growth than richer ones, and faster increase than in CPS.

Table 4 - Main macroeconomic results

Scenario	2015	2020	CPS (2030)	CPS (2050)	DDS (2030)	DDS (2050)
Population	203	212	225	233	225	233
GDP (Billion 2015 USD)	1,896	1,852	2,385	3,547	2,391	3,552
GDP variation in relation to CPS	-	-	-	-	0.3%	0.1%
GDP per capita (Thousand 2015 USD)	9.32	8.75	10.60	15.23	10.63	15.25
Trade Balance (% of GDP)	-0.4%	-1.0%	-0.4%	-0.2%	-0.5%	-0.9%
Unemployment rate (%)	9.5%	7.6%	6.9%	7.4%	6.8%	7.2%
Price index in relation to CPS (CPS=1)	-	-	-	-	1.01	1.04
Total net emissions (Gt CO_2eq)	1,518	1,488	1,665	1,889	1,005	17
Per capita emissions (t CO_2eq)	7.48	7.03	7.40	8.11	4.47	0.07
Carbon price (2015 USD/t CO_2eq)	-	-	-	-	25	65
Carbon pricing revenues (Billion 2015 USD)	-	-	-	-	12.9	34.6

Source: the authors.

Table 5 – Disposable income of households by scenario and per household income class, 2015-2050

Scenario	2015	2020	CPS (2030)	CPS (2050)	DDS (2030)	DDS (2050)
Disposable income_HH1 (2015=1) (poorest 20% of households)	1.00	1.05	1.44	2.40	1.45	2.45
Disposable income_HH_2 (2015=1) (40% of households)	1.00	1.04	1.37	2.15	1.38	2.17
Disposable income_HH3 (2015=1) (30% of households)	1.00	1.01	1.29	1.92	1.30	1.93
Disposable income_HH4 (2015=1) (richest 10% of households)	1.00	0.98	1.23	1.80	1.23	1.80
Disposable income_HH1 (in relation to CPS)	-	-	-	-	0.7%	1.8%
Disposable income_HH_2 (in relation to CPS)	-	-	-	-	0.4%	0.9%
Disposable income_HH3 (in relation to CPS)	-	-	-	-	0.3%	0.4%
Disposable income_HH4 (in relation to CPS)	-	-	-	-	0.1%	0.1%

Source: the authors.

SECTORAL DEEP DIVES

Agriculture, Forestry and Land Use (AFOLU)

Agriculture is an essential driver of Brazilian economic growth. Production has grown rapidly over the past decades, driven by rising global demand and technological advances. Changes in crop management practices and expansion in the harvested area have enabled Brazil to become a leading exporter of soybeans, beef, and cellulose.

Both the CPS and the DDS assume a continuation of historical trends in food preferences. Environmental concerns in developed countries lead to less consumption of animal food, giving rise to food rich in micronutrients and vitamins, such as fruits and vegetables. On the other hand, staple food (such as carbohydrates) continues to play an essential role in food preferences in low and middle-income countries. Global meat consumption per capita would increase due to a combination of income and population growth, especially in Asian and Latin American countries. Consumption levels in developed regions are already high. The demand for meat increases as it becomes more accessible in developing countries.

Agriculture, Forestry and Land Use Change (AFOLU) is the primary source of greenhouse gas (GHG) emissions. Therefore, mitigation actions in this sector are critical for Brazil to achieve climate neutrality in 2050.

In the DDS, agriculture production increases significantly, but is GHG emissions are kept in 2050 slightly (1%) under 2019 level. There is an expressive growth in crop production, while the agricultural area increases moderately due to high productivity gains. In 2019-2030, total output rises 23%, and 47% between 2030-2050. The area occupied by crops increases 8% by 2030 and 6% in 2030-2050, reaching 75 Mha in 2050. Beef production grows 75%, reaching 18.3 million CWE in 2050, with a total herd of 200 million heads. Livestock size decreases 6% over time due to productivity gains, and it is raised on 105 Mha of pasture land (a 35% reduction).

Cattle ranching intensification is the action with the most significant mitigation potential. Additional recovery of 60 Mha from degraded pastures associated with increased productivity of the cattle herd reduces emissions from enteric fermentation by 6% in 2019-2050. In this scenario, the stocking rate goes from 1.31 head of cattle/ha to 1.96 by 2050. Adopting low-carbon agriculture technologies (for example, the no-till system and biological nitrogen fixation), recommended by the Low-Carbon Agriculture Plan (ABC Plan), increases along with soybean and other crops.

The reduction of deforestation is key for Brazil to reach climate neutrality. The annual area deforested in 2019 in the Amazon biome doubled compared to 2012 and was 34% larger than in 2018 (INPE, 2020). The area deforested in the country in 2023 is projected to be 15% greater than in 2019. Efforts to curb deforestation will resume in 2023, given the possibility of change in governmental policies and increasing international pressure over agricultural chains associated with deforestation. After 2023, deforestation control policies are resumed, reaching a reduction of 10% in 2023-2025. Zero illegal deforestation in the Amazon biome will be achieved in 2050. twenty years later than the NDC target. Emissions from deforestation will amount to 71 $MtCO_2eq$ in 2050, which corresponds to a 92% reduction compared to 2019. Protected Areas (Conservation Units and Indigenous Lands) will remove 487 $MtCO_2eq$ in 2050 (24% more than in 2019), thanks to the addition of 53 Mha of public non-destinated forests, registered in the Brazilian Forest Service, to the 276 Mha protected today.

Fostering reforestation and restoration of 30 Mha with native species in public and private areas is also relevant. It removes 417 $MtCO_2eq$ by 2050 and it is a measure in line with the NDC (2015), the Bonn Challenge (Bonn Challenge, 2011), and the national Native Vegetation Recovery Plan (Planaveg, 2017). This mitigation action is challenging and goes beyond the area considered in the NDC target (12 Mha by 2030). It can be made possible with government support, international funds, payment for environmental services programs, and forest offsets allowed through the cap-and-trade system imposed on Industry.

Fast-growing planted forests (eucalyptus and pine) are critical carbon removals. They include homogeneous forests and crop-livestock-forest integration systems. The surface of planted forests will reache 13 Mha in 2030 and 19.5 Mha in 2050. This area meets the demand from all sectors: energy (charcoal and firewood), industry (pulp and paper, sawn wood, plywood, panels, and others), and pellets production for exports.

In the DDS, net emissions of the AFOLU sector reach negative values (-439 Mt CO_2eq), allowing the country to achieve carbon neutrality in 2050.

In the CPS, agricultural production grows more than in DDS (25% in 2019-2030 and 50% between 2030 and 2050). This results from a higher demand for biofuels in CPS due to more ICE and less electric vehicles than in DDS. Crop area increases 7% by 2030 and 7% in 2030-2050, reaching 76 Mha. Beef production grows 77%, reaching 18.5 million CWE in 2050, with a 23% larger herd reaching 263 million heads, and raised on 171 Mha of pasture land (5% increase).

Pasture land recovery in CPS is half of the DDS. 30 Mha are recovered up to 2050, increasing the stocking rate to 1.54 head of cattle/ha by 2050. Emissions from enteric fermentation grow 23% between 2019 and 2050. The penetration rate of low-carbon technologies, such as the no-till system and biological nitrogen fixation, is limited to the increase of the planted soy area. Emissions from the agricultural sector increase by 23% in 2050 compared to 2019.

As in the DDS, the annual deforested area increases until 2023 and decreases by 10% between 2023-2025. However, the annual area deforested in 2025 (1.97 Mha) is maintained in 2026-2050. Deforestation of this area emits approximately 1,024 Mt CO_2eq per year. Considering the current government's lack of interest in expanding the areas of environmental protection, as well as allocating human and financial resources for their management, CPS does not foresee the creation or expansion of protected areas in 2020-2050, with the 2019 level remaining constant until 2050 (279 Mha). This area will remove 391 Mt CO_2eq in 2050.

Although more modestly than in DDS, the reforestation and restoration of 3 Mha with native species in public and private areas remove 55 Mt CO_2eq by 2050. It is equivalent to 25% of the area considered in the NDC target for 2030 (12 Mha). The area of forests planted with pine and eucalyptus species grows 53% in 2019-2050, totaling 13.5 Mha.

In the CPS, net emissions from AFOLU total 1,080 Mt CO_2eq in 2050, a 21 % increase compared to 2019. Of this total, 60% comes from agriculture and 40% from land use change and forestry.

The Brazilian agricultural sector can become even more competitive globally if it increases productivity efficiently and sustainably. International pressures on the control of farming chains associated with degradation and deforestation contribute to making DDS viable. Countries that do not commit to reducing GHG emissions and controlling deforestation will face market barriers that will hamper exports. The soybean, beef, and forestry chains are examples of this context that apply to Brazil.

International and national financing programs focusing on climate change, sustainable agriculture, and the environment would help to make the DDS pathway feasible. Among them: Green Climate Fund, Global Environment Facility (GEF), Least Developed Countries Fund (LDCF - GEF), Special Climate Change Fund (SCCF - GEF), Adaptation Fund (AF), and the Amazon Fund.

Transport

The scenarios embody different visions of the future of Brazilian passenger and freight mobility. The CPS represents the continuation of current incentives for biofuels and energy efficiency, but with no increase in ambition after 2030. The DDS expands and diversifies the biofuels market, besides requiring other measures such as accelerating the electrification of the vehicle fleet and expanding the transport infrastructure in key areas.

Globally, the DDS demands a continuous reduction in the relationship between price and energy density of batteries. Fully autonomous vehicles remain a niche market, restricted to developed economies or pilot tests in emerging countries. Hydro Vegetable Oil (HVO) becomes an important energy source in oil refineries, taking advantage of the liquid fossil fuels distribution chain. International funding programs focused on sustainable policies and infrastructure become commonplace among the main financial agents.

In both scenarios, society experiences new mobility configurations linked to population aging, teleactivities, new technologies, and structural changes. Cities are planned to increase integration and decentralize activities to reduce commuting times and congestion. The major metropolitan areas focus on high-efficiency modes and active transport, creating pedestrian-friendly environments. Teleactivities lead to changes in the pattern of passenger and freight transport. In non-metropolitan areas, transport systems maintain the historical pattern of growth and design.

In the DDS, consumers choose more efficient and eco-friendly technologies, stimulating the penetration of electromobility and biofuels. Brazil increasingly invests in charging infrastructure and basic conditions for electric vehicles, such as standards and regulations, financing, and new business models. Unlike the CPS, new local manufacturers of electric trucks and buses, and automobile components change the industry pattern, reducing the impact of the devaluation of the local currency on imports. The electrification of the bus fleet and prioritization measures induce the population to increase public transport use, reducing the need to own a private car. Financial incentives to develop a national advanced bioenergy industry expand the offer and variety of biofuels, for example, biokerosene, bio-oil, and HVO.

No new passenger cars with internal combustion engines (ICE) will be registered from 2045. At the same time, the market penetration of electric vehicles is further accelerated compared to the CPS. In 2050, almost half of the vehicle stock is composed of hybrids (HEV), plug-in hybrids (PHEV), and fully electric vehicles (BEV). Total car stock reaches 76 million, with a much lower motorization rate than in the CPS (326 against 456 cars per 1,000 inhabitants). Private mobility (pkm/cap) accounts for a 41% share in this scenario. Electricity reaches 11% of the total energy consumed in passenger transport, while liquid biofuels account for 52%. As a result, GHG emissions fall by 52%, reaching 49 MtCO_2eq. Carbon (g CO_2/MJ) and energy (MJ/pkm) intensities fall by 41% and 54%.

Freight diesel railways are gradually modernized and electrified via contractual additives in their respective concessions. Regulatory frameworks increase productivity in rail and water transport. Sustainable logistics and certification programs increase efficiency in road transport. The redesign of transport networks focusing on high-capacity modes balances the modal split of Brazilian freight transport reasonably. In 2050, road transport accounts for 42% of the transport activity (tkm), and rail and water account for 35% and 22%.

BEV, HEV, and PHEV constitute 33% of the stock of freight vehicles, concentrated on urban transport. Despite the advances made, electricity is responsible for only 2% of the energy consumed in freight transport. In turn, biofuels account for 37%. These shares stem from the strategic prioritization of electrification of passenger transport, leaving freight transport to absorb the liquid fuel supply surplus. GHG emissions fall by 32%, reaching 62 Mt CO_2eq. Carbon (g CO_2/MJ) and energy (MJ/pkm) intensities fall by 32% and 46%.

In the CPS, the biofuels industry is restricted to biodiesel and ethanol. Electromobility incentives are limited to experiments in metropolitan areas. The end of sales of ICE cars is expected to occur only in 2050 when the total stock of cars reaches 106 million. Private mobility (pkm/cap) accounts for a 50% share, much higher than in the DDS. This participation is due to a lower proportion of public and non-motorized transport, as fewer investments are expected.

Electricity is not representative in this scenario, accounting for only 4% of the total energy consumed in passenger transport by 2050. However, biofuels account for 38% in the same year. GHG emissions from passenger transport increase by 25%, reaching 126 Mt CO_2eq. Even so, carbon (g CO_2/MJ) and energy (MJ/pkm) intensities decrease by 8% and 21%, mainly due to the increased participation of biofuels and energy efficiency programs.

Freight railways continue to have only diesel-electric locomotives. Rail and water transport activities grow at levels below their potential. In 2050, road transport accounts for 48% of the transport activity (tkm). BEV, HEV, and PHEV reach 20% of the stock of freight vehicles. Electricity is less consumed than in DDS, accounting for only 0.2% of the total energy consumed in freight transport by 2050. Liquid biofuels account for 18%. Freight transport emissions increase 18%, reaching 112 Mt CO_2eq. Carbon (g CO_2/MJ) and energy (MJ/pkm) intensities fall by 10% and 23%.

Industry

The Brazilian industry accounted for 26% of the national GDP, in 2019. This participation has decreased over the last 30 years due to successive crises. Industrial growth is assumed to restart in 2021. From 2020 until 2050, the value-added annual average growth rate of the cement, iron and steel, and chemical industries reaches 2.6%, 1.9%, and 1.7%, respectively.

The industry's sector emissions correspond to about 16% (162 Mt CO_2eq) of the country total, with half of them coming from the three above-mentioned sectors. **In CPS, assuming the same performance of current mitigation policies and measures, GHG emissions will reach 290 Mt CO_2eq in 2050**, 75% from energy consumption and 25% from IPPU.

In DDS, implementing well-known mitigation measures in the industry sector reduces 35% of its GHG emissions in 2050. No new industrial processes nor mitigation technologies are assumed. Mitigation actions include: substantial acceleration of energy efficiency improvement, allowing energy intensities to decrease from 21 to 25% in 2050, according to the industrial branch; fuel shift to renewables, including an increased use of charcoal for pig iron production and of wood and residues in cement kilns; and an increased use of ashes and slag to replace clinker in cement blending. The full replacement of HFCs by low GWP gases would be nearly completion (98% reduction of its emissions) by 2050. As a result, DDS emissions will reach 190 MtCO_2eq in 2050, 35% less than in the CPS, with energy-intensive industries accounting for 87% of these emissions.

Energy Supply

Offshore oil and gas production from the pre-salt layer increase steadily in both scenarios. After the sharp oil price reduction due to the COVID-19 crisis (from 66 USD/barrel in 2019 to 23 USD/barrel in 2020), it is assumed that oil price will grow linearly to 45 USD/barrel in 2025 and remain constant at this level until 2050. Under these assumptions, increasing shares of Brazilian oil production are directed towards exports, as production costs are kept low and remain competitive in the world market. In DDS, this share is higher as oil and gas domestic consumption are 30% lower than in CPS, which also allows to keep GHG emissions from refineries and fugitive emissions under control.

Total energy supply emissions in 2050 are 95 Mt CO_2eq in CPS and 68 Mt CO_2eq in DDS. Brazil`s energy supply-related emissions are expected to grow in the immediate future (mainly those from energy self-consumption and fugitive emissions, while emissions from power generation present little growth), peak around 2035, and then decline through 2050. Power generation expansion trend in Brazil is already based on renewable sources, and thus presents low GHG emissions than most other countries. In both scenarios, GHG emissions from power generation decrease further, from 24 Mt CO_2eq in 2019 to 16 Mt CO_2eq in CPS and only 1.7 Mt CO_2eq in DDS, in 2050.

Electricity consumption grows faster than overall energy consumption, but end-use efficiency gains allow for a lower growth in DDS. In CPS, electricity consumption grows by almost 78% from 2019 to 2050, reaching 972 TWh (terawatt-hours), but in DDS, its growth is limited to 928 TWh (70% increase), despite an increase of 25 TWh of its use in transport, thanks to a consumption reduction of 63 TWh in the industrial sector, compared to CPS.

In DDS, the Brazilian power generation reaches nearly net zero emissions by 2050. In both scenarios, hydro, wind energy and photovoltaics are the main sources to expand their power generation. After 2040 when the Brazilian hydropower potential will be almost fully explored, biomass will replace its role and complement wind and solar contributions. In 2050, the required installed capacity of hydropower is 146 GW on both scenarios. Onshore wind capacity reaches 50 GW in CPS and 46 GW in DDS, while photovoltaic systems account for 51 GW in CPS and 53 GW in DDS. Biomass reaches 31 GW in CPS and 28 GW in DDS. Natural gas is restricted to CPS with 11 GW and offshore wind to the DDS with 3 GW. Moreover, old thermopower plants are decommissioned and replaced by renewable power plants (wind, solar photovoltaic, and biomass) due to their lower costs in both scenarios. However, in CPS, natural gas still plays an important role in dispatchable power generation. On the other hand, in DDS, the development of large intermittent renewable capacities is made possible by increasingly using hydropower generation and batteries to ensure grid operation flexibility.

Global carbon pricing and fast technological development in renewable energy technologies (mainly batteries, solar and wind), are the key international enablers of DDS. A domestic carbon tax can reduce the competitiveness of power generation from natural gas, while technology improvements and growing international experience of developers can enable the competitiveness of renewables.

Waste

Both scenarios consider that national solid waste policy (PNRS) and national sanitation plan (PNSB) goals are met regarding the extension of service coverage.

Regarding solid waste, the percentage of collected waste increases from 90% today to 100% in 2030. Adequate final disposal goes from 40% to 95% in 2050. In DDS, landfilling is limited to around 70%, with biogas capture and methane destruction rate reaching 65%. As in developed countries, thermal and biological plants would be introduced, reaching 8% and 10% of total waste disposal, respectively. Recycling rate goes up to 10%. In CPS, only landfilling is the technical option considered, with biogas capture and methane destruction remaining at a constant rate of 15% throughout the period. The recycling rate remains at 3%.

Sewage collection rates go from 53% today to 84% in 2050, with anaerobic treatment plants treating 21% of the collected volume. Of the methane generated in these plants, in DDS the destruction rate goes from 40% to 80% in 2050, while in CPS it reaches only 55%.

GHG emissions in DDS are cut by 36% in 2050, while in CPS they grow by 82%. The substantial extension of sanitation services to bridge the current infrastructure deficit can lead to a huge increase of emissions unless biogas capture and burning technologies are massively introduced. The amount of cumulative avoided GHG emissions in this sector is high. These technologies will be cost-effective thanks to global pricing schemes leading to international trade of mitigation outcomes and the financial flows required to meet the funding requirements of these investments.

PART 2: KEY POLICY LESSONS

SYNERGIES AND TRADE-OFFS WITH COUNTRY NON-CLIMATE OBJECTIVES

Living standards in Brazil will improve slowly, and the distance to developed countries will be reduced by 2050, following the global trend. Under DDS, a **smart recycling of carbon pricing revenues delivers reductions of both GHG emissions and social inequalities.** Compensating poor households for increased price levels through green checks and fostering employment through reduction of labor taxes are the key enablers to maximize the synergy between climate and fiscal policies. Several complex iterations exist with SDGs, but overall synergies with DDS are summarized in **Table 6**.

Next synergies and trade-offs with non-climate objectives are discussed in detail at sector-level.

Table 6. Synergies with SDGs

Very high synergy with SDGs	
#13	Climate action (radical mitigation),
#7	Affordable and clean energy (power generation reaches nearly net zero emissions),
#11	Sustainable cities (cleaner cities due to higher use of biofuels, electric vehicles, and increased use of mass public transport systems),
#15	Life on land (radical reduction of deforestation and increase of protected forests).
High synergy with SDGs	
#9	Industry, innovation and infrastructure (more innovation and competitiveness in industry and higher investment in low-carbon infrastructure),
#17	Partnerships for the goals (higher levels of international cooperation),
#6	Clean water and sanitation (faster growth of public sanitation infrastructure thanks to higher investment targeted at GHG emissions reduction).
Moderate synergy with SDGs	
#1	No poverty,
#2	No hunger,
#3	Good health,
#4	Quality education,
#8	Decent work and economic growth,
#10	Reduced inequalities,
#12	Responsible consumption and production (slightly higher GDP/capita and disposable income to poorer households; lower unemployment rate and new jobs in the services, transport, forest, and biofuels sectors).
Neutral for SDGs	
#5	Gender equality,
#14	Life below water,
#16	Peace, justice and strong institutions.

AFOLU

Global food security and maintenance of high biodiversity can be complementary and synergistic goals by using sustainable agricultural practices that protect, restore, and promote rational use of ecosystems and at the same time reduce GHG emissions.

Increased use of sustainable agricultural practices such as mixed, rotational, and succession crops, with zero tillage and crop-livestock-forestry integration, deliver co-benefits such as optimization and intensification of soil nutrient cycling, greater soil water retention, conservation of biodiversity, and increased agricultural productivity.

Protecting, restoring, and promoting the sustainable use of forests, including forest diversification and management, prevents desertification, halts / reverses land degradation, and reduces biodiversity losses. In addition, the forest carbon stock also contributes to reducing emissions through the use of forest-based products to replace non-renewable resources.

Transport

Electric mobility provides considerable co-benefits for the urban population's health, energy security, and social security spending, besides reducing GHG emissions. There is a direct relationship between the health budget and air pollution in cities, mainly caused by vehicles equipped with internal combustion engines. The more urban planners perceive a reduction in hospital admissions for respiratory problems, the more they encourage the use of electric vehicles in metropolitan areas, especially buses and light trucks. The dissemination of electric mobility goes together with expanding the supply of electricity and telecommunications to remote areas. It allows the installation of larger commercial and industrial buildings such as hospitals and schools, which demand higher voltages. Finally, electric mobility in road and rail transport reduces dependence on diesel oil, which is currently a major problem in Brazil, especially in freight transport. In addition to being a more expensive and polluting source of energy, the high volatility of crude oil and diesel prices has caused social instability, including strikes and protests, as well as inflation.

Industry

Decarbonization through higher energy efficiency fosters industrial productivity and employment generation for skilled human resources in the industry and across its entire supply chain. The adoption of low-carbon industrial processes and other innovations increases competitiveness and resilience. Additionally, since these measures require investments in retrofit or construction of new facilities, they create direct and indirect jobs in the supply chain and induce new jobs due to workers' spending on goods and services. Furthermore, improving energy efficiency and increasing alternative fuels reduce external dependence and the risks associated with fluctuations in currency and energy commodity prices, as the steel and cement industries import a significant share of their fuels.

Energy Supply

Expanding affordable and renewable energy production (with power generation reaching nearly net zero emissions by 2050) fosters employment generation, reduces air and water pollution, and improves overall societal well-being and resilience. Decentralized wind and solar energy deployment allows for regional development, and it is an excellent opportunity for stimulating economic growth in distant communities. Bioenergy deployment in various forms, and for different purposes, has many synergies with industrial development and environmental protection in rural areas.

Waste

Cheap GHG emissions reduction available through capture and flaring of biogas encourage investment in sanitation and help to accelerate the building up of the infrastructure required to bridge the historical gap in the level of service coverage. Low-income households are the main beneficiaries of this service expansion that brings considerable social benefits. Power generation through controlled incineration of waste in big cities, the use of refuse-derived fuel (RDF), and biogas as a fuel in the industry increase energy supply.

PRIORITY SHORT-TERM POLICIES AND ACTIONS

The main priorities for the short-term derived from the scenario analysis are:

- Resuming policies successfully adopted in the recent past (2004-2012) to sharply reduce annual deforestation rates: both command-and-control and economic instruments.
- Developing smart financial mechanisms to foster the funding of investments in mitigation actions, and mainly in forest cover restoration and low-carbon infrastructure.
- Carbon Pricing: provide a long-term, stable signal to induce economic agents to choose low-carbon technologies through a well-structured cap-and-trade scheme for industry and a carbon tax on other sectors.
- Relying on the AFOLU sector to reduce and capture the largest share of emissions in the first half of the century to get close to the net-zero target by 2050 helps to reduce overall costs for Brazil and provides sufficient time for disruptive technologies to be economically viable.

For AFOLU, policies and actions focused on reducing deforestation and increasing carbon sinks are key in Brazil. The current government has discontinued several successful environmental policies, and therefore annual deforestation rates have increased in recent years. The resumption of command and control strategies - monitoring, inspection, collection of fines, and application of embargoes - that are already known and effective in reducing deforestation is considered a short-term priority. Other effective policies and actions are: promoting articulation and integration between the various government agencies; environmental and land tenure regularization; forest concession on public lands not assigned for any specific use; expansion of areas conservation units category, and demarcation of indigenous lands.

In the agricultural sector, effective policies and actions are associated with the conditioning of

soft public loans to farmers and ranchers upon compliance with the forest code and environmental regulations (Environmental Rural Registry - CAR); monitoring the origin of agricultural products (traceability) and restriction of the market for products associated with deforestation; and enabling financial mechanisms to foster low-carbon agriculture practices, including technical assistance and rural extension.

In transport, the fastest GHG emission reductions in the short-term can be achieved by an acceleration of the RenovaBio program with higher targets for biofuel sales and regularly updating energy efficiency targets for internal combustion engines. This includes greater public encouragement of second-generation biofuels, particularly HVO, increasingly added to biodiesel-diesel blends. The introduction of carbon taxes on gasoline and diesel oil is also necessary. Furthermore, a complementary set of policy instruments regarding the prioritization of public transport needs to be deployed. This means increasing subsidies and tax exemptions to mass public transport systems to improve the sector's capacity to deal with post-pandemic economic uncertainty and instability. The design and implementation of new business models associated with the penetration of electric buses can help the recovery and improvement of the urban buses transport service (highly damaged by the pandemics). Besides, the development and approval of missing standards and regulations, combined with education and awareness campaigns, are required to allow for the growth of the electric vehicle market (mainly in metropolitan areas).

Financial support for investment in low-carbon technologies through credit mechanisms and fiscal exemptions are short-term priorities for industry. The transition to a less carbon intensive industry is to be supported by significant investments and a change in the current financial structure that does not favour low-carbon technologies. Providing access to financial products and fiscal exemptions for those types of investment are required to make them more profitable. **In addition, a cap-and-trade system for GHG emissions reduction in industry, allowing for offsets from AFOLU up to a limit, is key to help decarbonize the sector.** Carbon pricing improves the competitiveness and benefits of those companies that take the lead.

Regarding the energy supply, is pivotal to keep the national energy policy oriented to tapping the potential for renewable energy deployment. A carbon pricing scheme will encourage biofuels use and production and avoid additional fossil fuel-fired thermopower generation capacity. Natural gas is a transitional fuel for a sustainable energy system transformation, while incentives are to be applied to accelerate the decommissioning of coal-fired power generation. The gradual elimination of fossil fuel subsidies, which do not help the poor and hamper renewable energy and energy efficiency efforts, is also a key measure. Reform of fossil fuel subsidies should be accompanied by targeted and time-limited transitional support for vulnerable industries, communities, regions, and consumers. Incentives for distributed solar PV generation have to be kept for a while (subsidies and tax exemptions to be fully withdrawn only in 2045).

In the waste sector, is key to design and implement incentives and adequate regulations to promote the capture and flaring of biogas and its use as a fuel. It is also fundamental to promote municipalities' capacity building and encourage partnerships to develop a portfolio of investment opportunities. Increased recycling rates can be achieved through stricter regulation and correct market signals to encourage the reinsertion of scrap materials and post-consumer wastes into the economic cycle.

INVESTMENTS PATTERNS

The highlights of the study with regards to investment can be summarized as follows:

- A significant share of avoided emissions can be obtained at negative or very low costs. Costs for a given mitigation option may vary throughout the three decades due to increasing economies of scale and variations in cost assumptions (e.g., decreasing costs for electric vehicles and renewable electricity).
- Additional investment in mitigation would sum about USD 83 billion in a pathway leading to net-zero GHG emissions in 2050.
- This would represent a 0.5% increase in the investment rate (Total Investments/GDP) in DDS over CPS.
- Most of the investments would be needed in industry, agriculture and forestry, and transportation sectors.

For AFOLU: Adequate investment patterns can be made possible by sales of forest offsets through a cap-and-trade system applied to industry, and by expanding credit for a number of sustainable forest uses and agriculture practices.

Mechanisms introducing payments for environmental services can attract private investments to restore native forests and compensate forest producers for maintaining forest stocks. Law 14,119/2021 makes provision for these payments and considers modalities such as compensation for reduced emissions from deforestation and degradation (REED +), green bonds, and Quotas for Environmental Reserve (CRA). In addition, changes proposed in the Forest Concessions Law (Law 11,284 / 2006) can streamline contracts and make the concession process viable.

In the agricultural sector, the leading financial players are banks, cooperatives, capital equity, industry, suppliers, traders, and distributors. Green bonds have the potential to support agriculture towards sustainable production. Law 13,986 / 2020 that creates a solidarity guarantee fund helps the country's agricultural sector to access international markets. One of the significant innovations facilitating access to capital markets is the possibility of directly issuing Agribusiness Credit Receivables Certificates (CRAs) in the offshore market.

For Transport: Strengthened national industry to support electric mobility and smart grids, reducing the negative effects of exchange rate volatility and inflation. Government can provide financial incentives and basic infrastructure to attract electric vehicle industries and suppliers. Also, credit lines can be supplied to finance intensively used electric vehicles (mainly buses and light trucks) at lower rates compared to conventional internal combustion vehicles. Access to financial instruments for green investments such as green bonds and structured green funds can also be increased. Modern standards and regulations can enhance legal security and guarantees for public/private partnerships to invest in railways and waterways. Also related to these transport modes, public and private partnerships can be fostered to improve intermodality, increasing the number of terminals, expanding road access to ports, and interconnecting regional railways and waterways.

For Industry: Specific credit lines for decarbonization - energy efficiency, fuel shifts, and new processes - of heavy industry (mainly cement and steel) are to be supplied. Creating specific and diversified credit lines through federal bank regulation is vital to promote massive investment in less carbon-intensive technologies and processes. Uniform guidelines for credit analysis and appropriate rates for the specificities of the industrial sector can be highlighted as important features for new credit lines. Access to green bonds can also help spur investments in low-carbon technologies.

Energy Supply: Higher investments required in hydro, wind, and solar power, as well as in bioenergy, benefit from smart financial mechanisms allowing to de-risk low-carbon projects and to attract larger financial flows at lower capital costs. Expanding or reinforcing the transmission system (national grid) is a pre-requisite to accommodate a considerable growth of renewable power generation, mostly located in remote sites. Similarly, it is necessary to expand the Brazilian gas pipeline network, which might be used in the long run for the transport of "green hydrogen". In addition, financial support is needed in the form of grants, loans, and tax cuts aimed at green transport, circular economy, energy efficiency improvements, and clean energy research, development, and deployment.

For Waste: An appropriate regulatory framework is required to enable funding mechanisms of investments for biogas capture and flaring in new and existing landfills and sewage treatment plants. This would also simultaneously foster waste recycling and re-use.

At economy-wide level, additional mitigation investments in DDS (compared with CPS) amount to USD 24.12 billion in 2021-2030, USD 90.62 billion in 2031-2040, and USD 148.75 billion in 2041-2050, in Transport (41.7%), Waste (25.7%), AFOLU (21.0%), Industry (9.4%) and Energy Supply (2.2%) sectors (considering the whole 2021-2050 period). **Table 7**–Additional mitigation investment in DDS compared to CPS, per economic sector, per decade details the additional investment (CAPEX) in DDS compared to CPS.

Figure 1 presents the marginal abatement cost curve (MACC) for the first period (2021-2030). **Figure 2** and **Figure 3** present the MACC for the following decades (2031-2040 and 2041-2050, respectively). Over the whole period, DDS includes the adoption of 32 mitigation actions. However, to better illustrate the relationship between mitigation costs and abatement potential, we highlighted separately in the three figures below the main mitigation actions (including only those avoiding at least 5 $MtCO_2eq$) contributing to the total abatement in each decade.

KEY INTERNATIONAL ENABLERS AND ACCELERATORS OF DOMESTIC TRANSITIONS

The key international conditions that make DDS plausible in Brazil are:

- Strong international effort to meet the Paris Agreement, with most countries adopting carbon pricing.
- Substantial support of Annex I countries to foster financial flows targeted at mitigation actions in non-Annex I countries, including both the climate finance tools within UNFCCC (GCF, SDM) and international financial initiatives to channel private capital to low-carbon investments.
- International oil price allowing the domestic offshore pre-salt oil production to be competitive
- Preferential commercial mechanisms to require traceability and proof of origin of agricultural and forestry product exports can contribute to the control of deforestation in Brazil.

AFOLU: Border taxes adjustments according to carbon footprints and market incentives for agricultural and forestry products with traceability and proof of origin can help control deforestation in Brazil. A growing international demand for wood pellets can help Brazil to massively plant forests for export. Global per capita meat consumption will increase, and Brazil will continue to be a major global player in beef supply. Demand will keep increasing as meat becomes more affordable in developing and least developed countries. Global economic growth, especially in Asian and Latin American countries with large middle classes, will support the growth in demand for meat, even with a decline in demand from developed countries.

Transport: Global awareness and local interests (policymakers and potential investors) will converge, making electric mobility the main technological change in the transport sector (to the detriment, for example, of hydrogen fuel cell vehicles, non-plugin hybrid vehicles, and internal combustion engine vehicles). The end of large-scale production of internal combustion engine passenger vehicles will take place first in the main manufacturing countries. At the same time, the relationship between price and energy density of batteries will continue to decline, reaching purchase price parity in Brazil between 2035 and 2040. The slow pace compared to major global players is due to the absence of local electric vehicle manufacturers and suppliers and an unstable local currency. The main routes connecting regional and national metropolitan areas between countries will provide charging stations for trucks, buses, and cars. Problems related to interoperability between stations managed by different operators, as well as the second life of electric vehicle batteries, will not be representative. Drop-in biofuels will be a key element when considering non-electric solutions across countries, mainly applied to long-distance freight transport.

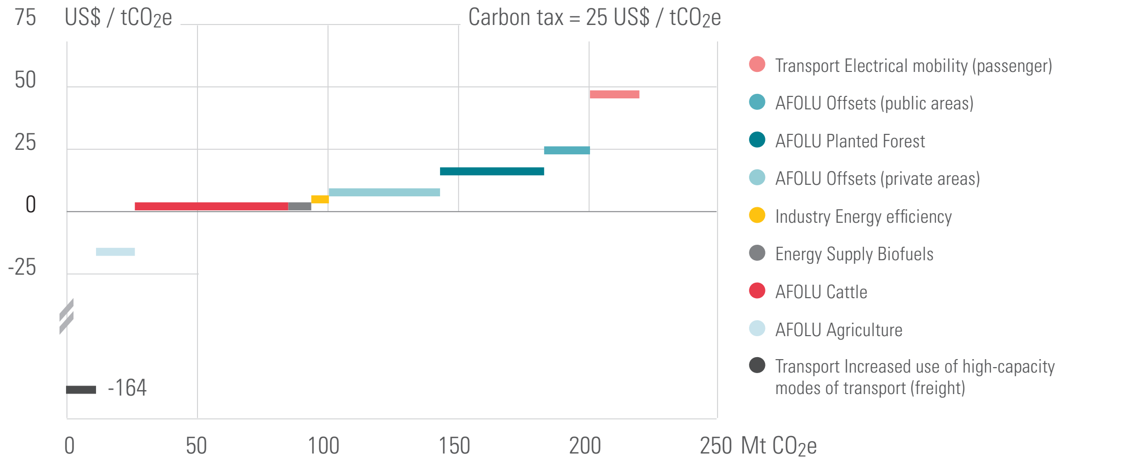
Industry: Global carbon pricing and deployment of low-carbon technologies help the national indus-

Table 7–Additional mitigation investment in DDS compared to CPS, per economic sector, per decade

Sectoral investment (USD billion)	2021-2030	2031-2040	2041-2050
AFOLU	4.26	14.59	36.38
Transport	17.02	38.32	54.55
Industry	2.39	7.88	14.63
Energy Supply	0.45	1.74	3.49
Waste	-	28.09	39.70
TOTAL	24.12	90.62	148.75

Notes: 1. Additional investment in energy supply considers power and biofuels. 2. Exchange rate 3.15 R$/USD (values of 2015). 3. Values not discounted.

Figure 1. Marginal Abatement Cost Curve 2021-2030 (mitigation actions avoiding at least 5 $MtCO_2eq$)



** Increased use of high-capacity modes of transport - in this measure, the following actions are taken: (i) expansion of the railway network, restricted to projects under implementation; (ii) investments in waterway and land access, such as port areas, as well as expansion of port capacity; (iii) increasing energy efficiency and expanding the capacity of profitable railroads; (iv) recovery of underused railways in strategic locations; (v) logistical optimization; and (vi) increased activity by reducing bureaucracy in cabotage and rail transport.*

Figure 2. Marginal Abatement Cost Curve 2031-2040 (mitigation actions avoiding at least 5 $MtCO_2eq$)

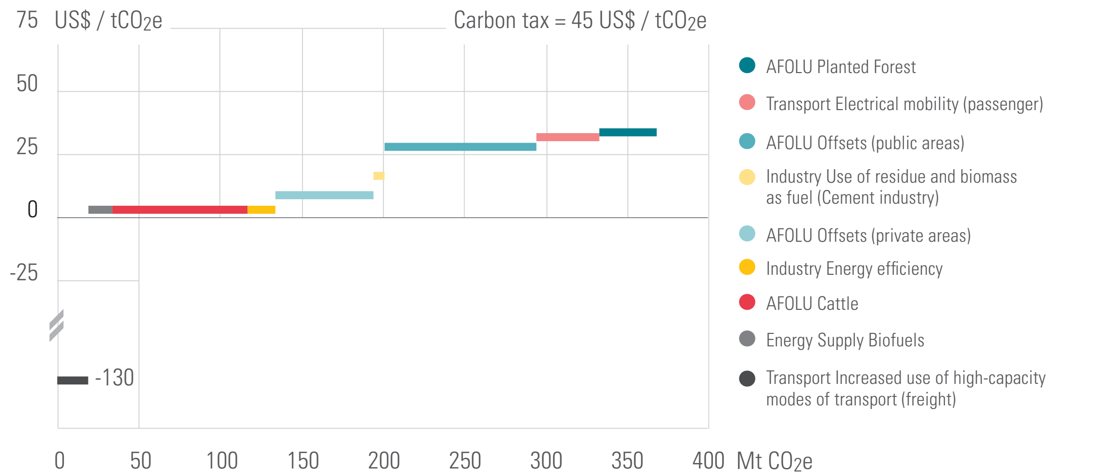
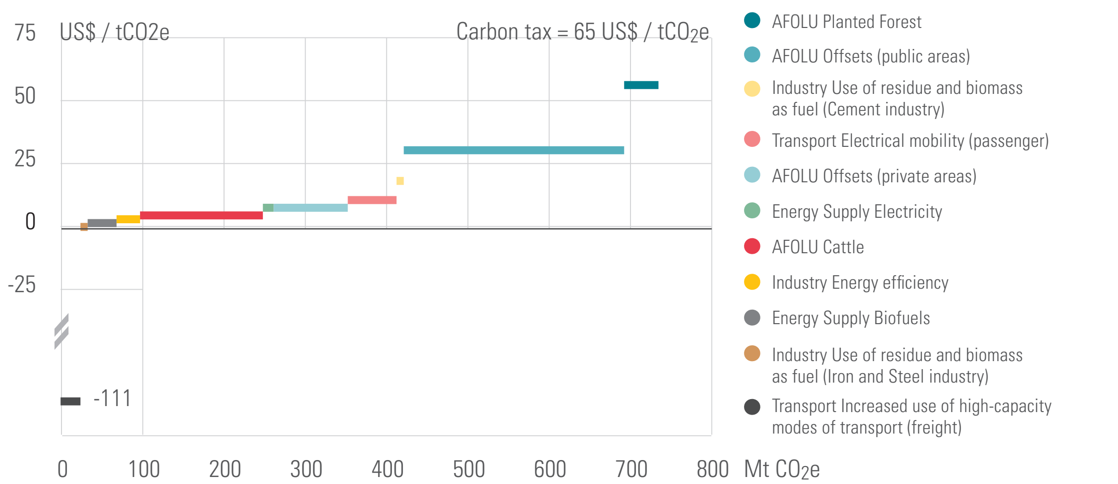


Figure 3. Marginal Abatement Cost Curve 2041-2050 (mitigation actions avoiding at least 5 $MtCO_2eq$)



try embark on a decarbonization pathway. Global carbon prices will make less carbon-intensive products more competitive, rewarding early runners investing in low-carbon technologies. New cost-effective industrial processes will reduce the carbon footprint of cement and steel. Investment costs are one of the major obstacles for the sector. Technologies like Direct Reduction Iron using hydrogen are expensive for the Brazilian industry. The consolidation of new technologies and decreasing its costs will be fundamental to help the decarbonization of the industry sector.

Energy Supply: More effective technology research, development and transfer, and international long-term investment funding are key enablers for decarbonization in the sector. Availability of natural gas cost-effective technologies to replace coal and oil products in the industry (e.g., direct reduction of iron ore for steel manufacturing), as well as for power generation at low load factor (for complementing intermittent power sources, like wind and solar generation) will help avoiding carbon lock-in (if natural gas was chanelled to baseload power generation). International oil prices will allow domestic offshore pre-salt oil production to be competitive. This will supply the opportunity of scaling up the use of oil rent for the improvement of education and health in the country. Recycling carbon pricing revenues to lower taxes on labor and reduce capital costs will encourage job creation and investment in low-carbon infrastructure, improving overall economic productivity.

Waste: International financial flows, both through Article 6 of the Paris agreement and voluntary carbon markets, can significantly increase investments in biogas capture and flaring. Promoting the use of biogas as an energy source, (e.g. as biomethane) and technology transfer of other environmentally friendly solutions can help mitigation in this sector.

SUMMARY OF KEY FINDINGS

- DDS is just one among many pathways for Brazil to reach climate neutrality by 2050.
- Underlying assumption: use of available technologies only; huge mitigation potential at low costs in Brazil even before the deployment of technological "breakthroughs".
- Sharp reduction of annual deforestation rate and native vegetation restoration in public and private areas have a significant abatement potential and lower costs than mitigation actions in other sectors.
- A pathway towards net-zero GHG emissions in 2050 can be reached with a carbon price of 25, 45 and 65 USD/t CO_2eq, respectively, in each decade.
- DDS allows to reach carbon neutrality while keeping slightly better economic and social development results than in CPS (smart recycling of carbon pricing revenues).

ANNEX

Visualization of country results

Figure 4. GHG Emissions under Current Policies & Deep Decarbonization Scenarios (Mt CO_2eq)

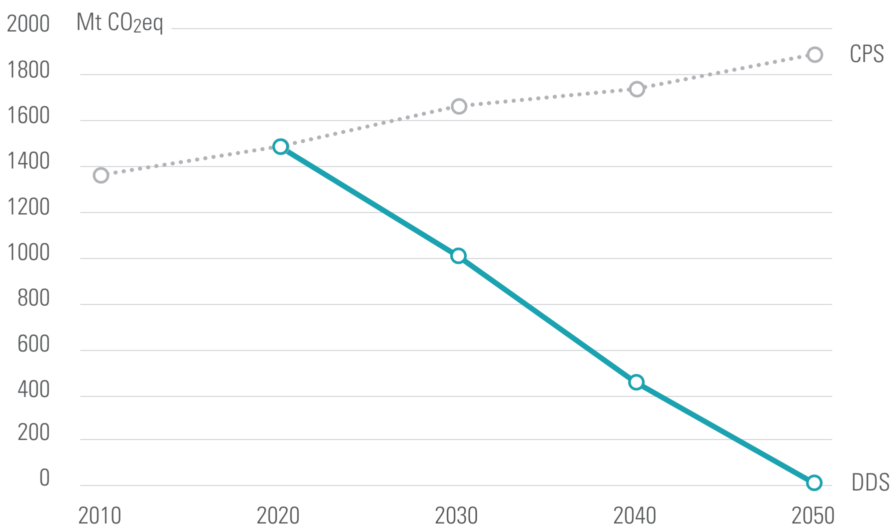


Figure 5. GHG Emissions, CO_2 and non-CO2 (Mt CO_2eq)

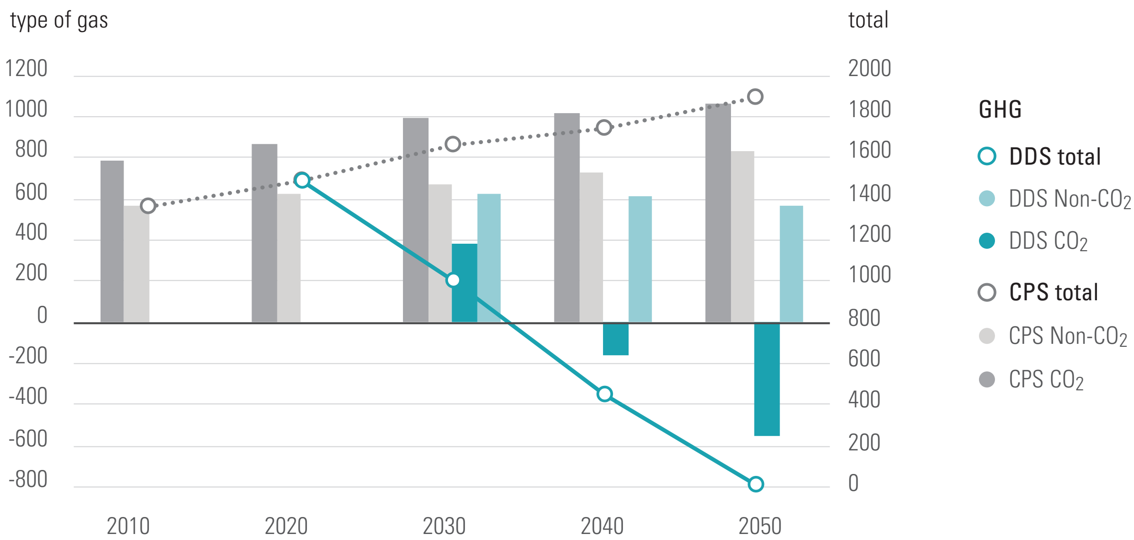


Figure 6. GHG Emissions x Population x GDP (2010 =1)

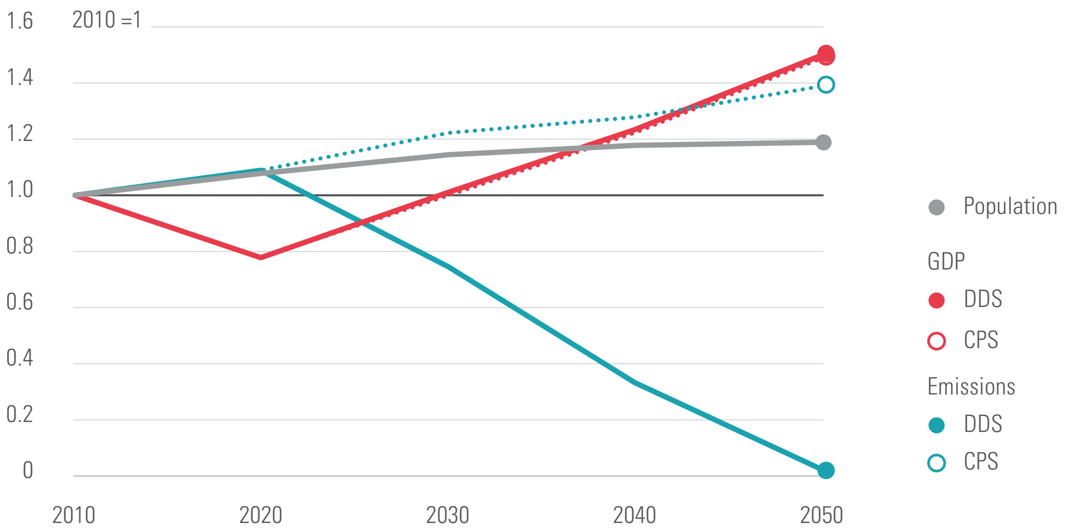
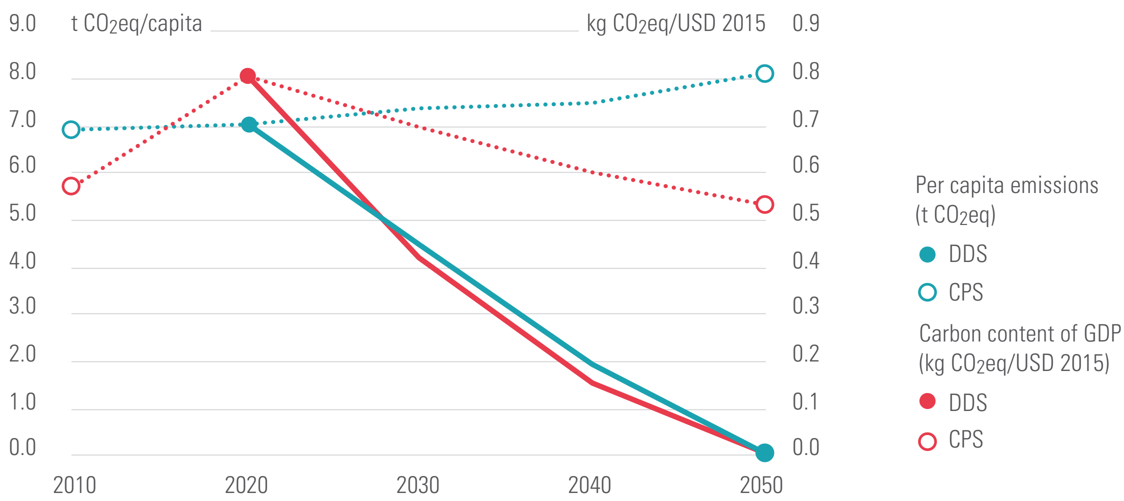


Figure 7. Emissions Intensity per capita and per GDP



INDIA

Disclaimer

The results presented in this factsheet are outputs of the academic research conducted under the DDP BIICS project as per the contractual agreement. The academic work does not in any way represent our considered opinion for climate negotiations and also does not reflect the official policy or position of the Government of India.

Garg A.[1]
Sudharmma Vishwanathan S.[2]
Chaturvedi R.[3]
Gupta D.[4]
Avashia V.[1]
Patange O.[1]

1 Indian Institute of Management Ahmedabad
2 National Institute for Environmental Studies
3 Birla Institute of Technology and Science, Goa
4 Indian Institute of Management Lucknow

India, with the second largest population in the world, is the only large nation amongst the G20 countries on track to achieve its commitment to achieve the Paris goal of 2C (CAT, 2020) and in top 10 countries in the world in Climate Change Performance Index (CCPI) 2021, second year in a row.

India's Nationally Determined Contribution (NDC) submitted to the UNFCCC in 2016 has been formulated keeping in mind the developmental imperatives of the country (NDC 2015). It consists of eight different goals including three mitigation-centric quantifiable targets, namely:

1. To reduce the emissions intensity of its GDP by 33% to 35% by 2030 from 2005 level (**NDC- 3**);
2. To achieve about 40% cumulative electric power installed capacity from non-fossil fuel based energy resources by 2030 with the help of transfer of technology and low cost international finance including from Green Climate Fund (GCF). (**NDC- 4**); and
3. To create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through additional forest and tree cover by 2030. (**NDC- 5**).

The other components of India's NDC pertain to the adoption of sustainable lifestyles based on traditional values of conservation and moderation, adaptation to climate change, clean economic development and environment- friendly technologies.

Development patterns supported by energy and sectoral policies seeking for accessibility, reliability and affordability have been the key drivers to India's historical emissions. Additionally, available resources (energy, water, land, critical minerals, labour) in the country and access to essential resources at global level in terms of quantity and prices also may enhance and/or aid to reduce emissions. In the past couple of decades, some of these policies have been endorsed by international commitments such as millennium development goals (MDGs) (2000-2015) and Sustainable Development Goals (SDGs) (2015-2030) in order to improve the nation's state of development and economy (SDG 2020).

In this study, we have attempted to **develop multiple pathways: a current policy scenario (CPS), which extrapolates trends of ongoing and planned policies until 2050,** and **two deep decarbonization scenarios (DDS), which propose alternative visions of transformations consistent with the Paris Agreement to inform short-term policies and the revision of the Indian NDC**. This report provides a summary of the scenario results and policy lessons emerging from the analysis.

PART 1: SCENARIO RESULTS

EMISSION PROFILES

Development has been and will remain a priority for India. The **current policy scenario (CPS) considers ongoing developmental policies** along with mitigation and adaptation strategies mentioned in the National Action Plan on Climate Change (NAPCC 2008) and Nationally Determined Contribution (INDC 2015). The CPS scenario extrapolates the ongoing policies till 2050. The deep decarbonization scenarios simulate ratcheting the ongoing policies with **DDS1 emphasizing on synchronizing development with deeper climate actions**, and **DDS2 ratcheting climate actions to move towards net zero emissions**. Both DDS1 and DDS2 scenarios focus on achieving development, however DDS2 prioritizes acceleration of climate actions thereby increasing mitigation costs in the near term. The implementation of policies and actions are at slower pace in DDS1 when compared to DDS2 in the short term.

The Indian CPS and DDS scenarios were observed to reduce the emission intensity of GDP by 41%-47% by 2030 when compared to 2005 levels. The emissions will reach 4.6 $GtCO_2$, 4.43 $GtCO_2$, and 4.24 $GtCO_2$ under CPS, DDS1 and DDS2 scenarios in 2030. The emissions will further reduce to 4.41 $GtCO_2$, 4.16 $GtCO_2$, and 3.9 $GtCO_2$ due to the addition of AFOLU as carbon sink under CPS, DDS1 and DDS2 scenarios (**Figure 1**). These pathways reiterate and solidify India's commitment above and beyond to achieve the Paris Agreement goals.

India is projected to require a carbon budget of around 136-142 $GtCO_2$ under CPS scenario (including LULUCF) for the 2020-2050 period. Under DDS scenarios, the estimate ranges between 86 and 114 $GtCO_2$ (including LULUCF), a reduction by 36.7% and 23.5% respectively when compared to CPS scenarios. The cumulative fossil and land-use-change CO_2emissions from 1850 through 2019 is ~ 1,800 $GtCO_2$ for fossil emissions and ~775 $GtCO_2$ for land-use change, for a total of ~2,390 ± 240 $GtCO_2$ (AR6 WGI SPM, page 38). India's historical cumulative emissions of the global cumulative emissions is less than just 5% from 1850 to 2019. Based on remaining carbon budget from 2020 for 2°C global warming limit (~ 900-2,300 $GtCO_2$) (AR6 WGI SPM), India's future carbon budget share ranges between 5.9%-15% in CPS scenario and 3.7%-11.6% in DDS scenarios. **Table 1** presents the implications of policies implemented on NDC and Paris Agreement across CPS and DDS scenarios.

Figure 1. CO_2e emissions including LULUCF

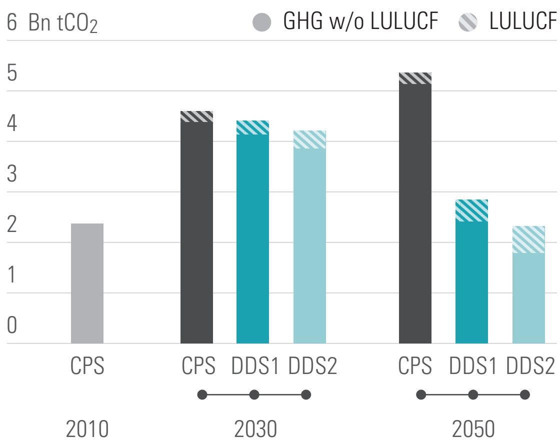


Table 1. NDC Indicator Goals across CPS and DDS scenarios

Indicator	CPS	DDS1	DDS2
NDC Goal 3 (Reducing GHG/GDP by 33-35% of 2005 level by 2030)	41%	44%	47%
NDC Goal 4 (Increasing non-fossil based generation capacity to 40% by 2030)	55%	59%	63%
NDC Goal 5 (Addition of carbon sink by 2.5 to 3 Bt by 2030)	2 Bt CO_2	3.17 Bt CO_2	3.89 Bt CO_2
Impact on Paris Agreement (Cumulative CO_2 emissions including agriculture non-CO_2) during 2020 and 2050) (*Including LULUCF*)	142 Bt CO_2e *136 Bt CO_2e*	114 Bt CO_2e *104 Bt CO_2e*	98 Bt CO_2e *86 Bt CO_2e*

SOCIO-ECONOMIC IMPLICATIONS

India has the second largest human population in the world with more than 1.35 billion people with 64% of the population in the 15-59 age group (WB 2018). A significant section of its large population depends on climate-sensitive sectors such as agriculture, fisheries and forestry for livelihood. India's population is expected to peak at 1.7 billion in 2060 (UN 2015). India is also one of the largest emerging economies in the world with average GDP growth rate from 1980–2014 observed to be about 6.2%; however, per capita GDP in India is still lower than global average. According to World Bank data, India's per capita GDP (nominal) in 2017 was $1,939 (only 3% of that of the United States and 22% of China's per capita GDP) (WB 2018). Still, it ranks sixth globally in terms of its GDP. **It is rapidly moving towards becoming a middle income economy with population projected to overtake China by 2025, and urbanization exceeding 50% by 2050** (UN 2019).

Transformational and resilient structural changes are required to reduce energy intensities and carbon intensities. The average growth rate of CO_2 emissions between 2005 and 2015 of 7.2% per year is the result of the following annual growth rates: population 1.8%, GDP/capita 4.9%, energy-intensity of GDP is -3.2% and carbon-intensity of energy 3.7%. GDP/capita, carbon intensity and population growth were the main drivers of the increase in Indian carbon emissions during 2005 and 2015 (**Figure 3**).

For CPS scenario, declining carbon and energy intensities are unable to offset income effects and population growth and, hence, carbon emissions are projected to rise. For DDS scenarios, the reduction in carbon intensity of energy supply of DDS1 is higher between 2030 and 2050, while for DDS2 is higher between 2015 and 2030. Similarly, decline of energy intensity in DDS1 is higher between 2030 and 2050 (-4%), while for DDS2 the decline is about -5% from 2015 to 2050. For DDS1 scenario, the reduction is due to i) the decarbonization of electricity and ii) a shift among fossil fuels towards the less carbon intensive fuels in industry and transport sector after 2030. For DDS2 scenario, i) the phased decarbonization of electricity from 2015, ii) a reduced share of fossil fuels after 2030, and iii) the use of bioenergy with carbon capture, utilization and storage (BECCUS) selected oil and industry sector.

The decline in energy intensities is due to combination of technical change (towards more efficient equipment, infrastructure and technologies) and structural changes in the Indian energy system. For example, in the power sector technical advancement includes improvement in energy efficiency through a) retiring old power plants, b) increasing plant load factor, c) shifting to less carbon intensive technologies, d) shifting to renewable sources, e) reducing transmission and distribution (T&D) losses and so on. Amongst these changes, integration of renewables in centralized power grid requires structural changes of the infrastructure, while the addition of prosumers

Figure 2. Urban population, Rural population and GDP per capita

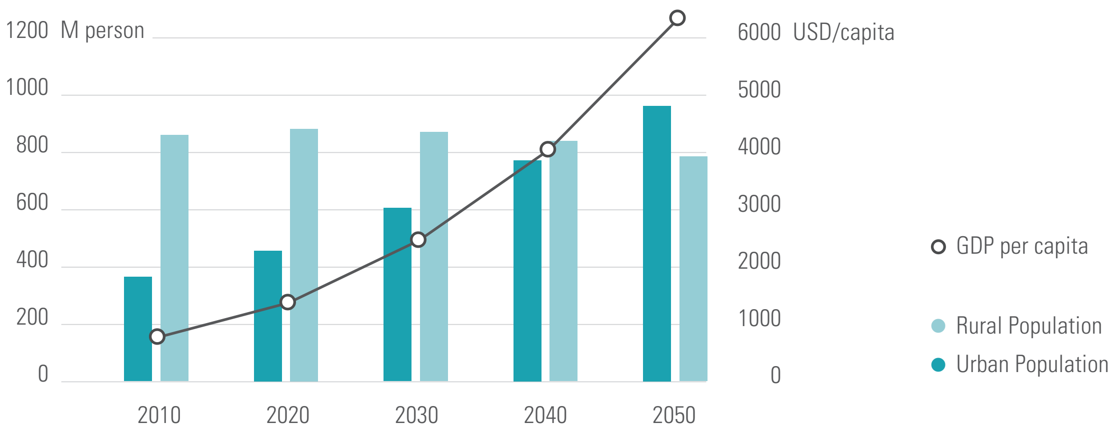
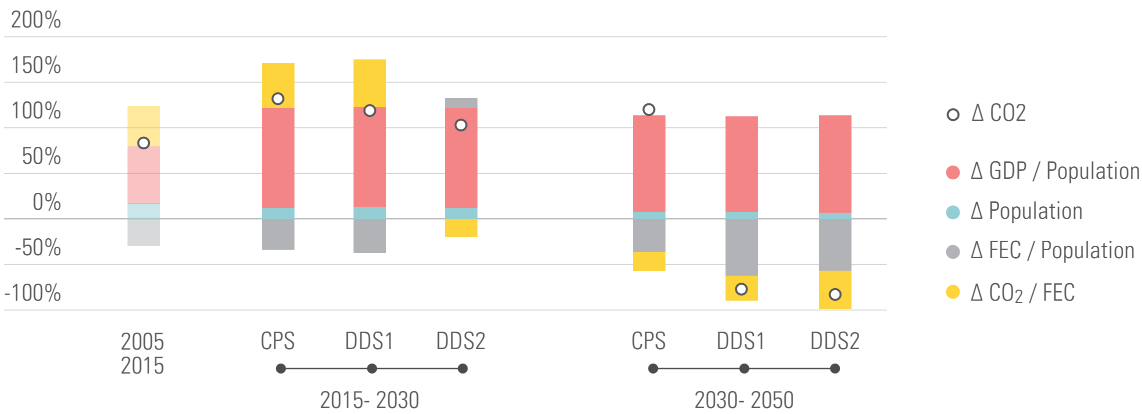


Figure 3. Decomposition of Indian energy-related CO_2 emission changes for historical (baseline, 2005-2015) and future time-frame (2015-2030, 2030-2050) compared to baseline



(providers as well as consumers) also requires change in tariffs, and subsidy policies at national, subnational and local level.

SECTORAL DEEP DIVES

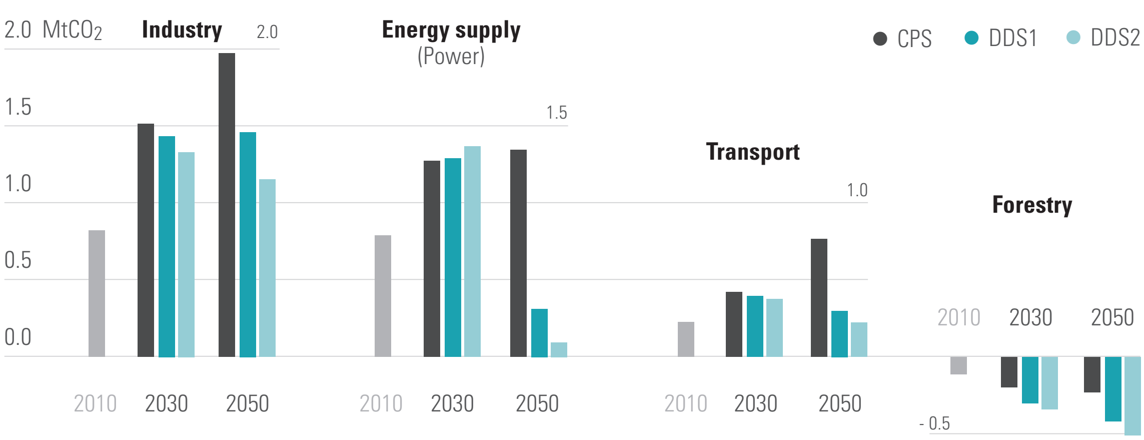
Decarbonization across all sectors will play an essential role in short, medium and long term. In 2016, electricity production constituted 40% of total GHG emissions followed by industry sector (18.7%), agriculture (14%) and transport (13%); whereas LULUCF removed 15% of country carbon dioxide emissions. For India, **power sector is the largest contributor to emission reductions followed by transport, industry and forestry sector in CPS scenarios** (**Figure 4**).

Power

Decarbonization of electricity sector is essential to move towards carbon-neutral India in DDS scenarios, as it subsequently impacts end-use sectors (transport, industry and building). Currently, India has the fourth largest wind capacity and the fifth largest solar generation capacity in the world.

Electricity generation will increase by four times in 2050 when compared to 2010. The share of fossil-fuel based generation capacity has declined from 66% in 2006 to 61% in 2020. A considerable shift is being observed towards non-fossil fuel-based generation due to increase in renewable generation capacity target from 100 GW in 2010 (to be achieved by

Figure 4. Sectoral CO_2e emissions (million tonnes)



2020) to 175 GW in 2015 (to be achieved by 2022) to 450 GW in 2019 (to be achieved by 2030). In DDS scenarios, a major decrease in CO_2 emissions is observed due to a shift towards nuclear, renewables with storage (due to ambitious targets) and large hydro, energy efficient capacity, and improvement T&D losses. The shift to alternative sources will result in the increase of coal and gas stranded assets by 2030s and 2040s in DDS2 and DDS1 scenarios respectively. The average carbon intensity of electricity of 721 gCO_2 per KWh (2010) reduces to 372 gCO_2 per KWh in 2050 under CPS scenarios, to 107 gCO_2 per KWh and 77 gCO_2 per KWh under DDS1 and DDS2 scenarios respectively.

Industry

Industry is second largest contributor to India's economy. The emission shares increase to about 36%, 51% and 50% in CPS, DDS1 and DDS2 scenarios respectively in 2050. The increase in share is due to coal, natural gas used for fuel combustion and emissions from industrial processes especially in the steel and cement industry. This is due to drastic reduction of carbon emissions in power sector. Overall, decoupling of industrial activity is observed due to a drastic decrease in carbon intensity of energy intensive industry. Emissions can be decreased in select 'heavy industries' through a combination of material efficiency, energy efficiency, product substitution, demand reduction and installation of carbon, capture and storage (CCS) units.

Light industry (including non-specific industries) contributed to almost 45% of the emission share in 2016. The share of light industries increases to 49%, 44% in CPS, DDS1 and decreases to 36% in DDS2 in 2050. It is observed that unlike power, it is difficult to abate overall emissions in both energy intensive and light industries with ratcheting the current energy efficient policies and shift to natural gas, and electricity.

Transport

Modal shift is key to decarbonization of the transport sector and subsequent foreign exchange savings. Indian Railways is the largest network in the world and is projected to account for 40% of the total global share of rail activity by 2050. The modal share in freight is projected to increase from 27% to 45% in 2030. India also has the second largest road network in the world. DDS1 and DDS2 scenarios assume a modal shift towards rail. Till 2030, road is assumed to be the dominant transport mode in both scenarios holding a share of 53% and 50% for DDS2 and DDS1 respectively. However, by 2050, rail transport will be the preferred mode in DDS2 and DDS1 scenarios with a modal share of 51% and 49% respectively. The DDS1 scenario reduces the fossil fuel demand by 68% in 2050 compared to 2012, thus leading to foreign exchange savings of 5.8 trillion US$.

The transport sector accounts for 13.3% of total energy CO_2 emissions with road transport dominating the mix with 90.1% share of total transport emissions. In road transport, almost 2/3rd gasoline consumption is by two- and three-wheelers. They have to be therefore targeted first for conversion to EVs. In the baseline year, fossil fuel-based vehicles hold the highest share in the freight sector for service demand procurement. However, with the ongoing policy and schemes, EVs are expected to increase over the years gaining dominance by 2050. In the LCV category, EVs will hold a share of 57% and 56% for DDS2 and DDS1 scenarios respectively. For the rigid HCVs, the share will be 56% and 55% in DDS2 and DDS1 respectively. However, for the articulated HCVs, EVs will not be the most preferred vehicle due to high cost constituting a share of 44% and 40% in DDS2 and DDS1 respectively.

The overall emissions in the sector will reduce by about 60% in DDS2 compared to CPS in 2030 and by about 85% in 2050. The emission reduction of 8.8 $BtCO_2$ can be achieved for the 2013-2050 from passenger transport, and freight transport contributes 5.6 $BtCO_2$ emission reduction in DDS2 scenario. Actions taken towards improving the urban transit infrastructure, implementing the projects related to metro rail and efficient technologies lead to a 16% emission reduction in the transport sector in 2050 compared to that in 2013. Freight transport by dedicated freight corridors and setting up of multimodal logistic parks contributes 8.4% reduction in transport sector emissions. Apart from this, adoption of biofuel blending and higher efficiency of vehicles and shift towards electric vehicles lead to a reduction of 6.9% and 26.7%. Shift towards electric vehicles makes the highest contribution to the emission reduction amounting 42%.

Introduction and scaling up of hydrogen as a fuel will require investment in R&D, technology transfer and financial investment. Fossil fuels dominate the energy share: accounting for 84% of total fuel consumption of the transport sector in CPS in 2050. However, there is a significant reduction, amounting to a 68% decrease in 2050 compared to baseline in the fossil fuel share under DDS2 scenario. In DDS1 and DDS2 scenario, hydrogen gains interest in the transport sector as an alternative fuel technology by 2050 with 4.37% and 6.34% share respectively. Interestingly, there is a sharp shift towards electrification with the share of electricity reaching 97% by 2050 in the DDS2 from the insignificant share of 1.6% in 2012.

Agriculture, Forestry, and Land use

Agriculture contributed to ~14% of national annual GHG in 2016. In contrast to energy systems where CO_2 is the main GHG emission, methane and nitrous oxide are the main emissions from agriculture sector. The emissions from the agriculture sector reduces from 574 $MtCO_2e$ in CPS, to 462 $MtCO_2e$ and 312 $MtCO_2e$ in 2050.

Landuse, Landuse change and Forestry (LULUCF) removed around ~15% of GHG emissions in 2016. The forest area comprises little more than one fifth of (20%) of its geographic area, more than 50% of its population depends on agriculture. Despite its large population density, India is largely successful in keeping deforestation at bay; however, it limits the increase of forest area for climate change mitigation and sustainable development. In this context, we argue that agro-forestry or trees on farmer's lands present a unique opportunity for growth of green cover and climate change mitigation for the South Asian countries by the 2050s and beyond. In CPS, carbon sequestration in Indian forests will increase from about 115 $MtCO_2e$ to 231 $MtCO_2e$ per year from 2015 to 2050. In DDS1 and DDS2 scenarios, it increases to 420 and 510 $MtCO_2e$ in 2050. Major mitigation opportunities come from planting of trees outside forests (ToF), expansion of forests (afforestation & reforestation), densification of existing forests in that order respectively.

Indian soils are generally poor in soil carbon content, hence increasing soil carbon in croplands presents a win-win scenario for improving yields and food security as well as for carbon dioxide removal. Soil carbon improvements are considered *via* two pathways, one being plantation of Trees outside Forests (ToFs) or expansion of agro-forestry on additional 15 Mha till 2050 (today ToF area in India stands at 10 Mha)–so that total ToF area in India increases to 25 Mha. This increment in soil carbon is rather straight-forward and associated with less uncertainty (up to 15-20 $MtCO_2$ per year in 2050). Another pathway being no tillage, nutrient recycling, and mauring on other croplands. This presents an additional 45-50 $MtCO_2$/yr of mitigation opportunity in 2050. However, this soil carbon increment is associated with larger uncertainty. Soil carbon monitoring and accounting is better positioned in India today with the initiation of the Soil Health Card Scheme (https://www.soilhealth.dac.gov.in) by the Central Govt. in 2015.

PART 2: KEY POLICY LESSONS

India's current NDC have been consistent with on-going development and economic policies. Under the Energy Conservation Act of 2001, India has been on the mission to make its energy systems technical and fuel efficient. The National Action Plan on Climate Change (2008) and Nationally Determined Contribution (2015) have played an active role not only in enhancing this mission but also playing a crucial role in reducing overall carbon emissions.

Feasibility of deep decarbonization scenarios is dependent on various factors, the most important of which being incremental mitigation targets, technologies (CCUS, hydrogen, nuclear, coal to other chemicals, smart grid, transformational urban planning), **socio-economic-political considerations, and financial support commitments** (domestic and international).

PRIORITY SHORT-TERM POLICIES AND ACTIONS

Coal

Coal currently is the backbone of India's energy systems. India is the second largest coal consumer of coal in the world. Coal consists of 56% of India's energy supply (2018), 72% of power supply (2020) and 54% of generation capacity share (2020). The deep decarbonization scenarios estimate phasing out of coal to be one of the primary drivers of emission reduction to move towards 1.5C Paris compatible pathways and carbon neutrality around 2080s. This move will need socio-economic and structural transformation leading to transitioning to cleaner sources of energy in power and industry and other end-use sectors. This will both induce clean air and better human health, and simultaneously impact employment and associated sources of revenues of coal mining districts, states (~35-45% revenue) and railways (~40% revenue).

Policies and actions by government, largest public sector undertakings and private firms have already committed to Paris climate goals and carbon neutral targets. For example: Coal India Limited, India's largest PSU plans to become net-zero by this decade. India will still need at least a minimum of 200 Mt of coking and non-coking coal imports due to domestic demand-supply gaps, even if the central government retains the suggested zero-import policy for steam coal. However, off late coal mine e-auctions have not attracted players for over 50% mines put on the block. This could be an indicator that coal mining under current circumstances and environment is not considered attractive.

Stranded assets in the form coal investments already made (e.g. plants, mines, transport) could increase as consequences of selected alternate pathways. Coal value chains directly and indirectly impact about 20 million plus people in India. It is a source of revenue for eastern and south-central states. **Coal transitions will impact locality, states, regions and people at social, political and economic level if implemented in a haphazard manner.** India is aware that it will require multiple discussions and due diligence to adhere to the just transition principles to transform the entire coal value chain especially its coal mining sector. There needs to be a long-term vision (30-50 years) and mission in place to explore the transition towards alternative and lucrative sources of employment for unskilled and skilled labour, in addition to diversification to alternative lucrative businesses and revenue for cities, states, private firms and Indian railways. Simultaneously, the entire Indian fossil-fuelled energy infrastructure needs to be transformed to non-fossil fuel based, resource efficient, environment friendly, affordable, sustainable and accessible energy systems. Acts, Missions, policies and programmes need to be developed which not only support the processes for these transformation through policies and investments but also explore traditional, hybrid, innovative and radical modes of implementation at various temporal and geographical scales.

Power

Deep decarbonization in India hinges on the power sector moving from a carbon intensity of about 0.8 tCO_2/MWh to a range between 0.1

to 0.3 tCO_2/MWh. Decarbonization of transport, building, agriculture and to a certain extent industry is significantly dependant on the shifting from fossil fuels (coal, diesel, petrol) towards decarbonized electricity and other alternative sources of energy.

Early action in the current decade may avoid long-term carbon-intensive lock-ins, however will also result in stranded (coal, gas) infrastructure, labour and regions. Actions include shifting to gas economy (as transition fuel), increased nuclear (for shift in base load) and large hydro (water and siltation challenges). Each of these options need to be available during the course of transitions in the next three decades. Policy support (regulatory, economic instruments) is required to promote R&D in technology, markets and capacity building for renewables, battery storage, grid integration and grid flexibility. Stranded assets in the form coal and gas based power plants will increase as a consequence of selected deep decarbonization pathways. Power sector in India is consciously diversifying to add renewables in its portfolio and actively addressing the implementation challenges of grid flexibility and integration at pilot level. In the short term, the challenges that need to be addressed include fuel availability (gas), production, storage (hydrogen, renewables), capital intensive (nuclear, large hydro), costs (storage battery), resource availability (critical minerals, land) and waste (nuclear, battery). Nuclear energy could help replace coal as base load for national power grid, thus, supporting very deep decarbonization leading to even net-zero. Therefore, domestic nuclear sector needs international support to make India a part of nuclear supplier group (NSG). Technology transfer and financial support should be provided.

Industry

Industry will be one of the 'difficult to abate' sectors' in India. Mitigation action implemented by large plants in energy intensive industries need support policies from the government like Perform, Achieve and Trade (PAT) schemes to achieve deeper decarbonization. Additionally, light industries and MSMEs will represent a large share of residual emissions in 2050, hence will require innovative finance and technologies to move towards carbon-neutrality. Emissions from coal demand can be reduced by installation of appropriate carbon capture, utilization and storage (CCUS) technologies at select locations and certain activities. It is too early for enhanced coal bed methane (ECBM); no storage feasibility studies have been conducted leading to high geological uncertainty. Enhance oil recovery (EOR) (but not necessarily with CO_2) is currently preferred by oil and gas industry to increase production of near saturating fields. CO_2 utilization for EOR could be an industry level probability but through select demonstration projects. Research shows that **CCUS could be an essential component of Indian energy policy going forward with around 780 Mt mitigation potential each year at under US\$60/t-CO_2 and around one bt at US\$75/t-CO_2**.

The use of hydrogen appears to be cost-effective only in chemicals industry in the short term. It is not yet a feasible option for steel industry in India. The Government of India has established a national mission on hydrogen wherein considerable R&D and promotion of hydrogen is included. The Indian industry is also investing heaviliy in green hydrogen. Enhanced nuclear could also facilitate hydrogen economy penetration. **There is a high probability that a part of the 450 GW renewable target could be used to produce green hydrogen**. Technological development and investment across the entire value chain for production, transport and storage of green hydrogen is required. The amount of electricity and water required may become a possible barrier for development and scaling-up of green hydrogen.

Our study indicates a significant amount of emissions from MSMEs based industries. Hence, **there is a need to facilitate the provision of cheaper finance through global financial institutions for climate change actions especially for MSMEs that employ over 110 million people in India**.

Transport

Electric vehicles, fuel efficient technologies in all modes, bioenergy and multi-modal logistics will play a crucial role in decarbonizing the transport sector. Interventions in urban transport such as urban transit infrastructure, metro rail projects and green mobility technologies along with the behavioural shift towards clean, convenient and affordable transport options contribute to emission reduction in the sector. The behavioral shift will be triggered through short-term interventions such as the provision of safe, accessible and affordable public transport services, and involving all stakeholders including the private sector in the transport infrastructure planning; for example the Business Development Units can be set up along the railway infrastructure.

Sustainable transport options include multimodal logistic along the dedicated freight corridors in addition to fuel efficiency improvement, move towards biofuels and electrification. Intensive electrification requires significant investments in the technology development, battery production and charging infrastructure.

The electricity sector must also move towards carbon neutrality in order for the transport sector to achieve the same. India's transport sector needs an overhaul with optimal modal mix, intermodal integration and first mile/last mile connectivity. Short-term actions to achieve this include introduction of uniform regulations across modes which are currently headed by disparate departments, increasing the capacity of railways having high levels of capacity utilization presently, and higher investment in metro projects and public transport services. The biofuels policy offers the opportunity to initiate bioethanol-based BECCUS which is one of the most economical technologies for CCUS. The captured CO_2 could also be utilized for EOR and further studied to inform the policy debate on negative emission technologies. Introduction and scaling-up of hydrogen as a fuel will require investment in R&D, technology transfer and financial investment.

AFOLU

Agro-forestry (Trees outside Forests, ToF) presents one of the largest mitigation potential in India's LULUCF sector till 2050 (132 $MtCO_2$ per year in 2050 under the DDS2 scenario). It can also help India achieving its long-term national goal of bringing 33% of its geographic area under forest and tree cover. Afforestation and reforestation especially reforesting degraded forestlands present one of largest mitigation opportunities for India till 2050 (196 $MtCO_2$ per year in 2050 under DDS2 scenario). Densification of existing forests too presents a significant mitigation opportunity for India in the LULUCF sector.

Indian soils are generally poor in soil carbon content; increasing soil carbon in croplands presents a win-win scenario for improving yields and food security as well as for climate change mitigation. Soil carbon improvements through the plantation of trees ourtside forests and via no tillage, nutrient recycling, maturing, on other croplands provides addtional sink of about 60-70 $MtCO_2$/yr. However, this part is associated with larger uncertainty. There is a need to launch soil carbon enrichment mission for croplands; soil health card scheme could provide an excellent baseline for this mission.

Agriculture is another hard-to-abate sector that needs specific attention from policymakers for not only mitigation actions but also from an impact, resilience building and climate change adaptation perspective. Almost 70% of the population in India depends on agricultural income. Hence, the extensive practices of cultivation and livestock rearing would remain. The penetration of neem-coated urea and nano- fertilizers are expected to have N_2O mitigation (~50%). Cross breeding programmes as well as systemic efforts to promote cattle feed options that help mitigation of CH_4 emissions from enteric fermentation need to be stressed upon. Promotion of manure management systems and technologies would support mitigation efforts from livestock rearing. Management of rice watering schedule helps reduce CH_4 emissions e.g. alternate wet and dry irrigation rather than continuous flooding reduced the methane production.

SYNERGIES AND TRADE-OFFS WITH NON-CLIMATE OBJECTIVES

India is committed to achieve its SDG and NDC goals by 2030. The Indian government stresses on meeting both development goals and climate targets. The current study integrates water, energy and carbon systems to model SDG-NDC linkages. Implementing NDC policies will result in the achievement of targets under SDG3, SDG6, SDG7, SDG8, SDG9, SDG11, SDG13 and SDG15. On the other hand, achieving the SDG targets can help accomplish resource-use efficiency goals in addition to NDC and Paris Agreement goals (as these targets are a subset of SDG13.

SDG13, SDG7, SDG15 are highly synergistic with NDC. SGD 3 and SDG6 will be subsequently impacted as we achieve the current NDC. At the same time, SDG16 (peace, justice, strong institutions) and SDG17 (global cooperation) are required to attain both SDGs and NDC. Sub-targets under SDG1, SDG2, SDG6, SDG8, SDG9, SDG11, SDG12, SDG15 are the drivers that have been used to model India's energy-economy-environment systems in this study. SDG4 (education and awareness especially pertaining to environment) impacts the achievement of all the SDGs as well as NDC. More work is required to capture the impact of SDG5 (gender equality), SDG10 (reduced inequalities), and SDG14 (life below water) on the current NDC. **Table 2** presents synergies and trade-offs with non-climate objectives.

Deep decarbonization will result in ratcheting up the mitigation actions (SDG13), with higher share of renewables and increased energy efficiency (SDG7), in addition to increased afforestation, reforestation (SDG15). The scenario will require innovation in industry (SDG9), transit-oriented, sustainable cities (SDG11), through responsible production and consumption (SDG12). Water efficient technologies in agriculture (SDG6) and dry cooling systems in power sector need to be installed simultaneously. The immediate impact from non-fossil fuelled energy systems will be clean air (SDG3). Like NDC, decarbonized pathways will require stronger institutions (SDG16) with bilateral and multilateral international cooperation (SDG17).

As a developing country, India will be a) urbanized and b) a significant section of the society with transition from low to middle income and middle to high income society. Hence, the **achievement of SDGs will be a work in progress to improve the standard and quality of life at both household and individual level**. Deep decarbonization scenario (DDS1) aligns

Table 2: Synergies and tradeoffs with climate and non-climate objectives

SDG	Power	Industry	Transport	Agriculture	Forestry	Comments
13 Climate action	Model analysis; High synergy	Model analysis; High synergy	Model analysis; High synergy	Model analysis; High synergy	Model analysis; High synergy	High. The synergies will be cross-sectoral. As stated earlier, India's NDC integrates climate change mitigation and adaptation measures into its national policies, strategies and planning.
7 Affordable and clean energy	High synergy; Model analysis	High synergy; Model analysis	High synergy; Model analysis	High synergy; Model analysis	Neutral; Model analysis	High. SDG sub-targets complement the NDC goals for renewables and energy efficiency.
15 Life on land	Neutral; Not analyzed in this project	Neutral; Not analyzed in this project	Neutral; Not analyzed in this project	High synergy; Model analysis	High synergy; Model analysis	High. SDG sub-targets complement and are synergistic with NDC goals in agriculture and forestry sector.
3 Good health and well-being	High synergy; Not analyzed in this project	High synergy; Not analyzed in this project	High synergy; Not analyzed in this project	High synergy; Not analyzed in this project	High synergy; Not analyzed in this project	High. Achievement of NDC targets will lead to improve local air quality.
16 Peace, justice and strong institutions	High synergy	High synergy	High synergy	High synergy	High synergy	High. String insitutions are required for timely implementation of policy instruments.
17 Partnerships for the goals	High synergy	High synergy	High synergy	High synergy	High synergy	High. Majority of the technological solutions (EV, hydrogen, CCUS) require strong international collaboration.
8 Decent work and economic growth	Moderate synergy; Out of model analysis	Moderate synergy; Out of model analysis	Moderate synergy; Out of model analysis	Moderate synergy; Out of model analysis	Moderate synergy; Out of model analysis	Moderate.
9 Industry, innovation and infrastructure	Moderate synergy; Out of model analysis	Moderate synergy; Out of model analysis	Moderate synergy; Out of model analysis	Moderate synergy; Out of model analysis	Moderate synergy; Out of model analysis	Moderate.
11 Sustainable cities and communities	Moderate synergy; Not analyzed in this project	Neutral; Not analyzed in this project	Moderate synergy; Not analyzed in this project	Moderate synergy; Not analyzed in this project	Moderate synergy; Not analyzed in this project	Moderate.
12 Responsible consumption and production	Moderate synergy; Out of model analysis	Moderate synergy; Out of model analysis	Moderate synergy; Out of model analysis	Moderate synergy; Out of model analysis	Moderate synergy; Out of model analysis	Moderate.
6 Clean water and sanitation	Moderate synergy; Model analysis	Moderate synergy; Model analysis	Moderate synergy; Model analysis	Moderate synergy; Model analysis	Neutral	Moderate.

- High synergy
- Moderate synergy
- Neutral
- Moderate tradeoff
- High tradeoff
- Model analysis
- Out of model analysis
- Not analyzed in this project
- Not applicable

Table 3: SDG indicators across scenarios in 2050

SDG	Indicator	CPS	DDS1	DDS2
7 AFFORDABLE AND CLEAN ENERGY	7.1 Percentage of households electrified	As of 2019, all villages have been officially electrified. However, there are at least 10-15 million households left to be electrified. So, all scenarios assume that all households are electrified by 2025.		
	7.1 Percentage of household with cleaning cooking fuel	100% by 2035	100% by 2030	100% by 2025
	7.2 Renewable share in total energy mix (% of GW)	55%	59%	63%
	7.3 Energy intensity in terms of primary energy and GDP	7.2	4.9	3.5
8 DECENT WORK AND ECONOMIC GROWTH	8.4 Percentage Renewable share in total final energy mix	55% by 2050	59% by 2050	63% by 2050
	8.4 Per capita fossil fuel consumption (in GJ/capita/year)	45.3 by 2050	31.1 by 2050	22.3 by 2050
13 CLIMATE ACTION	13.2 Pre 2020 action achievement of pre 2020 goals as per country priority	In terms of emission pathways, India has achieved its commitment to Copenhagen Accord 2009.		
	13.2 Achievement of NDC goals post 2020	In terms of emission pathways, India is the only country on track to move towards a global 2C world. All scenarios NDC (conditional, unconditional) goals before 2030. Forest sector NDC achievement is in-built in the CPS as well as all the three other scenarios.		
15 LIFE ON LAND	15.1 Forest area as proportion of land area	25.5%	32%	33%
	15.2. Area of trees outside forests	10 Mha	25 Mha	25 Mha
	15.3 Increase in Forest area in 2050 compared to 2015	6 Mha	8 Mha	13 Mha
	15.4 Percentage of degraded area restored (Bonn Challenge)	We assume Bonn Challenge has been achieve in CPS scenario. India originally pledged to restore 21 Mha over the period 2014 to 2030. It planned to restore 13 Mha over 2014 to 2020 and another 8 Mha from 2020 to 2030.		
	15.5: Restoration of soil carbon	Cropland soil carbon remains low	Cropland soil carbon increases by 2 MgC/ha	Cropland soil carbon increases by 3 MgC/ha

with the Sustainable Development Goals and development policies to address issues of energy security and air pollution. **Table 3** presents the extension of SDG goals to 2050.

INVESTMENT PATTERNS

India puts in about USD 100 billion each year for climate adaptation and ring-fencing its population and systems. This is likely to touch USD 360 billion by 2030. In accordance to Article 9 (paragraph 3) of the Paris Agreement, the developed countries need to provide financial assistance to developing countries of USD 100 billion annually till 2025, and much more beyond 2025 to the green climate for both mitigation and adaptation actions. For developing countries to enhance their mitigation commitments, additional financial flow would be required from developed countries. The CPS scenario for India may require an investment of around US$ 120 billion per year during 2020-2030 (Total ~ US$ 1.2 trillion). The 2C and well below 2C is projected to be US$ 160 – 270 billion per year during 2020-2030 (Total ~ US$ 2.1 trillion). Net-zero by 2050 will require US$ 160 – 260 billion per year during 2020-2040 (Total ~ US$ 4.2 trillion), while net-zero by 2065 will require US$ 120 – 140 billion per year during 2020-2045 (Total ~ US$ 3.3 trillion).

Green finance, innovative finance, internal carbon pricing, risk sharing instruments and carbon markets will play a crucial role for the implementation of DDS scenarios. Policies will need to be implemented in an integrated manner across ministries and sectors. (EV: Power, Transport, Solar PV: Power, Industry, Agriculture, Building, Hydrogen). At the same time, public and private institutions need to a) de-risk investments to mobilize finance at scale for technologies and strategies that aim at mitigation, adaptation and sustainable development actions; and b) mainstream the climate risks and opportunities into decision making.

Enhanced commitments by large industrial houses along with government push/facilitation could be deciding factors. The central government needs to signal and encourage the industry (large, MSMEs) to include ambitious mitigation actions in their short-term and long-term strategies through tax rebates and similar economic instruments to make them competitive in the short term. Domestic manufacturing should be strongly encouraged for solar PVs, batteries, and hydrogen technologies.

KEY INTERNATIONAL ENABLERS AND ACCELERATORS OF DOMESTIC TRANSITIONS

India will not be net zero by 2050 under all scenarios. For the world to be net zero by 2050, the developed countries therefore need to have ambitious plans to be net-negative energy systems. Additionally, more work is required on the management of carbon sinks (natural and geo-engineered). We need to **involve multi-national/transnational businesses and industry** in climate change discussions and actions (for technology transfer, financial investment and capacity building).

International support and facilitation is required to create a vibrant carbon market in India, and link it with other carbon markets around the world. This will enhance economic efficiency of GHG mitigation all over the world. The Paris agreement Article 6 covering Internationally Transferred Mitigation Options (ITMOs) could also be a relevant mechanism for this. **Some of the top Indian businesses have committed to become net zero and internalize carbon price gradually**, but it must be an international consolidated expression by large businesses.

It is evident that the future of coal in each scenario hinges on the developments in power sector in the coming decades. It is also observed that the industry sector will also become more efficient, however it will still be hard to abate emissions due to coal and industrial processes without significant investments in alternative technologies.

Deep decarbonization in India and the move towards carbon neutrality hinges primarily on the power sector. End-use sectoral deep decarbonization especially transport, building and industry is significantly dependent on shifting to electricity. Decarbonized electricity decreases the overall emissions by 1-1.3 Bt CO_2 in 2050 in DDS1 and DDS2, when compared to CPS. Future of coal use and mitigating climate change are closely interconnected, and more so for coal-dependent economies like **China, India, USA, Germany, Russia, Japan, South Africa, South Korea, Poland, Australia, Turkey and Indonesia, which together account for over 88% of global coal extraction and use per year. Coal is a global concern, therefore the solution to phasing out of coal should also be global.** Individual coal-dependent countries, especially developing countries, would be concerned with their energy security and economic-social-political compulsions. These countries may continue with coal until provided with international support through clean technology transfers, financial investments and associated capacity building to move towards a decarbonized economy.

India ranks third in crude oil import netting around 4,544 bpd as of December 2018. It imports from Iraq, Saudi Arabia, Venezuela and Nigeria. Imports from African countries such as Angola, Cameroon and Chad decreased by 18% of total energy consumption due to high international prices. Oil consumption share in the energy fuel mix was around 29% in 2017. **Our study projects a decrease in oil demand after 2030 due to a shift towards electric vehicles (2W, 3W, 4W, buses, Metro, Train). Pricing of oil impacts pricing of natural gas (Henri Hub, NBP, Japanese market).** Natural gas makes up only 6% of energy consumption in 2017, however imports for the liquefied natural gas (LNG) increased 9.7% year-on-year. India currently imports around half its gas, largely from Qatar, the US, Australia and Russia. CPS and DDS1 scenarios rely on natural gas for base load. Hence, pricing of oil and natural gas (energy commodities) will also be an important market mechanism to transition towards a low-carbon/carbon neutral society.

Developed countries and India will need to collaborate for incentivising solar (power, building), wind (power), BECCUS (power, industry, agriculture), and green hydrogen fuel transformation (industry, transport) technologies in the next 2-3 decades. There is a need to create a common technology development pool (battery storage, grid integration, electric vehicles, CO_2 capture utilization and storage (CCUS), hydrogen, advanced bioenergy and nuclear power) in which industrialized and developing countries are equal partners. These technologies are required to upscale DDS scenarios for even earlier net zero by India. South-South collaboration is also possible between India, other developing and least developing countries especially in South East Asia and Africa for solar and bioenergy.

The Indian Ministry of science and technology currently supports three bi-national science and technology (S&T) centres which are independent entities established under inter-governmental bilateral agreements with France, USA and Germany. Presently India has bilateral S&T cooperation agreements with 83 countries. During recent years the cooperation has strengthened significantly with Australia, Canada, EU, France, Germany, Israel, Japan, Russia, UK and USA. Nature of access to technology development, production and manufacture depends on ownership of technology and the financial mechanism in which the technology is transferred. The types of mechanisms include trade, FDI, JV, licensing agreement, strategic acquisitions and alliances, overseas R&D, joint R&D and local innovation. For example, moving towards a hydrogen fueled economy will become viable only through international support, even as the source of hydrogen (blue or green) will be highly debated for the coming decade.

INDONESIA

Boer R.[1]
Siagian U.[2]
Retno Gumilang Dewi[2]
Rossita A.[1]
Anggraeni L.[1]
Immanuel G.S.[1]

1 Center for Climate Risk and Opportunity Management (CCROM) in Southeast Asia and Pacific, IPB University

2 Center for Research on Energy Policy (CREP), Bandung Institute of Technology (ITB)

Indonesia submitted its Long-Term Strategy (LTS) to the UNFCCC in July 2021. In its most ambitious pathway, this strategy describes options for peaking national greenhouse gas emissions in 2030 and reaching 756 $MtCO_2e$ in 2050, with the possibility of achieving carbon neutrality in 2060 or sooner. This submission demonstrates a firm commitment to the Paris Agreement of a country of utmost importance for the global ambition—the 4th largest in terms of population, 16th largest economy and 8th largest greenhouse gas emitter in the world. It is particularly noteworthy as it comes from a developing country with severe development challenges—ranked 107 in HDI index—and brutally affected by the COVID-19 crisis, demonstrating that ambitious climate action and socio-economic development can go hand-in-hand. The detailed strategic visions supporting the emission pathways reveal the required efforts for the national low-carbon transition and highlight the key domestic and international enablers.

Indonesia's LTS has been developed through an in-depth participatory process led by the Government of Indonesia and guided by detailed research analysis of transition pathways exploring different technical and socio-economic trajectories from the present to mid-century. More specifically, the LTS considers three pathways: the Current Policy Scenario (CPOS), which reflects an extended version of Indonesia NDC's unconditional scenario; the Transition Scenario (TRNS), with a more diversified energy sector; and the Low-Carbon Compatible with Paris Scenario (LCCP), which shows national emissions peaking in 2030 and reaching 735 $MtCO_2e$ in 2050, at a rate that, if maintained in post-2050, would lead to carbon neutrality in 2060 or sooner. This document presents a synthesis of key results of the decarbonization scenarios developed to inform Indonesia's LTS, particularly the CPOS and the LCCP (which is referred to as DDS in this document). It describes the key national and sector level techno-economic transformations to 2050, their main socio-economic aspects and resulting emission profiles. It also distills main policy implications and challenges, investment insights and necessary developments in international enablers.

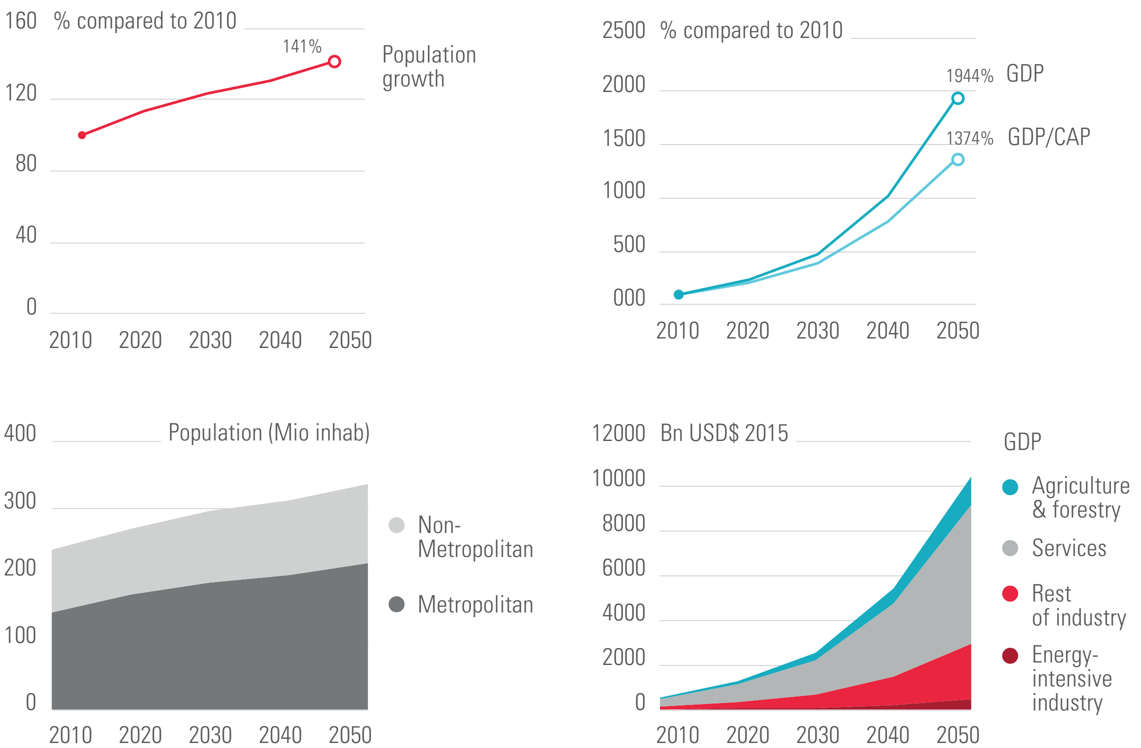
PART 1: SCENARIO RESULTS

SOCIO-ECONOMIC FEATURES OF THE SCENARIOS

Article 28 H of Indonesia's constitution (UUD 1945) mentions that it is the state's obligation to ensure a decent life and healthy environment for citizens. From the formulation of the National Action Plan of GHG emission reduction document (Rencana Aksi Nasional Gas Rumah Kaca, RAN-GRK) to the ratification of the Paris Agreement in 2016 and the First NDC submission, Indonesia has been strongly engaged in climate commitment. It is not without interference for Indonesia, as a developing country, to maintain the mitigation pace while reaching its goal as an upper-income country and world food barn. Therefore, it is a necessity to incorporate the socio-economic conditions and political direction which act as the drivers of change in activity level and GHG intensity to the long-term climate commitment.

Under the 5% average of historical GDP annual growth, Indonesia is entering upper-middle-income countries in 2019 with USD 4,135 GDP per capita (current USD price) (data.worldbank.org). And the national goal is to escape the middle-income trap in the next two decades. In 2020, the COVID-19 pandemic has become the turntable, dragging the national economy to recession. It is assumed that the recovery process will take longer than a year, hence shift the future GDP growth to 3% for the 2020-2025 period. The growth will return to 5% in the period 2025-2030 and lead to the peak of GDP growth in 2030-2035 to 6%. The GDP growth is assumed to be saturated at a 4.5% level in the period of 2045-2050.
At the regional level, a higher pace of economic growth in the period 2030-2050 with intense infrastructure growth (e.g., international airport, commercial building equipped with air conditioner, etc.) and crowded air traffic is predicted to be found in East Kaliman-

Figure 1. Economy-wide assumption for both CPOS and DDS scenarios



tan, where the new Capital City of Indonesia located. However, it is estimated that the traffic load in Jakarta will remain high. Massive development of transport infrastructure, including MRT and LRT, will occur in new metropolitan cities. Following rapid economic growth, Indonesia's economic structure will shift to industry and services/tourism. Under the utilization of CCS in industrial fossil energy systems, electrification of industry equipment, and use of renewables (e.g., hydropower in metal industries), GHG emission intensity for industry under mitigation scenario is expected low.

Indonesian population in 2010 was 239 million people and projected to increase to 296 million people in 2030 (1% p.a.) and reach 336 million people by 2050 (0.9% p.a.). Population structure proportion (0-14, 15-64, over 65 years old) in 2010 was 29% (0-14), 67% (15-64), 5% (over 65); 22%, 68%, 10% in 2030; and 19%, 66%,15% in 2050. At present, people live in the rural/countryside 48% and 52% in the urban cities. From historical data, the urbanization rate is 4.1% per year. By 2030, the share of people living in urban areas is projected to reach 60% and 80% by 2045. The high rate of urbanization also affects labour in the agriculture sector, which demands labour efficiency by large-scale agricultural technology and machinery adoption.

EMISSION PROFILES

Based on this socio-economic picture, two scenarios have been developed: Current Policy Scenario (CPOS) and Deep Decarbonization Scenario (DDS). CPOS reflects an extension of current policy packages to 2050, whereas DDS has in-built increased mitigation ambition to set a path to carbon neutrality.

Indonesia's DDS reaches 496 $MtCO_2e$ in 2050, towards net zero in 2060. It represents a deep cut of fossil fuel in the power sector, the utilization of CCS technology and emphasizes the net sink role from the AFOLU sector.

Under the increased population and pressure to maintain staple food self-sufficiency, the dynamics of food demand (i.e., food consumption, food waste, and food loss) and land-use efficiency/land capacity to produce commodities are pivotal to achieve a net-sink target for the AFOLU sector. In the DDS scenario, net sink is reached in 2030 and emissions are negative (-201 $MtCO_2e$) in 2050. This sequestration role requires a massive cut of both legal and illegal deforestation, conservation and restoration of the degraded peatland at an accelerating rate, and increased land-use efficiency (e.g., improved productivity and cropping intensity, efficient technology from harvest to post-harvest to reduce food loss, etc.) followed by sustainable consumption.

Implementation of efficiency measures, decarbonization of power using large renewable and coal with CCS/CCUS, and biofuel use in transport will enable the energy sector to achieve significant emission reduction. After peaking at 1,274 $MtCO_2$ in 2030, the emissions of the energy sector decline to around 720 $MtCO_2$ in 2050 in DDS scenario.

SECTORAL DEEP DIVES

AFOLU

Activity level.

Main activities considered in the AFOLU sector are reduction of deforestation, forest conservation and sustainable forest management, protection and restoration of peatland, carbon sink enhancement, water management in the rice field, the use of the low emitted variety, biogas from livestock waste, feed supplement for livestock, and application of organic fertilizer.

Indonesia's land cover is classified into the forest area and non-forest area or other land uses (APL), with an area of 120.6 Mha and 67.4 Mha, respectively. Natural forest in forest area is approximately 82.5 Mha, of which 6.3 Mha are located in the convertible production forest, hence subject to deforestation. As supported by a number of regulations, including a ban to convert forested land in the forest area and moratorium to natural forest and peat, cumulative area to be deforested until 2050 for CPOS and DDS scenarios are 14.6 Mha and 6.8 Mha, respectively.

The Medium-Term National Development Plan (RPJMN) plans to have in concession area and APL approximately 5.2 Mha of natural forest indicated as protected zone. Under the concession area, the degradation rate of these forests could be minimized by mandatory issuance of certification system through sustainable logging technique. At present, only 76% of the forest concessionaire have issued this certification. Under the CPOS scenario, the issuance rate will follow the historical pace, while for the DDS scenario, it is expected that all the concessionaires have implemented sustainable harvesting practices. For the area outside the concession area, the effort emphasizes enhanced natural regeneration (ENR) to assist in faster natural regeneration. The implementation of the ENR in 2050 for CPOS and DDS scenarios are 1.6 Mha and 8.8 Mha, respectively.

As peatland contributes to half of AFOLU emissions, the Government of Indonesia has provided supporting policies to protect peatland and its management. Under the CPOS scenario, it is expected that the improvement of peatland and water management by 2030 and 2050 reaches 0.86 Mha and 1.04 Mha consecutively, while under the DDS scenario it reaches 0.95 Mha by 2030 and 1.04 Mha by 2050. For peatland restoration, peatland being restored under the CPOS scenario should reach 1.03 Mha by 2030 and 1.7 Mha by 2050, while under the DDS scenario, the target will be more ambitious to 2.7 Mha by 2030 and 4.2 Mha by 2050.

Total unproductive land (i.e., shrubs, grassland, and bare land) in Indonesia is considerably high, amounted to 30.1 Mha. Approximately 18% of these areas are considered as critical and very critical land, which demand immediate rehabilitation through several programs (e.g., social forestry, land rehabilitation program, multi permit, etc.). Under the CPOS scenario, the targeted area for land rehabilitation is about 4.32 Mha by 2030 and 8.6 Mha by 2050. Under the LCCP scenario, a more ambitious target is set to 5.3 Mha by 2030 and 10.6 Mha by 2050.

Mitigation actions in rice fields are categorized based on the availability of water management in the fields. For a field without water management, the mitigation action is to use low emission variety, while for an area with proper water management, SPR/STT, minimum input, and improved water use efficiency system, is the most feasible action. Under the CPOS scenario, the adoption of low-emission variety is expected to be 0.93 Mha by 2030 and 1.96 Mha by 2050, while an ambitious target is set in the DDS scenario to 0.97 Mha by 2030 and 2.07 Mha by 2050.

Following the GDP per cap growth, it is expected that demand for meat and milk will continue to increase. To increase the milk productivity and tons of carcass, feed supplement has to be added, a combination of the greenery, and an additional feed supply of tannin from legume crops or urea molasses block, in the livestock diet. The cumulative target for feed supplement under the CPOS and DDS scenarios in 2050 is 3.42 million head and 6.58 million head, respectively. In addition, to utilize the livestock waste, mitigation action for biogas implementation is taken into account. The CPOS and DDS have a similar target for biogas implementation, which amount to 41,000 head in 2030 and 94,000 head in 2050.

For cropland areas, the main mitigation activity is to reduce dependency on nitrogen fertilizer by substituting urea application with organic fertilizer. Under the CPOS scenario, the adoption of this mitigation action in 2030 and 2050 are expected to reduce the use of urea to 3,089 ton and 58,513 ton, respectively. Under the DDS scenario, the reduction of total urea used in 2030 and 2050 is expected to be 5,374 tons and 65,697 tons, respectively.

The main policies considered in the AFOLU sector scenarios are:

Social forestry/TORA

Ministerial Regulation No.83/2016 has stated social forestry as a scheme aimed to allocate 12 million ha forest area for the community. In addition to that, approximately 5 million ha to be released as non-forest area, under agrarian reform policy-TORA. Under the social forestry/TORA, agricultural land under forest area is now receiving legality status and can receive an incentive and/or capacity building program from the government. With more assured financial access and technical support, the yield gap between the community and private is expected to be reduced. Social forestry is also a key policy to address the tenurial issue for the community near the forest area. Under the Deep Decarbonization Scenario (DDS), the implementation of this policy should meet the target in 2030, while for the Current Policy Scenario (CPOS), approximately only half of the allocated area meets the target.

Forest and peatland moratorium

Presidential Instruction No.5/2019 states permanent extension for forest and peatland moratorium and its governance improvement. The regulation aims to protect the remaining natural forest which is primarily located in production forest area (subject to conversion) and further degradation to peatland ecosystem due to draining and land conversion.

Multi permit scheme
The government of Indonesia has developed new policy on multi permits–multiple uses of forest management–which allow any entities to have multiple business activities including agriculture (in the past, each entity could only be granted with one permit, e.g., timber plantation). At present, many areas under concession are occupied by communities for agriculture activities. These areas are claimed by communities and cannot be utilized and managed by concessionaires. Under the multi-permit policy, concession holders can establish a partnership with communities who occupied their concessions to establish mixed farming or develop a new scheme for environmental services-based business.

Sustainable agriculture land
Referring to the high urbanization rate in the future (more than 60% of the population will live in cities in 2035), it is expected that massive conversion of paddy fields and cropland will occur following the expansion of the urban area. Law No.41/2009 regulates the protection of sustainable agricultural land by restricting the conversion of agricultural land to non-agriculture land. The rationale behind this law was to ensure sustainable and consistent food production for independence, resilience, and national food sovereignty.

Integrated livestock and plantation
To ensure the fulfilment of land demand for livestock, the utilization of grassland is allowed after the need for land for livestock is satisfied. In this case, increasing grassland demand for livestock might lower unproductive land available for afforestation/reforestation. Under the ambitious national plan to reach meat self-sufficiency, an increased livestock population is expected. Integrated livestock plantation, as regulated by Ministerial Law of Agriculture No.105/2014, will increase land-use efficiency and its economic value. In addition, the integrated system will support palm oil production and strengthen meat production under a low carbon framework, of which the livestock will provide organic fertilizer that improves soil texture, reduce the production cost, and increase oil palm productivity.

SDG 12: responsible consumption and production
Following population increase in the future, it is estimated that rice consumption per capita will increase by 0.94 kg p.a. Under this pattern, calory intake per capita in 2010, 2030, and 2050 are assumed to be 1,825, 2,184, and 2,450 kcal/cap/day, respectively. In addition, following the increased GDP per capita, food waste is assumed to be increased in a logarithmic pattern, from 21 kg/cap/year in 2010 to 97 kg/cap/year in 2050 under the current policy scenario (CPOS). Under Deep Decarbonization Scenario (DDS), food waste increases less rapidly, up to 76 kg/cap/year in 2050.
In reverse to food waste, increased GDP which triggered advanced technology and efficient on-farm procession, food loss decreases, from 70 kg/cap/year in 2010 to 40 kg/cap/year under the CPOS scenario and 34 kg/cap under the DDS scenario in 2050. At present, the government encourages the use of technology and machinery, and has aid measures to support the adoption of the technology. However, large-scale adoption is limited by financial constraints. Increased financial access to bank or non-banking financial institutions (NBFI), as well as improvement of farmers grouping, is key to increase the adoption of post-harvest technology.
In case of food waste, large-scale campaign and education for consumer side and business owner side (e.g., administrative sanction and certification, minimizing food waste and reprocessed food waste for livestock feed) is needed. In addition, as national policy regarding waste is still general, there should be a formulation of a new policy that is specified in food waste (i.e., food waste categorization, food waste management, etc.).

Physical transformation.
The key transformation to achieve net zero-emission in the AFOLU sector is increasing land-use efficiency (e.g., increased productivity, increased cropping intensity) and maintaining sustainable consumption. Under this condition, land demand for food and forest product is fulfilled without being exacerbated by massive clearance of natural forest and land degradation.

Though supporting policies are available to make the LUCF sector shifted into a net sink, these policies are still poor of implementation scheme and enabling mechanism.

At the local level, Forest Management Unit (FMU) has a crucial role to play to reduce the risk of deforestation in the forest area. At present, the capacity of most of the FMU is still lacking in terms of human resources and supporting infrastructure as well as authorities for managing forest; capacity enhancement of the FMU should therefore be the main priority in near future.

In the case of increasing land-use efficiency, technology improvement and high-quality inputs (e.g., seeds, fertilizer, etc.) are central. Agricultural machinery is the key to increasing productivity to address increasing food demand in the future. Currently, pre-harvest machine distribution accelerates at a higher pace than post-harvest machines. In addition, the adoption of technology highly relies on government support. Increase farmer's access to other sources of financial support is one of the breakthroughs required in the AFOLU sector. Convenience access to financial credit should increase technology adoption in the future.

Currently, credit distribution for agriculture, forestry, livestock and fisheries, forestry, and plantations represent only 9% of total bank credit, due to collateral requirement issues and farmer's income fluctuation. Under the CPOS scenario, value chain finance such as the Warehouse receipt system, Peer to Peer lending (P2P), and credit program provides credits to buy agricultural inputs and tools for technology adoption to support low-carbon agriculture. To enable low-carbon transformation, the development of an innovative scheme is needed. Under the DDS scenario, innovation in value chain financing schemes is needed to sync with food security-related policies that were in line with emission reduction targets, for example, the development of main food commodities and provision of forest areas for social forestry.

Under more advanced agricultural technology, the labour skill should be improved. Under the CPOS scenario, revitalization of institutional and agricultural extension institutions will make a positive contribution to improving agricultural human resources. Under the DDS scenario, providing sufficient space for the private sector (e.g., traders, modern market) and research agencies/universities to actively engage in empowerment programs can be a solution to increase production and market.

Emissions.

Under the CPOS scenario, total emissions consistently decline and reach -41.25 $MtCO_2e$ in 2050. Under the DDS scenario, total emissions decline more sharply than the CPOS scenario and reach net-sink in 2030 with -235 $MtCO_2e$ in 2050. Emission breakdown for LULUCF and agriculture for the DDS scenario are provided in **Figure 2**.

Figure 2a. Emission measured under CPOS and DDS Scenarios for LULUCF

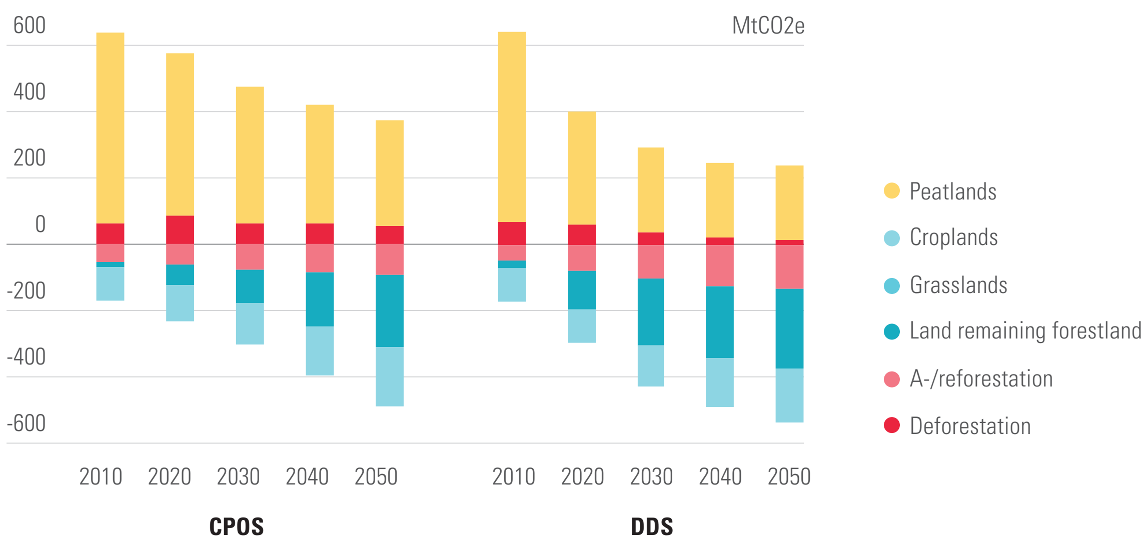
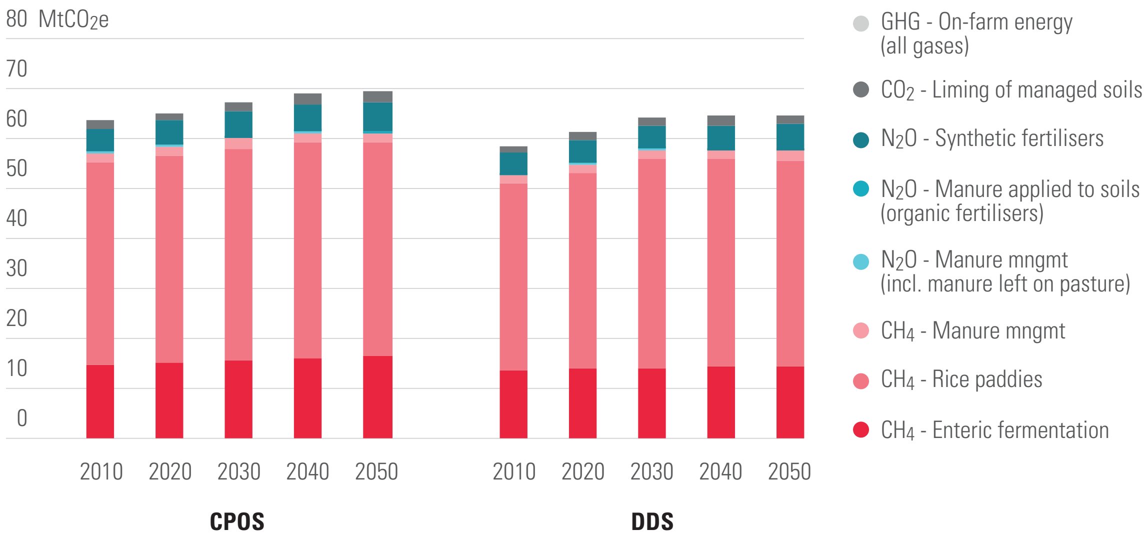


Figure 2b. Emission measured under CPOS and DDS Scenario for agriculture sectors



ENERGY (POWER AND TRANSPORT)

Activity level.

Energy demand grows in accordance with the development drivers (economic and population). Annual GDP growth in 2010-2020 is 5% and decrease to 1% in 2020 due to COVID-19 pandemic, then gradually increase to 6% in 2025, with the growth of 2025 to 2040 is 5% growth and 2040-2050 is 4.5%. This annual economic growth is lower than those assumed in the National Energy Policy (Kebijakan Energi Nasional-KEN) projection which is 7%-8%. Therefore, the primary energy projection of DDS in 2050 is around 500 Mtoe, lower than that of the KEN which is 1,000 Mtoe in 2050. As the result of efficiency measures, the energy intensity of all energy-consuming sectors in 2050 is much less than that of the base year.

In major industry fuels (gas, electricity, oil fuels, coal with CCS/CCUS), the establishment of a CO_2 cap will have been implemented, CCS/CCUS business using pipeline transport and trucking are already in place, and CO_2 from major industry will be handled by CCS/CCUS.

The energy input to industries will be transformed from primarily coal and oil fuels to natural gas, renewable (especially in smelters), and electricity, in decreasing order. By utilizing CCS/CCUS in industrial fossil energy systems, electrification of industry equipment, and use of renewables especially hydropower in smelters, GHG emission intensity for the industry is expected to decrease. However, the level of GHG emission intensity will depend on the carbon content of the electricity supplied by the utility and the access of smelters to hydropower resources.

Decarbonization of the energy sector in DDS results in peaking of CO_2 emissions at 1,164 Mton in 2030 and declining to around 766 Mton CO_2 in 2050, largely enabled by the implementation of efficiency measures, decarbonization of power using large renewable and coal with CCS/CCUS, and biofuel use in transport.

Physical transformation.

Electric Power

Demand for electricity comes from residential, commercial, and industry, with a small fraction of the demand coming from transport (train). In the future, a significant fraction of electricity will be used by transport which is expected to shift to electric vehicles. Indonesia's electricity consumption grows at an average rate of 5.9%, from 190 TWh in 2010 to 240 TWh in 2019 (source: HEESI-2020).

In 2020, Indonesia household electrification reached 98% (MEMR 2020), which was connected to on-grid (large power plants) and off-grid electricity (smaller plants, mostly renewables). It is targeted that in the future all households will have electricity access through grid and non-grid as well as roof-top solar PV.

Based on past experience, the demand growth of electricity will be around 5% per year. The need for new capacity, replacement, and transmission expansion will be in line with the demand growth. At present, power generation is mainly fuelled by coal, while other power plants use gas, hydropower, and geothermal. It is expected that in 2050 the power sector will practically be decarbonized through: (i) utilization of renewables (hydro, geothermal, solar, wind, biomass) on a massive scale; (ii) most coal powerplants are equipped with CCS/CCUS; and (iii) biomass power plants are connected to CCS (Biomass Energy with Carbon Capture and Storage or BECCS).

Since Indonesia is an archipelago, the power system will be developed in the form of distributed power, instead of a large centralized system. Power systems with various types of power plants and different degrees of intermittency will have to cope with grid stability. Therefore, the power sector will require reliable technology and dispatch management that ensure electricity grid stability. Given that BECCS is expected to play a significant role in GHG mitigation of the power sector, a large amount of solid biomass supply for the BECCS needs to be prepared and developed; therefore, an integrated land use planning is crucial to ensure sustainable feedstock supply of biofuel and wood biomass for BECCS.

The power situation in 2050 under DDS is envisaged to be as follows:

- Power generation mix are: renewables (43%), coal (38%), natural gas (10%) and BECCS (8%).
- The renewables include hydro, geothermal, solar PV, biomass, biofuel, and wind.
- Around 76% of the coal power plant are equipped with CCS to achieve zero emissions in coal power plants.
- The installed capacity of renewable power generation mix is solar PV 113 GW, hydro 68 GW, geothermal 23 GW, wind power 17 GW, biomass 13 GW, biofuel 14 GW, and BECCS 23 GW with negative emissions.
- The supply availability of some renewable power plants is intermittent, and therefore, in order to have a reliable supply system, it will require integration with a continuous stable power supply system (baseload) such as coal power plants.
- The carbon intensity of power generation: 104-gram CO_2/kWh.
- Increasing development of off-grid and micro-grid.
- Due to a significant portion of intermittent renewable (solar and wind) will be deployed in the future, it will require the development of a smart grid that can handle large supply intermittency.
- A power plant with 100% renewable energy in remote areas will need Smart Micro Grid.

Transport:

In 2010 the metropolitan population accounts for 18% of the total population and is projected to reach around 25% in 2050 with increased population density in city centres and urban peripheries.

The type of land use in old town areas of metropolitan cities can be categorized as mixed land use where residential development, shops, employment community, and recreation facilities, parks, and open space are located close to each other. However, the recent development of areas in metropolitan can be categorized as specialized land use, where the industrial area is located outside the cities and new housing is built at the periphery of cities. In non-metropolitan cities, the land use type can be categorized as mixed land use. Previous spatial distribution of population did not consider transport network. Recently, site selection for new housing complex especially in metropolitan cities begins to consider the development of transport networks such as BRT, LRT, dedicated lane for buses, and inter-modality. Current transport infrastructure development focuses on motorized transport systems. Sociocultural practices, lifestyles, and social status affect transport. Transport infrastructure development has focused on motorized transport systems. In the future, the majority of the population will need to use public transport due to overloaded traffic by excessive use of private vehicles. Information and Communication Technology (ICT) development will encourage tele-activity and eventually lessen personal transport load in metropolitan as well as in non-metropolitan cities. Carpooling which has been partially practiced recently in metropolitan cities will continue to be implemented, driven by needs such as avoiding traffic jams.

The transport sector in the future is envisaged to drastically change, with the passenger transport mode being mostly mass public transport (buses, MRT, LRT) in metropolitan, buses in smaller cities, trains and big buses for inter-city transport, and air transport for between metropolitan and inter-island (ships and ferries). At the moment, freight transport relies on train for the inter-city trips, trucks/trailers, air, and ships for inter-island cargoes, as well as small trucks in cities.

The main energy sources for transport are biofuels, oil fuels, and electricity. Mitigation target in transport will be achieved by: (i) electrification of transport; (ii) supplying more biofuels for diesel substitute (fatty acid methyl ester and bio-hydrocarbon or green diesel), and (iii) gasoline substitute (bioethanol and CPO-based gasoline). For the past 10 years, the government has introduced biofuels made from CPO, which is blended with petroleum diesel and is called B20 (20% biodiesel plus 80% petroleum diesel).

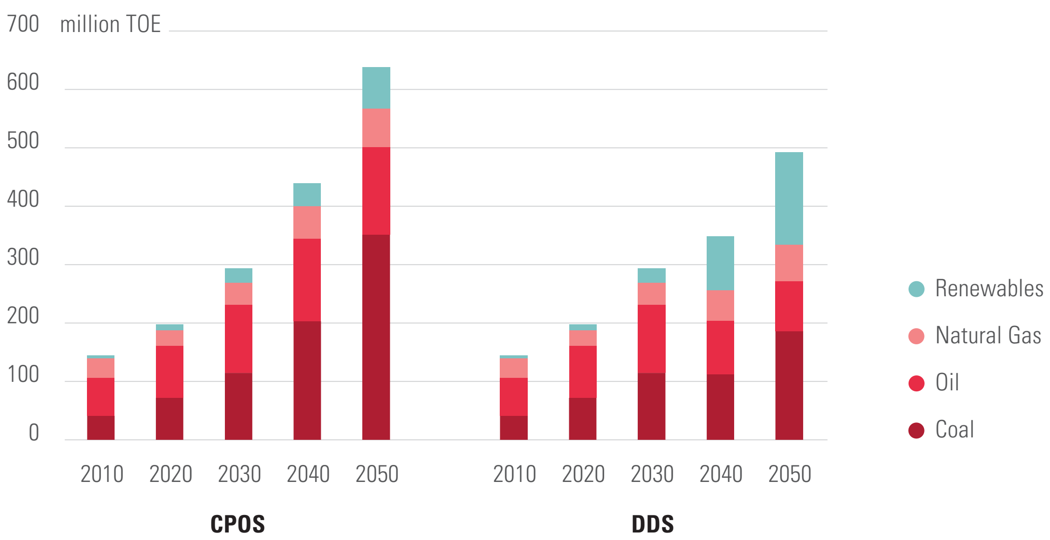
It is envisaged that the Indonesian transport situation in 2050 under DDS will be as follows:

- Transport distance of non-constrained transport (leisure, social, or family visits) in metropolitan is around 10 km.
- The travel distance of constrained transport (home-to-work/school) is around 40 km (in Jakarta).
- Some fraction of the workforces are working from home (teleworking) by opening businesses at their homes such as small shops, maintenance, and repair services, and restaurants.
- The breakdown of transport energy in 2050 are biofuels (52%), oil fuels (30%), electric vehicles (14%), and natural gas (4%). The biofuel (CPO-based) program is considered successful and will be continued to 2050 by supplying biofuel with higher biodiesel proportions (B30, B40, B50), which will be produced from sustainable sources.
- "Mobility as a service" will continue to grow.
- Household expenditure for transport is around 20% of total household spending.
- Choice of the mode of transport is affected by cost, comfort level, and social status.
- Many cities are connected by inter-city trains, especially in Java. The existing plan shows that 3,200 km of train tracks will be built to serve transport in Sumatra, Java, Kalimantan, and Sulawesi.

Primary Energy Supply:

The types of primary energy used in Indonesia are coal, oil fuels, natural gas, and renewables (hydropower, geothermal, solar, wind and bioenergy). Coal and natural gas are also used as final energy in industry, natural gas is also used as final energy in residential and commercial. It is estimated that from 2010 to 2050, the primary energy supply will grow, on average, around 3% per year. The projections of primary energy by types of energy for the 3 scenarios are presented in **Figure 3**. The Figure shows that CPOS gives the largest energy supply (due to the largest energy demand), which indicates that current policy will not lead to efficient energy systems. The DDS has a lower energy supply due to lower energy demand resulted from energy efficiency measures in end users.

Figure 3. Projection of primary energy supply under CPOS and DDS



The scenario that will result in the lowest primary energy supply is the DDS. **Figure 3** shows all energy types will continue to increase until 2050 except for oil. The share of oil will become the lowest in 2050. Under DDS, a notable change is projected to occur in 2050 where the share of renewable will become the highest in the energy supply. **Figure 3** also indicates that even until 2050, the role of coal in the energy supply will remain significant, especially in the power sub-sector which will be equipped with carbon capture and storage (CCS) systems.

Final Energy Demand:

The projection of by-type final energy demand for the 2 scenarios is presented in **Figure 4**, which indicates that there will be a significant change toward 2050 i.e., electricity is projected to be the most dominant type of energy.

Figure 5, which shows the projection of final energy demand by the consuming sectors, indicates that the distribution of the sectoral energy consumption in 2050 will remain the same as that in 2010 and the share of commercial and residential consumption significantly increase in 2050 due to the increasing role of the commercial sector in the economy and increase of people welfare.

Electric power generation and grid emission factor

The projection of the power generation mix and the associated emission factor of electricity are shown in **Figure 6**, which shows that electricity generation will increase significantly as a result of economic development, people welfare, and population growth. From 2010 to 2050, electricity generation will increase on average 5.5% per year, which is about the same as the average economic growth. This may be the result of electrification of end-users where people prefer electricity than combustion energy systems, also because of the development of a commercial sector where its energy consumption is mostly in the form of electricity.

Figure 6 shows a significant difference in the power generation mix in the two scenarios: CPOS will rely primarily on coal, while the DDS is more diversified, as DDS has more coal power plant equipped with CCS/ CCUS and renewables, including BECCS in 2050. Under DDS, where the share of CCS is significant, the resulted emission factor will be significantly lower than the other scenarios. In 2050, the emission factor of CPOS and DDS are 502 and 104 gram CO_2 per KWh respectively.

Figure 4. Projection of final energy demand by fuel type under CPOS and DDS scenarios

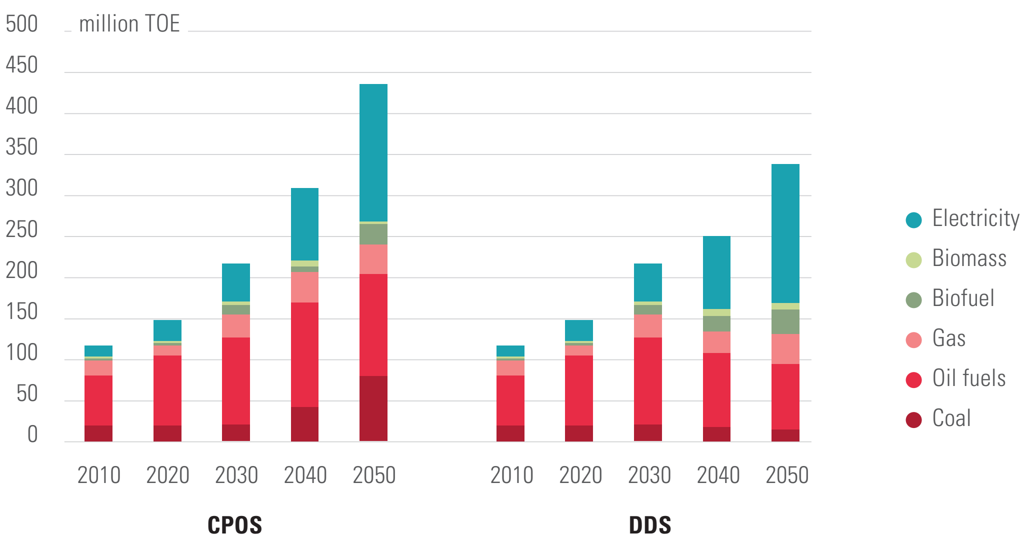


Figure 5. Projection of final energy demand by consuming sector under CPOS and DDS scenarios

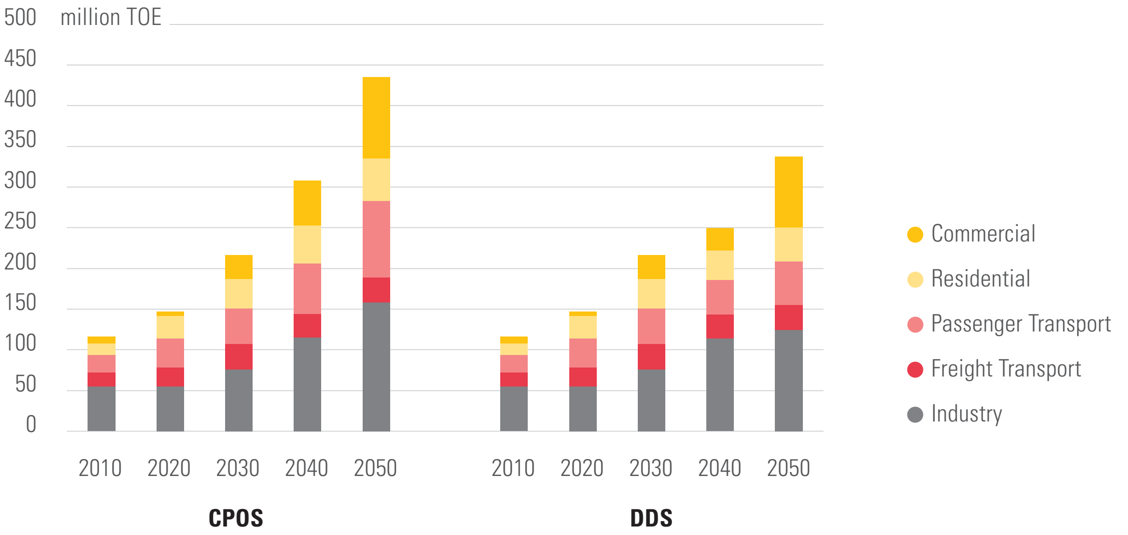
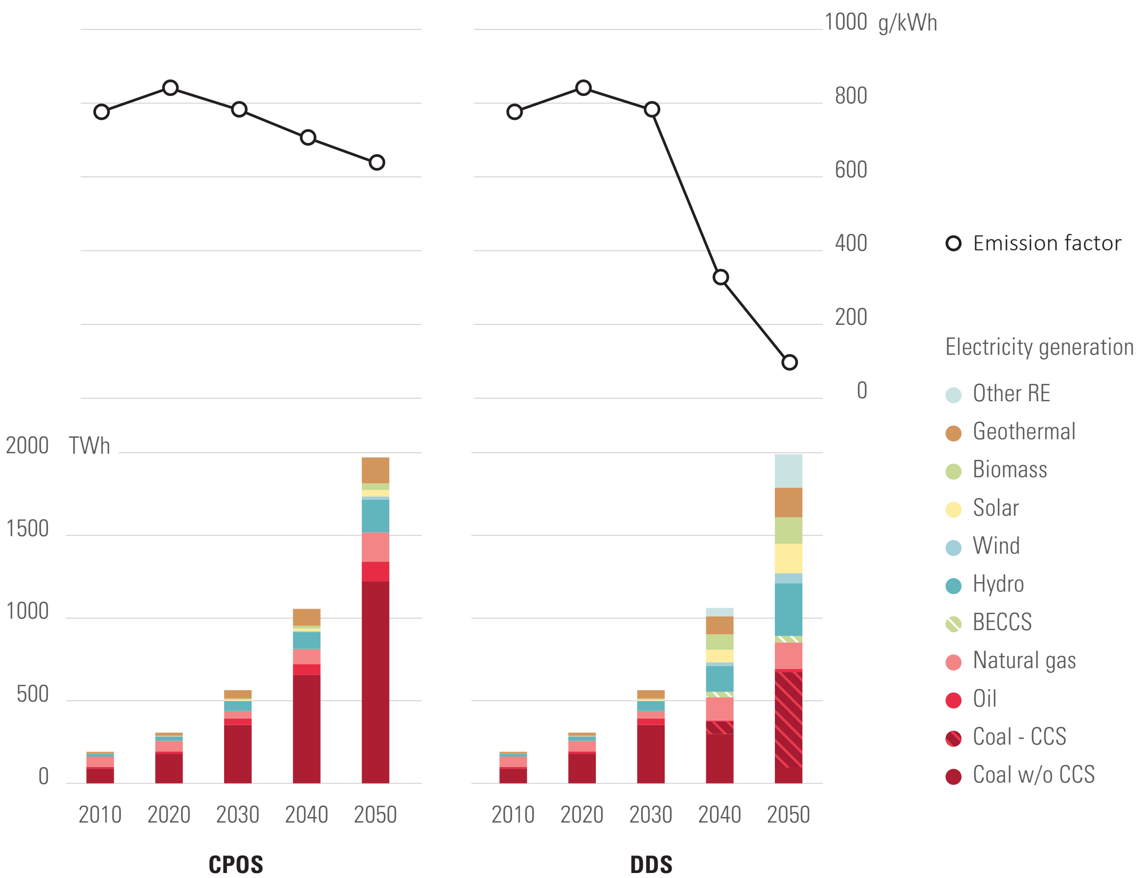


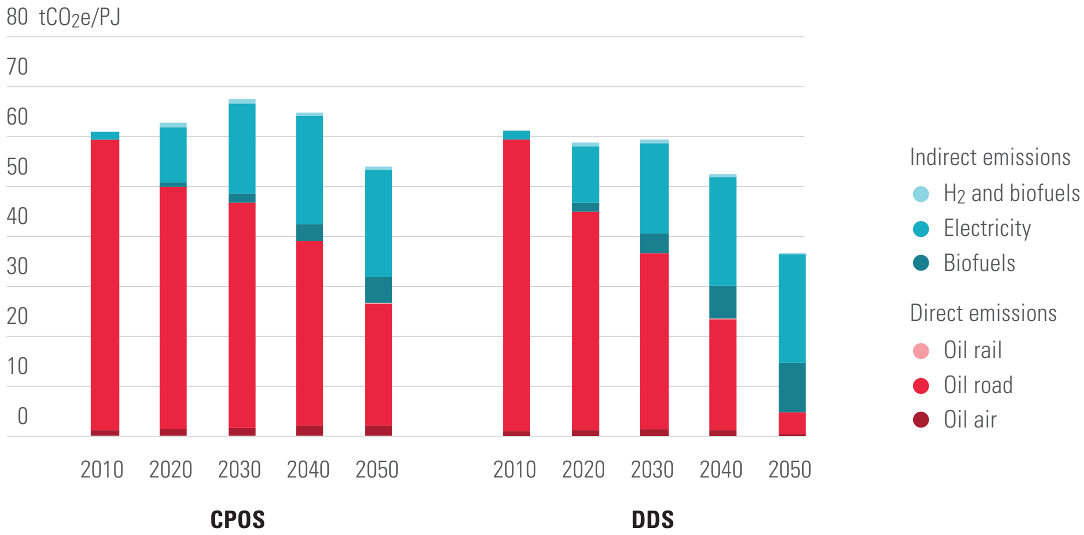
Figure 6. Projection of the power generation mix and grid emission factor under CPOS and DDS scenarios



Emissions.
Under the CPOS scenario, total emissions from passenger transport consistently decrease and reach 32 $MtCO_2e$ emissions in 2050. Under the DDS scenario, total emissions reach 15 $MtCO_2e$ in 2050 (**Figure 7**).

Under the CPOS scenario, total emissions from the energy sector consistently increase and reach 3,170 $MtCO_2e$ emissions in 2050. Under the DDS scenario, total emissions reach their peak in 2030: 1,274 $MtCO_2e$. After the peak period, emissions start to decrease and reach 720 $MtCO_2e$ in 2050.

Figure 7. Emission (CO2) from passenger transport under CPOS and DDS scenarios



PART 2: KEY POLICY LESSONS

PRIORITY SHORT-TERM POLICIES AND ACTIONS

Aiming for net-zero emissions under the DDS pathways requires breakthrough policies transformation and growing enablers to ensure policy implementation. The factors that make the difference between CPOS and DDS in the energy and transport sector mainly include the coal phase-out direction and the use of biofuels.

Coal use in power generation had been dominant in the past 4 decades. In order to alter the upward trajectory of GHG emissions, it is critical to phase down or phase out coal power. Short-term policies and actions in support of this objective are needed otherwise there will be a lock-in in coal power; and in the long run it would be difficult to obtain economic and social justification to stop the lock-in plants for phasing out coal as it would be expensive.

Fortunately, PLN (Indonesian national electric power utility) has moved toward the coal phase-out direction. It will retire some existing coal power plants beginning 2025. There will be no new coal power contract after 2025. Some that are already on schedule will remain on stream until 2028. Coal power retirement staging based on the coal technology type and age is already scheduled. The phase-out will begin with subcritical technology (2025-2035), followed by supercritical technology (2040-2045), and then ultra-supercritical (2045-2055).

The coal complete phase-out is expected to occur in 2055. Substitutes for coal power are gas and renewables. Massive development will occur in solar power. Solar PV plus the battery is expected to serve as baseload power. Another non-fossil power that will be developed is nuclear, which is expected to begin on stream in 2040. PLN targets to achieve carbon neutrality in 2060. According to the DDS scenario, other important mitigation actions are the deployment of CCS in coal power plants and biomass power plants (BECCS). Short-term priority policy actions in support of these mitigation actions, such as capacity building policy for CCS technology development, need to be designed and implemented. Other short-term policy actions that are critical in support of decarbonization are incentives for non-utility renewable power such as solar rooftops. An example of an incentive is to provide an attractive feed-in tariff and power purchase guaranty.

Other large coal use also occurs in some industries such as cement, pulp and paper, iron-steel, and petrochemicals. These industries are known to be hard-to-decarbonize industries. Some international pressures for decarbonization through carbon-footprint criteria may be applied for some export-oriented industries such as pulp and paper. The cement industry primarily supplies the domestic market and cannot be encouraged to decarbonize by carbon-footprint mechanism. Besides, there is a limited option for cement decarbonization technologies.

In the transport sector, the main component of decarbonization is through massive substitution of oil fuels by biofuels. Critical short-term policy action that is needed in biofuel development is the incentives to biofuel production through special funding for biofuel feed development especially replanting and biofuel production technology.

Reaching for AFOLU net-sink demands a massive-scale paradigm change to perceive forest and a carbon-rich ecosystem as part of a nature-based solution. In the AFOLU sector, Indonesia's land-based policies have been growing remarkably and aligned with Indonesia's vision for the DDS scenario. The only thing that distinguishes the existing policies and the ambitious DDS scenario is the implementation rate of the policies, which includes all the enablers and implementation schemes.

Transformative policies required for Indonesia's AFOLU sector include social forestry, multi permit scheme, peatland moratorium policies, and forest conversion ban, oil palm domestic certification, and increased agricultural land-use efficiency.

Ministerial Law of MoEF No.9/2021 and No.83/2016 has stated social forestry as a scheme aimed to allocate forest area legally for the community and to provide an access to incentive and/or capacity building programs to increase land productivity. By regulation, cultivated land inside forest areas is not allowed and is considered an illegal area and illegible to receive government support (e.g., incentive). Under this policy, not only tenurial issues can be addressed but potential income for the community from non-timber forest products (e.g., medicinal plants, forest honey, etc.) can also be increased. At present, the effectiveness of the policy implementation is still low. Based on the progress of the implementation of the social forestry program, by 2030 community access to the social forestry program may reach only 1.4 Mha (12%) and by 2045 it will reach 3.4 Mha (28%). However, under the deep decarbonization scenarios, the social forestry and TORA program should be fully implemented by 2030. One is by simplifying the administration process and pairing up the scheme with the country's land rehabilitation agenda, to ensure support from the government permanent nursery. In addition, referring to Government Regulation No.26/2020, the social forestry program could receive support from the regional government and other sources (including the private sector). Increasing the participation of the NPA's actors in this scheme will eventually lower the burden of mitigation cost from the state budget.

MoEF has established a multi-permit scheme that allows any entities to have multiple business activities and partner with communities, particularly in the disputed land (under profit-sharing mechanism), to establish mixed farming. The multi-permit scheme also allows the utilization of natural forest inside concession areas for non-timber forest products (NTFP) and environmental services-based business. With multiple benefits accrued, further, the implementation of the scheme should be used as part of the sustainability certification standard. As this scheme is relatively new, there is a growing interest from the private sector to join the scheme; however, only if the incentive from the environmental services benefits is assured. Along with the domestic carbon market that is currently prepared by the GoI, the multi-permit scheme is potentially implemented by all forestry concessionaire owners.

Peatland moratorium policy (Presidential Instruction No.5/2019) is intended to protect peatland forests subject to conversion and degradation, and under Government Regulation No.104/2015, the conversion of productive production forest for development purposes is banned, except for a region with no unproductive lands available. These policies are central to forest protection in the DDS scenario with cumulative deforested area amounted to 6.8 Mha until 2050.

Degradation of natural forest under the concession area could be minimized by mandatory issuance of certification system through sustainable logging technique. At present, only 76% of the concessionaire have received good forest certification. To support the forest degradation quota in the DDS scenario, the certification should become mandatory and be supported by incentive and disincentive schemes. Regarding the certification scheme, GoI has also established Indonesia Sustainable Palm Oil (ISPO) as an oil palm domestic certification scheme. To date, ISPO has been improving along with recently published Presidential Regulation No.44/2020 which was ratified in March 2020. The regulation is replacing the previous Ministerial Law of Agriculture No.11/2015, with the main amendment on a more independent ISPO process compared to the previous process, monitoring process from an independent party, public participation in the certification, and mandatory for all oil palm plantation with a 5-year grace period. Under a more strict monitoring process, it is expected that ISPO certification could assure forest protection under the oil palm concession area.

Mitigation activity in the agriculture sector is in indirect synergy with the FOLU sector. The success of the implementation of FOLU mitigation depends on the agricultural conditions, where high planting intensity and improved productivity with support from advanced technology will reduce pressure on the forest and avoid forest conversion. Improved agricultural technology is the key to this case. Adoption of technology by farmers should not merely rely on government support (input subsidies, credit program) but should also mobilize other sources of support including access to bank or non-banking financial institutions-NBFI (cooperatives, warehouse receipts systems, financial technology companies). In addition, improving agricultural human resources by the revitalization of institutional and agricultural extension institutions, development of the agricultural vocational school is important to ensure technology adoption in the future.

INVESTMENTS PATTERNS

Compared to the CPOS scenario, there will be some changes needed in investment patterns for DDS. The shift of development trend in the power sector especially PLN, which is moving away from coal power, is partly driven by consideration that financing for dirty power plants would be very difficult. Although investment may be made from domestic funds, PLN is aware that domestic financial institutions are not independent of international ones. It is expected that under Paris compatible pathways, international pressure for green financing is not only by preventing/disincentivizing carbon-intensive investments but also to provide incentives for green financing- made it easier to obtain loan/financing for low carbon power plant investments. A similar change of investment pattern will also occur in sectors such as transport (more investment in biofuel and EV) and industry. Investment in EV components, especially batteries, is expected to increase in the future as the government continues to pursue higher local content in many development sectors.

Some policies were taken by the government of Indonesia to increase the diversification of finance sources from both national and international–public and private sources. Fiscal policy as a financial strategy to meet the emission reduction commitment has been strongly progressed in Indonesia. The main fiscal instrument that potentially fills the budget demand for the DDS scenario is carbon pricing (e.g., emission trading, carbon tax), ecological fiscal transfer (EFT), and payment for environmental services (PES).

EFT is a grant mechanism, transferred from higher-level government to the lower-level government with the inclusion of ecological variables (e.g., forest area). The EFT has been applied by numerous jurisdictions (e.g., North Kalimantan Province, Jayapura City). Contrary to the other two fiscal instruments, the PES instrument existed before; however, the instrument has been applied commonly by NGOs and private sectors. Under Government regulation (PP) No. 46/2017 concerning Environmental Economic Instruments, PES is expected to be mainstreamed and applied by the local government.

For the public investment strategy, the Ministry of Finance has launched Green Planning and Budgeting Strategy for Sustainable Development, specifically aimed at the key sectors to low-carbon transition (e.g., renewable energy, etc.). In addition, GoI has also issued Green Bonds and Green Sukuk as innovative financing to funds green and SDG-related projects.

Indonesia's Financial Service Authority (OJK) holds a key role in the development and implementation process of innovative financing for the climate. Currently, OJK has established the Roadmap for Sustainable Finance in Indonesia, Guidance for Green Building, and OJK regulations for sustainable finance implementation (e.g., green bonds, banking supervision to support low carbon emission vehicles).

Furthermore, Indonesia continues to mobilize international financial sources through bilateral, regional, and multilateral channels, including result-based payment for REDD+ under the Paris Agreement, grants, and other potential sources and mechanisms.

SYNERGIES AND TRADE-OFFS WITH COUNTRY NON-CLIMATE OBJECTIVES

There are several synergies between climate objectives and non-climate objectives such as SDG. Carbon pricing policies in energy sectors (power, industry, transport) will drive the use of greener fuels, moving away from coal and oil fuels, which will lead to cleaner air. In addition, the application of a green building policy will lead to a more efficient energy system (long-term economic benefit).

For the bioenergy case, palm oil fund collection and management by the Agency for the Management of Palm Oil Mill Funds (BPDPKS) will support research on biofuel production technology and at the same time provide support for replanting of palm oil plantations. This gives financial incentives for plantation companies as well as farmers.

The development of solar power could drive domestic solar industries (improve investment and employment) especially when international enablers help provide funding and technology transfer schemes. However, besides synergies, there is also a possibility of a trade-off between climate objectives and environmental objectives. For example, EV with battery and renewable power sources will be good for climate and employment creation but this development may create problems with mining wastes and smelters associated with solar cell production and metals (Li, Co, Ni) for battery production and also the possibility of waste handling problems of used battery disposal. To ensure the synergy of the DDS ambition, Indonesia's vision toward net-zero needs to be mainstreamed to the local development planning. To enable the top-down implementation of the climate commitment at the local level, local governments are mandated to conduct Strategic Environmental Assessment (SEA) to ensure a sustainable development plan under Governmental Regulation No.46/2016. This provides guidance on the integrated, comprehensive, spatially explicit land-use planning at the national and sub-national level aiming at food, water, and energy security based on sound ecosystem management. The environmental benefits as captured from the SEA could bridge the regional government to receive additional funds from the ecological fiscal transfer (EFT) scheme, to improve local community welfare.

KEY INTERNATIONAL ENABLERS AND ACCELERATORS OF DOMESTIC TRANSITIONS

Key international enablers that will assist the decarbonization pathways include the application of emission standards/carbon footprint to internationally traded products. Such standards are expected to drive producers to manufacture products with a lower carbon footprint.

While CCS holds an important role in cutting emissions from the energy sector, CCS is very expensive and when implemented will require significant additional investment. For such cases, an international enabler in the form of financial support/low-interest loan is needed.

PV development under the Paris-compatible pathway will involve installation up to 100 GW in 2050. Therefore, it is reasonable to expect that a local manufacturer of solar PV cell and support systems would be required. To accelerate local manufacturing capacity, international enablers in the form of investment financing and technology transfer would be required. To be more specific, the expected technology transfer is in the area of efficient solar cell manufacturing.

At the international level, a fair-trade deal is crucial to maintain the country's supply of the exported agricultural product while fulfilling partner countries' demand for sustainable commodities. It means that agricultural production for the international market should not cause deforestation through Indirect Land Use Change (ILUC). International financial support is also important for Indonesia's forestry to achieve the net-sink target with less cost burden on the state budget. In addition, international cooperation on low-carbon transition research with a research centre and think tanks is also needed to support the evidence-based policy in the country.

International enablers (carbon footprint requirement, investment financing, technology transfer), besides providing support to the achievement of decarbonization objectives, will also positively impact the Indonesian socio-economy (GDP growth, employment creation, trade balance, improved environment quality).

SOUTH AFRICA

Hilton Trollip,
Honorary Research Associate,
Energy Systems Research Group,
Department of Chemical Engineering,
University of Cape Town.

Thanks to Bryce McCall and Fadiel Ahjum at the Energy Systems Research Group (ESRG) at the University of Cape Town as core team members of SA-DDP for providing quantitative analysis for this work. The first step of our analysis, to identify what is possible and important, is based on the ESRG modelling work.

The techno-economic features of emissions pathways have been modelled to show how a low carbon pathway might be approached by 2050 and to inform policy analysis to serve a short-term action agenda[1]
The pathways rely on highly detailed modelling to assess economic sectors, industries and activities relevant to CO_2[2] emissions and to highlight areas for priority mitigation action and policy attention.

To be meaningful, long-term techno-economically plausible ambition requires feasible short-term action
An inspiring and effective action agenda requires clarity about what is important, which then informs consequent prioritisation and pragmatic action. Techno-economic modelling shows what technical actions are necessary in an ideal simulated world, and what actions to avoid, and the timing of the actions, in order to move onto, and then stay on, the long-term pathways.

Structure of this report
Groups of key techno-economic features of long-term pathways are presented for time periods and sectors. On the basis of these, priority techno-economic measures are identified. Then, policy analysis incorporates political and institutional factors to come up with recommendations for feasible strategic short-term policy actions to implement the techno-economic measures within the real world of competing priorities and interests.

1 This is a stand-alone paper but has been produced in conjunction with three other papers: "Policy Lessons Decarbonization policy implementation in South Africa", "South Africa Climate Mitigation Policy Ambition" and "South Africa – DDP Sectoral Deep Dives: Green Iron.
2 It also covers quantitative analysis for all other significant GHG emissions to serve the processes of prioritization and an action agenda. All emissions quantities, unless otherwise specified, refer to CO_2.

PART 1: SCENARIO RESULTS

CONSTRUCTING THE SCENARIOS

Two scenarios were modelled using the SATIMGE[3] model: the current policy scenario (CPS) and the deep decarbonisation scenario (DDS)

The CPS and DDS use the same underlying assumptions about economic structure and growth. For mitigation policy, the CPS incorporates existing policies-and-measures (PAMS). For DDS, an 8GtCO_2eq cumulative emissions cap[4] is imposed with SATIMGE to identify least-cost options and associated energy system, economic and emissions pathways.

Optimistic[5] general economic policy scenarios are modelled as a context for mitigation

Optimistic scenarios rely on successes in policy reforms to address structural economic issues to reverse a decade-long increasingly severe poverty and unemployment crisis. They align with similar optimistic scenarios in a number of official definitive papers from the South African Reserve Bank and National Treasury, notably the National Treasury paper "*Economic transformation, inclusive growth, and competitiveness: Towards an economic strategy for South Africa*" (National Treasury, 2019). The Covid-19 pandemic introduced severe short-term negative impacts which are factored in[6].

Scenarios use mid-level UN population forecast of 75m in 2050, a 25% increase over 30 years. Urban/rural ratio goes from 66:34 to 80:20

Economic growth and the evolution of economic structure are endogenously modelled

Along with population growth, assumptions regarding three core drivers of economic growth, namely total factor productivity, foreign investment and labour supply growth are used in the SATIMGE model to endogenously simulate growth and evolution in economic structure.

GDP increases 221% and GDP/cap by 174%

GDP increases accelerate: 22%, 31% and 38% in 2020-2030, 2030-2040 and 2040-2050. Income inequity decreases and poverty is substantially reduced as the 'low income' household category decreases from 48% to 28% from 2020-2050.

Conservative assumptions[7] are rigorously adopted in modelling decarbonisation transitions in core parameters such as cost evolutions of low-emissions technologies.

The intention in choosing the conservative end in ranges of parameters, especially those projecting far into the future, is to avoid skewing the essential features of the decarbonisation transformations towards making them more plausible than the level of uncertainty suggests. Validating assumptions on core parameters and adjusting where appropriate has been a key focus of policy analysis and stakeholder engagements to inform modelling.

The core global-scale exogenous parameters include costs of electricity generation technologies, energy storage; vehicle drive-train and basic material industry process technologies

3 SATIMGE: energy systems model linked to a detailed economic model developed at the Energy Systems Research Group, University of Cape Town. Detailed bottom-up modelling (SATIM) of the energy system (including all economic and consumption activities is done linked to an economy-wide computable general equilibrium (CGE)

4 An 8Gt cumulative emissions cap would imply significant progress on the South African 2015 NDC. Appropriate levels for the next iteration of the NDC are subject to official processes that this DDP analysis seeks to inform.

5 A full range of scenarios would include scenarios covering (not completely unlikely) exogenous general economic policy conditions causing ongoing economic stagnation etc.

6 As of end of 2020 – the pandemic has had further substantial negative impacts and continues to (22 September 2021)

7 The modelling requires assumptions to be made on key numbers such as the cost of a battery electric vehicle in 2040, or the cost of an industrial process not yet fully commercialized, such as hydrogen-reduced direct reduction iron. Much expert opinion and the best available science are employed. The modelling aims at being as open source as practicable and is backed up by numerous public domain reports.

RECENT ECONOMIC HISTORY AND CURRENT SITUATION

The economy is characterised by a decade of economic stagnation, falling investment and de-industrialisation, increasing unemployment, now at 34.4%, increased poverty and inequity and increasing social instability
The South African National Planning Commission[8], stated in December 2020 that: "*Over the past decade, there have been clear signs of danger that South Africa could veer towards a downward spiral. … We are in a vicious circle ensuing from a toxic confluence of factors, namely falling investment, further diminishing tax revenues, and debt service costs that crowd out all other spending and thus constrain resources for investment in development. The results are falling employment and rising poverty and inequality.*"

The worsening socio-economic situation, exacerbated by the Covid-19 pandemic, has recently been further complicated by the July 2021 insurrection.
Poverty and unemployment provide a fertile ground for social and political instability. The insurrection started in conjunction with the arrest of former president Zuma. Three-hundred and thirty-six (336) people were killed and there was widespread violence, destruction, and economic damage with key transport routes closed and infrastructure damage. This exacerbates the economic *'vicious cycle'*.

8 NPC (2020) Economic Progress towards the National Development Plan's Vision 2030. Executive Summary. South African National Planning Commission (NPC). December 2020. Available at: www.nationalplanningcommission.org.za/publications_reports.

An economically crippling electricity shortage has been one of the main causes of economic decline
This is detailed in the electricity section below. From an economy-wide perspective, international policy enablers are relevant to supporting emissions mitigation policy which is also the most effective measure to simultaneously address the electricity shortage.

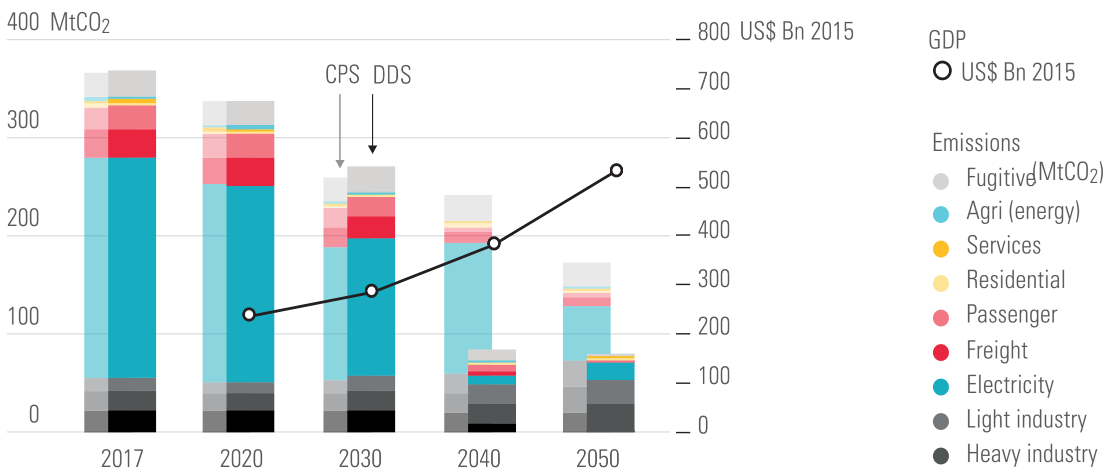
TECHNO-ECONOMIC KEY FEATURES OF THE SCENARIOS

2020-2050: Economy-wide scenario

Substantial economy-wide decarbonisation of the South African economy from 377 to 78Mt[9] CO_2 is techno-economically possible with little impact[10] on GDP
The most striking feature comparing the scenarios for overall emissions mitigation policy over the long term is that GDP is very similar for the CPS and DDS. This means that, to reach 78Mt of residual emissions in the aggregate, there is no aggregate GDP net loss to the economy compared with the CPS.

9 All emissions numbers stated in Mt refer to annual emissions (i.e. Mtpa) unless otherwise specified. This does not include non-CO_2 emissions – see section on industry for details on these. Unless specified, this report only considers decarbonisation. This includes CO_2 as a process emission.
10 Within the resolution** of input data and assumptions and the modeling the differences between CPS and DDS GDP results are very small: smaller than the resolution – in 2050 DDS GDP is 1% less than CPS. It is 2% higher in 2030 and 1% lower in 2040..

Figure 1. GDP growth and emissions from energy for CPS and DDS



GDP is dominated by services, but minerals based industry and coal-generated electricity remain tightly inter-linked with the economy and contribute most emissions. Industry accounts for more than 50% of electricity demand. Over the 2020-2050 period industrial GDP contribution decreases from 26%-22%. This could vary widely depending on economic and industrial policy – see later.

In the DDS, electricity generation (200 to 16Mt) and transport (51 to 3Mt) decarbonise almost completely. Industry CO_2 emissions increase (30 to 53Mt).

Residential and services emissions remain at a low ~5Mt.
Residential and commercial buildings account for 45% of electricity demand but because electricity decarbonises completely their induced emissions are close to zero by 2050.

The differences in emissions reduction between CPS and DDS are striking, between overall decadal rates and between sectors.
Emissions reduce about 20% for both scenarios over 2020-2030, but then reductions in CPS stall and DDS has a huge 70% reduction from 2030-2040. Then DDS stalls from 2040-2050.

These differences are stark pointers to where (in which sectors) and when policy action is necessary and also to the challenges that have to be addressed by effective decarbonisation policy.

Decarbonisation of electricity is important in its own right but also a central requirement for decarbonisation of all other sectors

It is crucial that the DDS is viewed not only as an emissions pathway but also as a socio-economic development opportunity
This is both from the perspective of social and economic justice but also from the perspective of the minimum progress in addressing poverty and underemployment being necessary to sustain the political stability consistent with South Africa's other transitions: the democratic transition and a transition from undue impacts of an extractive[11] economy which has historically been and still is a main cause of gross inequity and poverty. These transitions are intertwined.

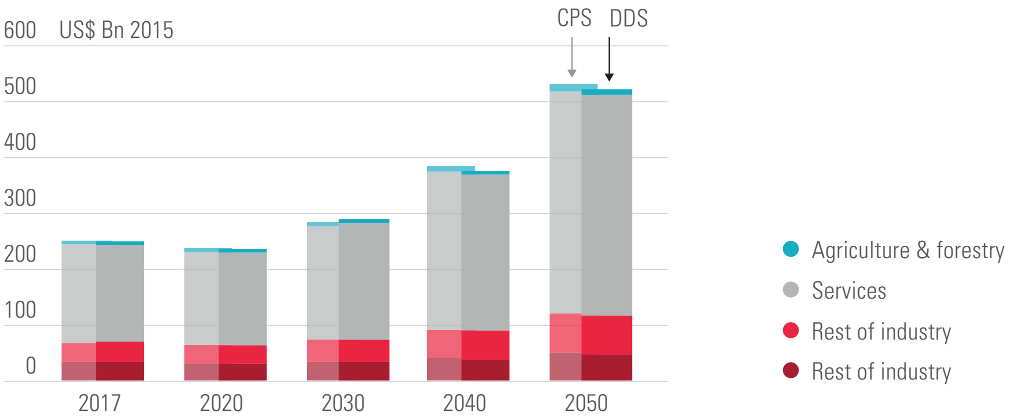
2020-2030 Decade

Both CPS and DDS emissions reductions of about 20% over 2020-2030 are very similar. Thus from 2020-2030, the DDS is basically a least-cost pathway. CPS requires an additional R170Bn capital investment costs compared to DDS

Costs of renewable energy electricity generation drive reductions in electricity emissions from 200-141Mt (59Mt) which is 90% of the total economy-wide emissions reductions of 67Mt over 2020-2030.

11 This is meant in the sense of an economy based on extractive institutions, not the physical extraction of minerals – see Acemoglu, D. and Robinson, J. A. (2012) Why Nations Fail: The Origins of Power, Prosperity and Poverty. 1st edn. New York: Crown. ;

Figure 2. Economic structure - GDP



For the CPS, electricity generation is specified by the officially mandated generation capacity expansion plan, the Integrated Resource Plan (IRP2019). Virtually the same electricity generation and emissions patterns result for the DDS.

Transport emissions also decrease 20%, from 51-41Mt (10Mt) but are a much smaller proportion of the total. Transport emissions reductions are driven by transport policy, mainly modal shift.

Possibly the most critical result in the techno-economic analysis is the urgent need to add wind and solar-PV generation as soon as is practicable to close a serious short-term supply gap and then to implement 20GW of renewable energy, at least, from 2021-2030 both as a least cost energy plan, regardless of emissions and to get onto the DDS. This result provides the focus on electricity for the main parts of this paper below.

2030-2040 Decade

The large difference (158Mt) of emissions reductions in the CPS and DDS pathways between 2030-2040 is one of the most notable features of South African decarbonisation.
CPS and DDS start at similar levels of ~265 but CPS hardly drops and DDS goes down to 83Mt, resulting in a huge difference of 158Mt by 2040. About 80% is due to electricity generation emissions reductions.

It is also notable that for DDS, significant additional mitigation costs are incurred over least-cost CPS. An additional capital investment of R400Bn is required for electricity over the period.

Most economy wide emissions reductions (130/158Mt) result from a shift to renewable energy electricity generation.
This requires substantial additional investments in renewable energy generation capacity. Existing coal power stations are run well below capacity, substituted by wind and solar-PV.

Transport decarbonization involves a shift to electric and hydrogen technologies which relies on decarbonization of electricity.

Passenger transport decarbonizes at the same rate in DDS as CPS mainly due to reductions in battery-electric vehicle costs.
Emissions reduce from 20 to 6Mt, a 75% reduction.

Freight transport emissions reduce from 20 to 9Mt in CPS vs. 20 to 9Mt in DDS, indicating no additional costs for mitigation in DDS.

The first successes in substantial industrial process emissions mitigation occur in this period, in zero-emissions iron production.

2040-2050 Decade

DDS emissions reductions stall in 2040, decreasing marginally from 83 to 78Mt in 2050. Mainly industrial emissions remain.

In 2040 there are 11Mt electricity, 21Mt heavy industry and 19Mt light industry emissions.
About half of this residual 83Mt could be affordably decarbonised with existing technologies, though at additional cost, leaving a residual of 40Mt, mainly in heavy industry processes.

Residential and services emissions.
These contribute less than 1% of total emissions in 2020 and 2050: a total of ~5Mt in 2050.

'Residual' emissions Policy – Not a current priority

There is high uncertainty over how the last 40Mt of heavy industry[12] emissions will be decarbonised.
But it is likely that solutions will be found in the coming thirty years and so the DDS can be viewed as approaching a net-zero 2050 target. While these 40Mt need attention, we don't allow that to divert our focus for this piece to serve a short-term action agenda.

12 This is with the current exception of iron and steel production which is decarbonised in the DDS

SOCIO-ECONOMIC FEATURES OF THE SCENARIOS

Distribution of costs and benefits

There has been considerable contestation around emissions mitigation policy and resistance to implementation.

Uneven distribution of costs and benefits would be associated with transition to renewable energy if not addressed by complimentary policy measures

While reaching 78Mt[13] has a neutral GDP effect on the overall economy there is a very uneven distribution of benefits and costs. Renewable energy generators and related equipment and services suppliers will benefit directly. Owners of coal-related assets including mineral rights, mines, and coal power stations will suffer very large (>ZAR trillions) direct losses. This creates large challenges. Some of these will be addressed in this chapter but problems such as the loss of coal-sales revenues to minerals rights holders, espcially when they have significant economic and political influence present difficult policy challenges.

There are also "indirect[14] " transition costs/impacts not captured in the model that pose policy challenges

Many workers will lose jobs in coal and related industries, and other industries such as motor vehicle manufacturing[15] and cannot simply take up the new jobs in (for example) renewable energy industries. This could be because of skills mismatches or because, for example, coal industries are concentrated in a few geographic areas and whole communities in these areas are dependent on coal workers and cannot simply move.

13 With pro-active policy intervention it could be positive

14 These costs are no less important for not having direct calculable impacts in quantified financial terms. The number of jobs lost can be calculated but the social costs of either transferring to a different industry or being unemployed, especially when whole communities are regions have large impacts are not easily quantifiable. However they are real and have social welfare, economic and political ramifications that need to be addressed in policies that implement the transition.

15 Some industries such as internal combustion engine (ICE) motor vehicle (MV) manufacturers may not be able to transition because of large capital costs and international competition and demand is expected to drop rapidly for their products.

Dedicated policies could have an additional and substantial positive impact on aggregate GDP and employment. If these are implemented they could assist with distribution of benefits and alleviating negative impacts

As mentioned above, economic growth was modelled endogenously in SATIMGE. Factor productivity[16] drives incremental growth. However, substantially higher growth driven exogenously is possible. Global decarbonisation will create demand for decarbonised commodities (such as hydrogen as a fuel), intermediate goods (such as zero-embodied emissions steel) and zero/low-embodied emissions final products. South Africa has a comparative advantage in its renewable energy resources, especially high insolation and land for solar-PV farms which could make these low/zero-embodied emissions commodities and goods competitive in export markets where there could be shortages of zero-emissions electricity and hence higher prices.

Thus, a central and foremost economy-wide policy challenge is to identify, acknowledge and assess the imbalances of distributional impacts across industries, sectors and stakeholders, to identify social costs, and then to find policy solutions to address these

This is necessary both from a social justice perspective and to facilitate necessary support to implement these policies. South Africa is a rights-based constitutional democracy and transitions of the magnitude involved in decarbonisation need to be designed and implemented according to principles of procedural justice involving those affected by the transitions in planning the transition and justice in outcomes, ensuring negative impacts are addressed and ensuring positive benefits are equitably distributed.

Income poverty

SATIMGE simulates income poverty via income distribution among three household income levels at national level: high, medium and low, with low-income indicating a poverty[17] category. SATIMGE has additional descriptions of detailed household energy

16 This is a core economic modeling parameter in the CGE model of SATIMCGE

17 Below certain household income thresholds a number of other household poverty indicators are highly likely although poverty measures are complex.

services which can also indicate poverty. Cooking and heating with coal, wood and paraffin are strong indicators. Most South African households are connected to electricity but affordability linked to low income leads to energy shortages and use of fuels with severe health and safety impacts.

There will be a substantial shift from 55% to 85% of households with affordable electrified energy services from the current situation of widespread energy poverty.

Given the core goals of decarbonisation and poverty eradication, this is an important indicator mainly because it shows that, at the aggregate level, decarbonisation can take place at the same time as reduction of income poverty. On their own, such aggregates are just an indicator and need to be integrated with other poverty reduction considerations. With the much lower proportion of low-income households (15%) by 2050, dedicated measures to alleviate income-effects on poverty become much more politically and economically feasible, such as dedicated energy assistance packages with the potential to eradicate energy poverty.

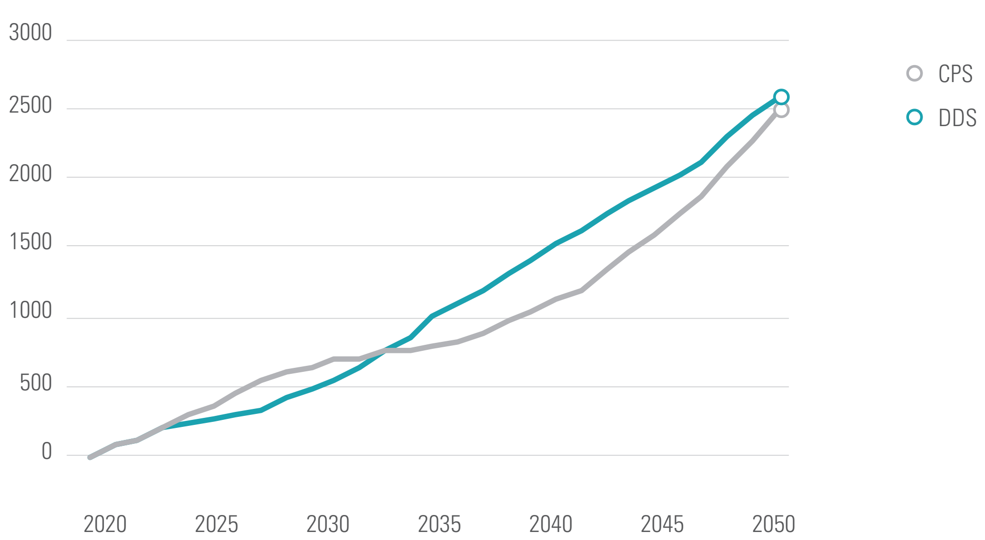
SECTOR-LEVEL RESULTS

Electricity

Overall electricity production, GDP and links to industry

In DDS scenario, electricity production increases from 217 to 380TWh (175%) in the 2020-2050 period, substantially less than the 221% GDP increase. This aligns with the services-dominated GDP increase and low level of industry decarbonisation via electrification; electricity only increases from 40 to 50% of energy usage and there is little improvement in energy intensity. Energy-intensive industry is by far the biggest user at about half of electricity demand, but its sectoral GDP only increases about 150%. The increase in total electricity production in the DDS is similar to CPS until 2030 and then only about 15% higher over the subsequent two decades. Industry remains largely un-decarbonised and if decarbonisation of these sectors is ultimately is via electrification (such as in Green Iron (GI) see industry section below), this will likely require substantial additional electricity to the current DDS. To achieve 8Gt the current DDS does not yet decarbonise most energy intensive industry either because it is too costly for thermal uses (swapping coal in boilers with electricity), or will rely on innovative industrial processes that have yet to be developed.

Figure 3. Cumulative electricity capital investment post 2021 in CPS and DDS [ZARm]



Physical transformations of electricity supply

The model-based analysis delivers an optimal least-cost pathway that involves a penetration of 20GW of renewable energy over 2020-30 for both CPS and DDS, but for both CPS and DDS this path is currently being disrupted and could be far from optimal in terms of broader economic considerations. The disruptions that have been underway for six years are the result of paralysis in electricity policy implementation and investment in new generation (see policy analysis section below). This will take at least a few years to 'correct' from when action begins. The disruptions are evidenced by an electricity shortage crisis, not mitigation policy. Because renewable energy is the largest part of a least cost and fastest solution this could likely speed-up emissions reductions through earlier substitution of coal generation because of poor coal plant performance. This could result in substantially more than 20GW of wind and PV being built. The reduction in electricity emissions in the DDS from 2020-2030 results from a generation system pathway which aligns with the current official IRP2019 generation expansion plan. This plan is based on least cost: emissions reduction was not an objective in formulating the plan. At the core of this plan is the addition of more than 20GW of PV and wind generation which will substitute coal-generation. Achieving the DDS mitigation pathway for electricity by 2030 therefore only requires existing policy to be implemented. In practice, however, the last decade has evidenced severe problems with implementing officially mandated policy.

It is imperative that at least 20GW of renewable energy generation are added by 2030. Its deployment should start as soon as possible and be done as fast as possible until the supply gap is filled. The core of a least-cost solution to an existing critical capacity shortage of between 4,000-8,000MW would be immediate rapid acceleration of wind and solar-PV additions to the grid. This is a no-regret techno-economic option. Neither the shortage nor this acceleration are modelled in the simulations underpinning CPS and DDS scenarios. While the most damaging effects of the shortage are managed black-outs, 'voluntary' curtailments of electricity-intensive industrial production, and running diesel-turbines, the record of the contribution of existing ~6GW of renewable energy generation shows that, despite this being variable and non-dispatchable, it has contributed substantially to reducing the intensity and periods of shortages on the national grid.

About 4,400MW of new coal generation is 'forced' into the DDS and CPS because it is in the current official IRP2019 generation expansion plan. From a purely techno-economic perspective, the IRP2019 report states that new coal generation is not part of a least-system-cost solution, even with no emissions constraint in the 2020-2030 period. Detailed studies[18] confirm this. From a broader economic perspective, two recent attempts to establish new coal power stations in South Africa, even with very favourable government support, failed to find financial backing[19]. Eskom's existing fleet of largely old coal-fired power stations is operating at very low and declining energy availability factors (EAFs). It is highly plausible that the power shortage could worsen. The situation has been deteriorating and EAFs are far lower than the SATIMCGE assumptions use in CPS and DDS scenarios. Altogether, it is becoming increasingly likely that the new coal capacity will not materialise. If so, on a least-cost pathway, a substantial increase in wind and solar-PV will be required.

Least-cost electricity generation from 2030-2040 without an emissions constraint (CPS), results in electricity emissions levelling out – coal electricity production stays constant and the increase in demand is met mainly by solar-PV[20]. However, with the economy-wide 8Gt emissions constraint (DDS), there is a profound shift with coal generation phasing out completely. Previous coal generation of some 125TWh (in CPS) is substituted, plus an increase in demand is provided by 209TWh of wind generation out of a total of 274TWh. This is made possible by an addition of 41GW of wind from 2030-2040 and requires an

18 McCall, B. et al. (2019) Least-cost integrated resource planning and cost optimal climate change mitigation policy: Alternatives for the South African electricity system. Available at: https://sa-tied.wider.unu.edu/sites/default/files/pdf/SATIED_WP29_February_2019_McCall_Burton_Marquard_Hartley_Ireland_Merven.pdf.; Wright, J. G. et al. (2019) 'Long-term electricity sector expansion planning: A unique opportunity for a least cost energy transition in South Africa', Renewable Energy Focus. Elsevier Ltd, 30, pp. 21–45. doi: 10.1016/j.ref.2019.02.005.

19 Government energy policy and regulatory agencies approved the power stations and offered sovereign guaranteed power purchase agreements. Even if government attempted to directly finance these through state ownership, substantial barriers would be experienced owing to Eskom's financial crisis and its aims to receive assistance for this via international climate finance.

20 Wind plays a role and gas (or other 'firm' power to cover variability) too but we focus on the main features of the transition in energy supply.

additional investment of R400Bn over CPS to accelerate phase out of coal to renewable energy electricity generation.

It is important to note that recent changes to regulations to allow private generators of less than 100MW onto the grid without requiring a license and empowering municipalities to procure power from independent power producers were not taken into account in the model-based scenarios. Both DDS and CPS use assumptions about the timetables in planning, procurement and regulatory processes which these latest regulations change substantially. Beforehand it was assumed that most generation additions would be the result of complicated government procurement and subject to complicated regulatory processes. The recent policy change could see 5,000MW of mainly solar-PV coming onto the grid in the next few years. Most of this would not have come onto the grid or would have been added much more slowly. Municipalities, and municipality customers could also add substantial amounts quickly. In the context of the economically crippling 'voluntary' curtailment of demand and controlled blackouts, this could significantly change the 2020-2030 pathway in terms of substantial additional renewable energy generation coming onto the grid much earlier than previously assumed. However, this won't substantially reduce emissions until the power shortage is over because it will be meeting suppressed demand.

Upstream renewable energy equipment industry links and economic benefits[21]

Additional economic considerations in relation to the power sector transformation, not explicitly included in the modelling, reveal further important techno-economic factors relevant to short-term policy. The largest is that the upstream renewable energy equipment manufacturing industry could be a substantial contributor to economic development and employment[22].

Most of the equipment installed in the 6GW, R200Bn renewable energy independent power producer procurement programme (REI4P) was imported. South Africa has the potential to manufacture most of this. The upstream equipment supply sector is included in the CGE part of SATIMGE, but SATIMGE currently optimises least electricity generation system costs, not including the upstream equipment manufacturing industry. This needs to be considered in broader economic and industrial policy analysis.

In DDS, 12GW of wind-generation capacity is added in 2020-2030; then 41GW in 2030-2040; and then 19GW in 2040-2050. If this equipment were to be supplied from local manufacture, this erratic demand would not facilitate easy linkages between the renewable energy construction programme and growing local renewable energy equipment manufacturing. From a national economic development perspective, upstream linkages should be factored into new renewable energy generation build rates.

Electricity demand and downstream energy intensive industry links

South Africa has a potential international advantage in the costs and amount of available renewable energy.Thus export markets become highly relevant. The recently accelerating commitments by countries and companies to zero-emissions targets are stimulating international demand for zero-embodied emissions commodities and goods. This demand could stimulate exports from South Africa that could create a demand for electricity many times that of the addition in the domestic demand-driven transition[23]. In essence, this involves exporting embodied renewable energy electricity. As SATIMGE models electricity demand endogenously[24], differing from other approaches that provide other feasible, plausible and relevant futures with a wide range of

21 The aim is to attempt to limit the analysis in this paper to techno-economic issues modeled in SATIMCGE but there are some important additional areas that need to be mentioned if not quantified

22 Definitive analysis of potential employment in upstream renewable energy equipment manufacturing is outstanding but there are indications that this could be among the most substantial and significant benefits of the transition to renewable energy. This is in addition to the incontrovertible analysis that shows that, even with imported equipment, the 2020-2030 period transition provides a least-cost electricity system while also playing a core role in addressing the electricity shortage.

23 See: Roos, T. and Wright, J. (2021) Powerfuels and Green Hydrogen (public version). https://www.researchgate.net/publication/349140439_Powerfuels_and_Green_Hydrogen_public_version ; Patel, M. " (2020) Green hydrogen: a potential export commodity in a new global marketplace. ww.tips.org.za/images/TIPS_Green_hydrogen_A_potential_export_commodity_in_a_new_global_marketplace.pdf ; Bischof-niemz, T. (2021) Green Hydrogen Export Opportunity for South Africa. Available at: www.ee.co.za/wp-content/uploads/2021/02/Tobias-Bischof-Niemz-presentation.pdf

24 As mentioned in the introductory section on *"CONSTRUCTING THE SCENARIOS"*, this method uses domestic demand drivers to derive growth.

electricity demand, the detailed exploration of export markets becomes central to energy policy planning. Under DDS, the production of "Green Iron" for export deep dive was explored and revealed the strong links with electricity demand projections (see Industry section below for details).

Dispatchable and firm power system assets and network services

DDS power sector transformation relies on the transition from one main energy source for electricity generation, namely coal, to renewable energy sources: wind and solar-PV. The latter are variable and non-dispatchable. To supply reliable power at every time of the day and night and every season, when "the wind might not be blowing and the sun not shining", sources of firm power are needed. Also, the transmission and control networks have to transition to handle very different power flows and new geographic distribution of generators. SATIMGE modelling includes the necessary firm power and estimates of network costs associated with the transitions to renewable energy generation in both CPS and DDS.

Industry

Overall sector production, GDP and emissions

Overall industry production growth of 184% is lower than overall GDP growth of 221% but is still substantial. Light industry remains at 13% of GDP while heavy industry decreases from 13% to 9% of GDP. However, this still involves growth of 154% and 214% respectively for light and heavy industry.

Average emissions intensity for all sectors remains relatively constant except for iron and steel. In general, the 8GT cumulative emissions cap did not lead to decarbonisation of industry except for iron production, which is a special case – see below. SATIMGE became unstable when lower emissions caps were attempted and thus, for this analysis, these sectors remain in the "difficult to abate" category in overall terms. Basically, for most of the heavy industries technologies do not exist to model abating emissions economically and South Africa does not have carbon capture and storage (CCS) resources. For light industry the differential between coal and gas prices for heating and electricity for heating which could technically be used for decarbonisation are simply too large for credible decarbonisation at this stage. Other technologies such as concentrated solar power or more stringent mitigation policy could theoretically achieve full decarbonisation under more stringent emissions reduction policy.

Figure 4. Overall sector production (Mt)

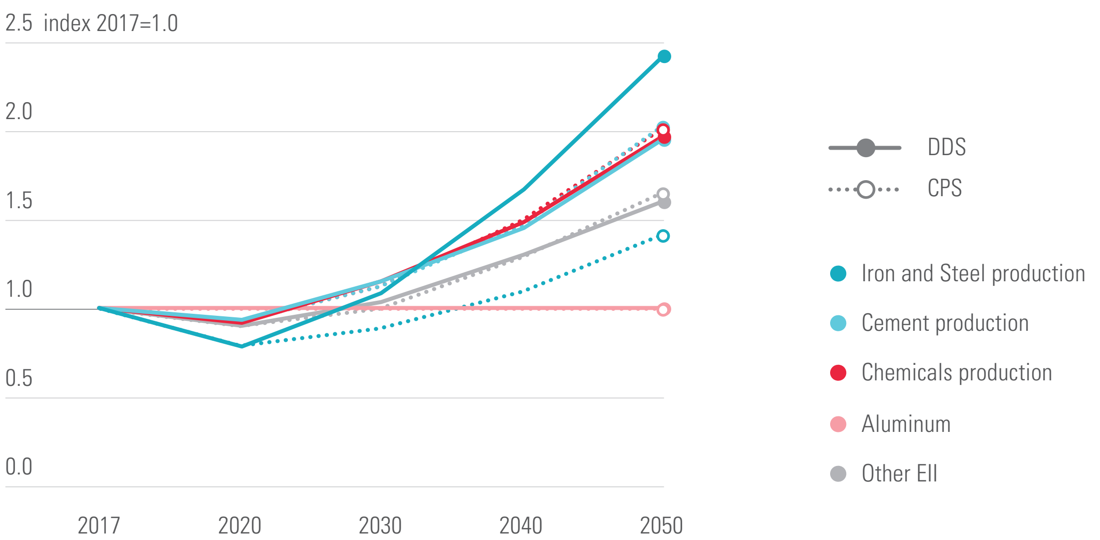
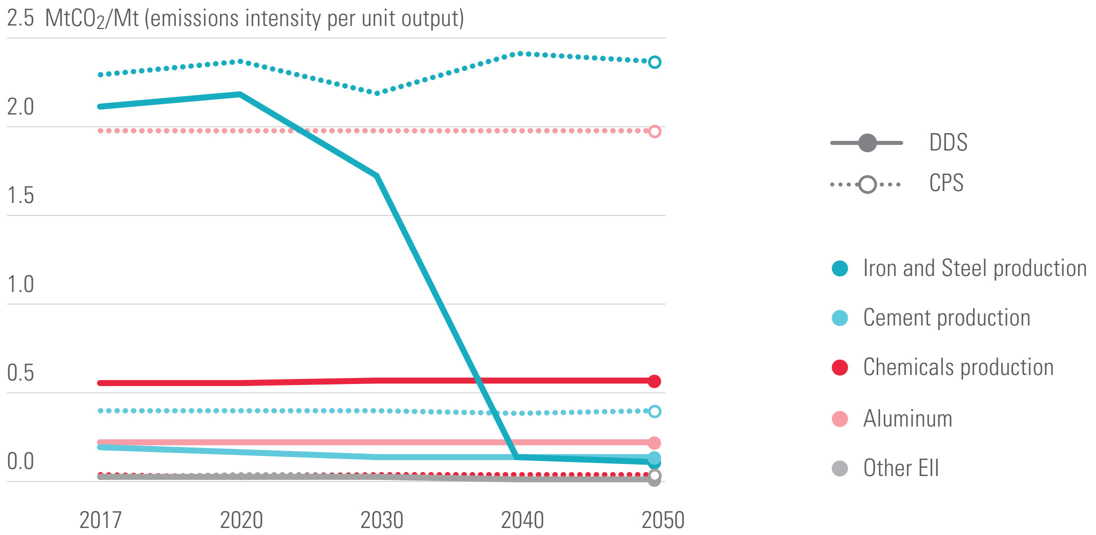


Figure 5. Sector combustion emission intensity



For the present exercise we assume firstly that heavy industry excepting steel production is not decarbonised but most importantly this is done with the caveat that it is likely that there will be technology developments and more stringent emissions mitigation policies in the ten-twenty year future term that will allow for economic decarbonization.

Passenger travel[25]

Passenger land travel is completely decarbonised through technology cost drivers mainly before 2040. There are no significant differences between the CPS and DDS for relevant indicators shown in the figure. From 2020-2050 for CPS and DDS Passenger mobility [p/cap/yr] increases by around 20%26. Public transport as a share of motorised passenger travel, increases from 50% to 56%[27].

From a decarbonisation perspective, in the DDS full decarbonisation of land travel is due to the evolving costs between conventional internal combustion engines (ICE), electric-drive technologies and energy costs such as hydrogen, electricity and oil product.[28] This is associated with an increase in mobility of roughly 20% [pkm/cap].

Other factors are relevant to the finer details of the pathways. One important example is around modal shift: the presumed decarbonisation from 2020-2030 results mainly from a modal shift to public transport. Passenger trip numbers plateau in 2030, with a proportional shift until 2050 towards private mobility. However, the extent of such a modal shift is largely dependent on stemming the markedly deteriorating quality and availability of public transport. The complexity of transport and in this case specifically the complexity of modal shifts in South Africa, limit the contribution that the aggregate national measures at the level of the basic DDP pathways can make to strategic short-term mitigation policy.

One centrally useful feature of the pathways is that for emissions mitigation policy, the modelling indicates that regardless of land transport policy, decarbonisation will be driven by technology costs and the sector will

25 We prefer passenger 'travel' to passenger 'transport' because in South Africa most trips are by foot and so no transport is involved. Also many ideal passenger mobility and access outcomes do not involve much transport.

26 These are rounded numbers according to the assessed resolution of the simulations over the time-periods

27 There is an increase from 1 to 1.5 from 2020 to 2030 for CPS and DDS and then a decrease back to 1 for CPS. These evolutions are dependent on highly uncertain policy implementation and ultimately do not affect decarbonisation and do not add much useful detail – see main text.

28 The non-zero residuals in the figure are all owing to air travel growing rapidly and remaining un-decarbonised. See below. This also masks the 70% reduction in surface transport emissions from 2030-2040.

fully electrify and decarbonise by 2050. Based on this, dedicated mitigation policy is not required to decarbonise passenger surface transport. Electricity demand for passenger transport will be about 5% of total electricity demand in 2050. For this exercise air travel was not considered for decarbonisation and emissions are 3Mt in 2050, although it is quite conceivable that in some ten-twenty years liquid fuels for aviation will be produced economically via an electrification route.

There are non-vehicle/fuel technology passenger mobility and access issues that are crucial to basic social welfare among very large poor populations who suffer much hardship owing to spatial planning and sub-standard basic infrastructure that require attention. Most relevant solutions can have positive emissions mitigation impacts. For example, "non-motorised transport" policy driven initiatives especially regarding pedestrian safety. Safety could be substantially improved with better pedestrian safety measures next to roads including walkways and lights, enforcement of Minibus taxi vehicle-standards and traffic regulations, and security on busses and trains.

Figure 6. DDS and CPS passenger transport drivers

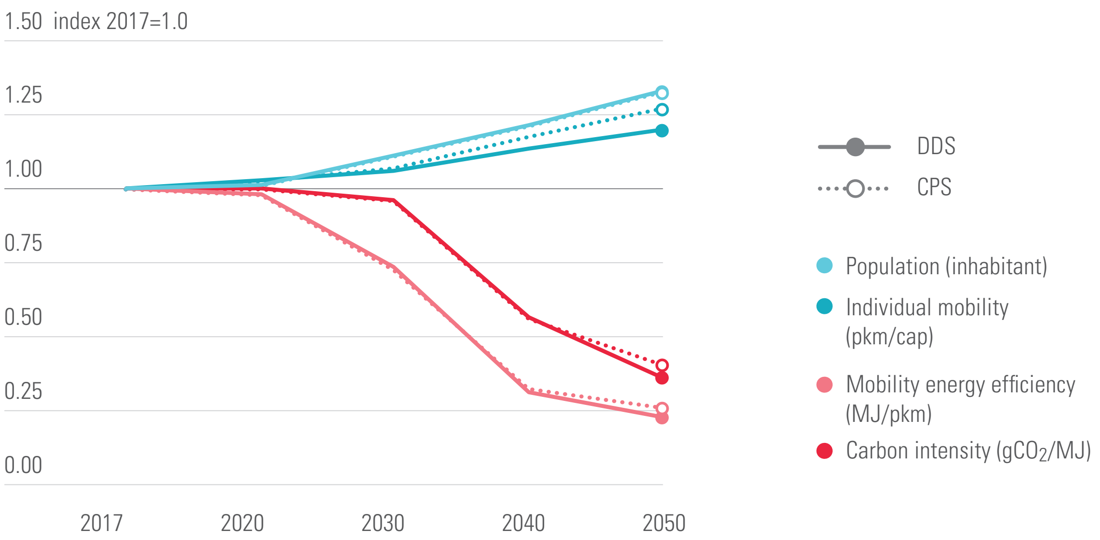
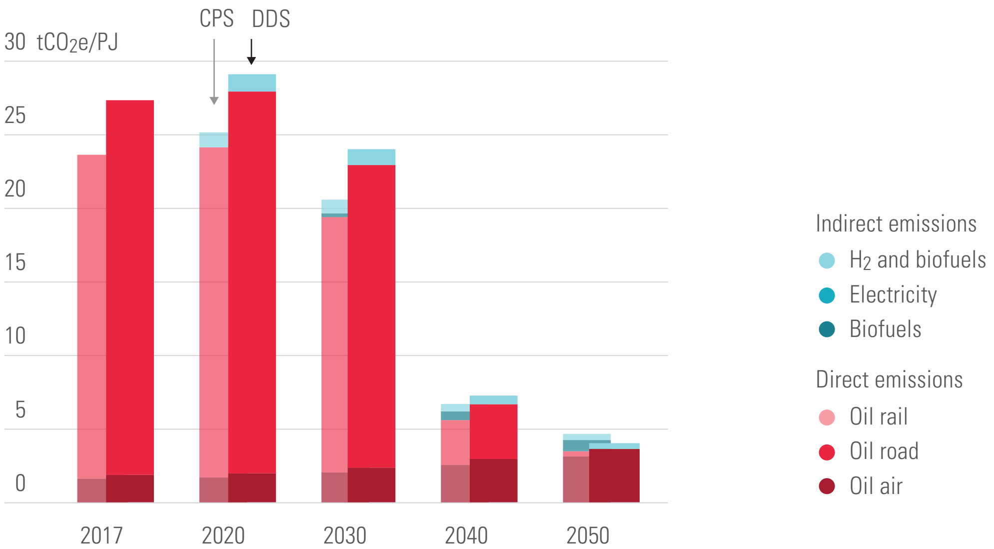


Figure 7. DDS and CPS passenger transport energy carbon intensity



Freight transport

Activity and modal split

From 2020-2050 total land freight transported for both CPS and DDS scenarios increases by around 70%, tracking growth projected for GDP.

Decarbonisation is driven by evolving costs between conventional internal combustion engines, electric-drive technologies and energy costs such as hydrogen, electricity and oil product, with full decarbonisation achieved in DDS

From 2020-2050 for a road-to-rail shift, there is a dramatic shift in rail corridor freight from less than 20% to approximate 70% for the DDS, whereas a less dramatic shift to 50% occurs for the CPS[29].

This may affect the rate of decarbonisation, depending on the rate of electrification of diesel-powered rail, but neither of these affect ultimate decarbonisation.

29 These are highly uncertain and depend on policy implementation and the relative quantities of bulk minerals exports, for example coal and iron ore compared with other goods.

Figure 8. Freight transport - Emission drivers

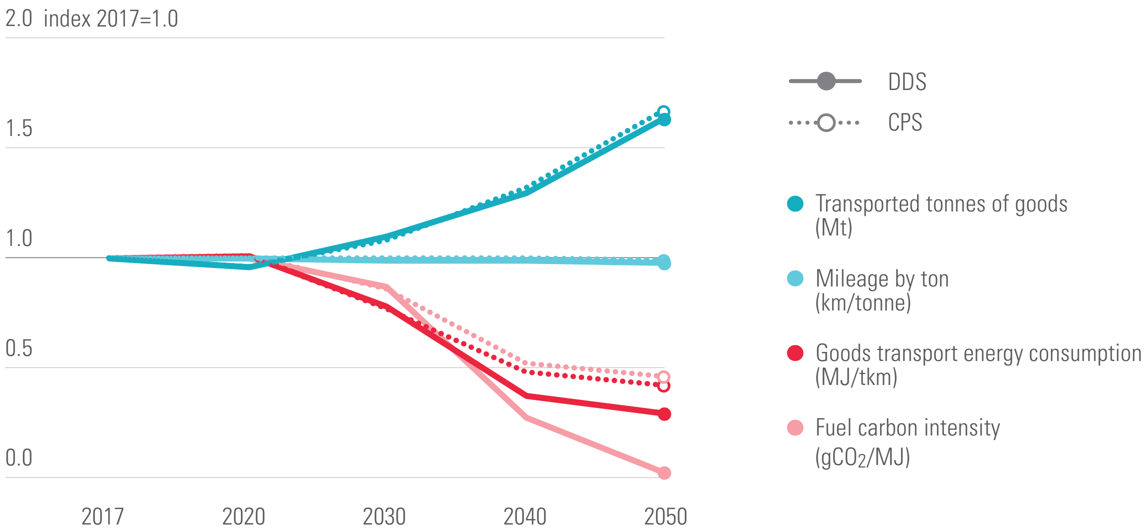
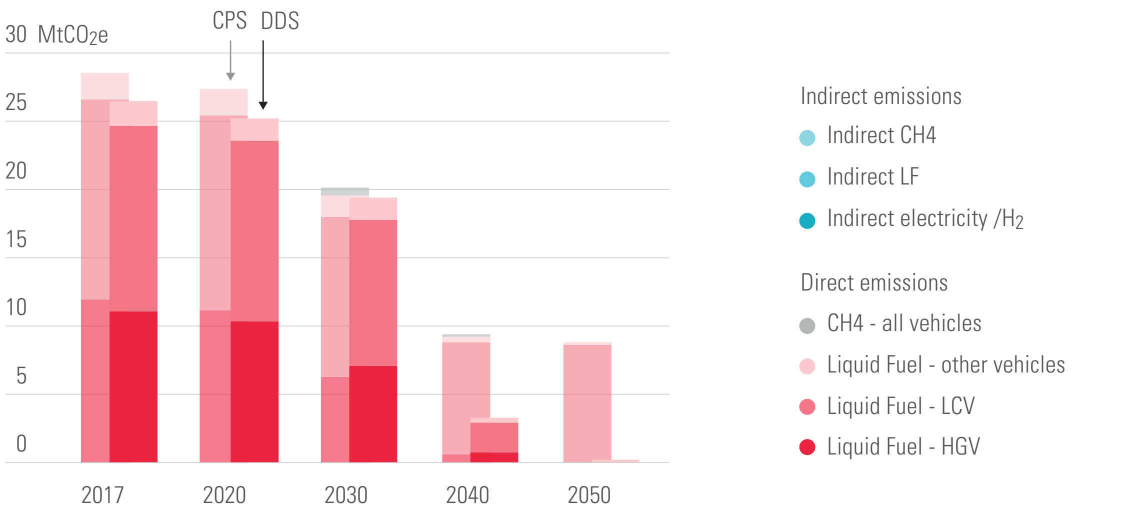


Figure 9. Emissions from fuel combustion



Emissions profile

Freight transport in the DDS is fully decarbonised from 29Mt, on a cost optimal basis, irrespective of the uncertain rate of modal shift.

Electrification in freight transport is primarily driven by uptake in the light commercial vehicle (LCV) segment in both scenarios. Declining costs of battery electric options, in line with international projections, is the main reason. For CPS the (highly uncertain) cost trajectory of battery electric light commercial vehicles (LCVs) is the main reason for the very big difference between CPS and DDS.

This leads to a similar stock (about 1.5m each) of ICE, hybrid-ICE EVs and battery-EVs in 2050. This leads to 9Mt of emissions in 2050 for CPS vs zero for DDS where there are only BEVs by 2050. A full switch to BEV LCVs requires an economy wide emissions constraint (carbon budget) in place.

LCV vehicle traffic almost doubles from 2020-2050. Given that much of this is in urban areas, especially already highly congested metros, there are notable implications for road infrastructure.

Heavy goods vehicles decline in population by about a third due to a modal shift to rail, with total transport energy consumption consequently decreasing by two-thirds.

Freight transport electricity demand will account for about 10% of total electricity demand in 2050. Infrastructure for electricity and hydrogen supply will require new investment to support some 200,000 BEVs and 100,000 fuel-cell EVs (FCEVs) by 2050.

Freight transport policy

Similarly, to passenger transport for emissions mitigation policy the SATIMCGE modelling has conclusive results that regardless of surface transport policy, decarbonisation will be driven by technology costs and the sector will fully decarbonise by 2050.

PART 2: KEY POLICY LESSONS

SHORT-TERM PRIORITES STIMULATED BY TECHNO-ECONOMIC ANALYSIS

ECONOMY-WIDE PERSPECTIVE ON PRIORITIES

From an economy-wide perspective, by far the highest priority short-term policy to get onto a Paris-compatible pathway, from combined economic and emissions perspectives is to add substantial renewable energy generation to the power system as quickly as reasonably possible. Apart from incremental improvements in energy use and other efficiencies, the potential substantial reductions in transport and industrial emissions only occur post 2030. While some preparations are necessary to facilitate the substantial post 2030 reductions these are not short-term policy priorities. The electricity sector also offers the greatest positive opportunities for direly needed short-term economic and socio-economic benefits (see details of electricity shortages and economic performance earlier and "renewable energy equipment industry links" above) and poses the most challenging negative socio-economic effects (see section 2.3.5 "Distribution of costs and benefits" above). These also indicate high priority for urgent short-term strategic policy attention even from a non-emissions reduction perspective.

In 2030-2040, electricity continues to be by far the most crucial area for policy attention. This is due to the huge emission reduction potential between CPS and DDS during this decade combined with the fact that DDS requires additional investments of R400Bn in renewable energy generation over 2030-2040 to prevent the stall in CPS emissions reductions in 2030. Nevertheless, over 2030-2040, several transformations, particularly within industrial sectors, may become crucial to macro-economic aspects of just transition (JT) pathways. The zero-emissions iron production is an important example of the potential contribution zero-emissions commodity exports can make to the national economy and to the South African participation in least-cost global sectoral decarbonisation. For South Africa to participate early in global sector decarbonisation requires more than technology transitions. Dedicated policies involving innovations in new business models and co-operation along value chains are required to achieve significant cost reductions in global decarbonisation. These are detailed in the section below on the "Green Iron Deep Dive". The emission abatements are small in relation to those achieved by greening electricity but important as an example of how kick-starting decarbonisation of a major industry can be achieved in what has been regarded as a hard-to-abate sector and of implications for future attention to abating 'residual' emissions in this sector.

SECTORAL DEEP DIVES

Electricity

There has been much in-depth analysis[30] that provides a solid resource for policy lessons to inform mitigation policy going forward. The progress of national electricity planning processes and associated implementation measures has been recorded and analysed in depth. These analyses have covered the legal and techno-economic features within broader contexts of emissions mitigation policy and national economic, political and security crises. The policy analysis below builds on them.

30 Baker, L. (2017) 'Post-Apartheid Electricity Policy and the Emergence of South Africa's Renewable Energy Sector', The Political Economy of Clean Energy Transitions. doi: 10.1093/oso/9780198802242.001.0001.; Wright, J. G. and Calitz, J. R. (2020) 'Systems analysis to support increasingly ambitious CO_2 emissions scenarios in the South African electricity system'. Available at: http://hdl.handle.net/10204/11483.; Wright, J. G. et al. (2019) 'Long-term electricity sector expansion planning: A unique opportunity for a least cost energy transition in South Africa', Renewable Energy Focus. Elsevier Ltd, 30, pp. 21–45. doi: 10.1016/j.ref.2019.02.005.; McCall, B. et al. (2019) Least-cost integrated resource planning and cost optimal climate change mitigation policy: Alternatives for the South African electricity system. Available at: https://sa-tied.wider.unu.edu/sites/default/files/pdf/SATIED_WP29_February_2019_McCall_Burton_Marquard_Hartley_Ireland_Merven.pdf.; Lawrence, A. (2020) South Africa's Energy Transition. Palgrave Macmillan. Palgrave MacMillan.; Baker Lucy and Jesse Burton Hilton Trollip (2020) 'The Energy Politics of South Africa', in Hancock, K. J. and Allison, J. E. (eds) §The Oxford Handbook of Energy Politics. Oxford University Press. doi: 9780190861360.001.0001.

Policy context

The South African electricity system is almost[31] entirely state-owned and state operated. Electricity prices are administratively set at all levels. Apart from a small amount of on-site own supply[32] and some municipal generation and storage facilities, 100% state-owned Eskom either owns all electricity generation assets or controls these assets through long-term PPAs. Eskom also controls the national transmission grid. More than 85% of energy is generated by coal power stations. These Eskom power stations consume 120Mt of coal a year, procured for some R70Bn from privately-owned coal mines.

One of the significant successes of democratising South African governance has been the Electricity Regulation Act (ERA) passed in 2006, requiring the Energy Ministry to regularly publish generation capacity expansion plans, called integrated resource plans (IRPs) according to strict regulatory rules including that they be based on least-cost planning and that departures from least cost would need to be sufficiently[33] motivated. Before the ERA, these plans had been formulated behind closed doors, and only sometimes made public.

National government controls[34] all additions of generation capacity to the grid. New generation is allowed onto the grid via a two-step process tightly specified by the Electricity Regulation Act (ERA). Firstly, government (the Department of Energy, DOE) publishes a generation capacity expansion plan, called the Integrated Resource Plan (IRP) which specifies how much of each technology will be connected to the grid in each year over the medium to long term. Secondly, the energy minister issues a "determination as to whether the new generation capacity shall be established by Eskom, another organ of state or an IPP".

31 There are small, but important exceptions, most of which will be addressed below, because these largely represent (so far) how renewable energy has been able to gain a toe-hold in the national electricity generation mix.

32 And a small amount of municipally owned or controlled assets.

33 In general, South African law requires administrative action to be demonstrably rational

34 There has been a recent relaxation of this control – see details regarding the *"Recent policy changes to allow private generators of less than 100MW onto the grid"*. Concessions have also been made to municipalities to allow them to source power from independent power producers.

An exemplary, and exceptional, successful mitigation policy implementation from 2008-2014

A very recent comprehensive paper[35] on mitigation policy states that "After a promising start, South Africa's climate institutions have been largely still-borne, neither managing to develop nor exercise any influence over the country's overwhelmingly dominant and highly concentrated emitting sector: coal-based energy. From an international view, this state of affairs is not immediately obvious". The only substantial effective direct impact in terms of emission reductions of mitigation policy implemented to date has been in the electricity generation industry. Even in this most successful policy implementation, the results have been small and mixed.

This sole substantial mitigation success involved a sequence of mandates at the highest government level and much cross-departmental co-operation, as follows: the Long-Term Mitigation Scenarios (LTMS) (Cabinet mandated 2005-2007), Copenhagen Peak Plateau Decline (PPD) commitment (President of South Africa 2009), incorporation of PPD in 2011 South African Climate Policy White Paper's Department of Environmental Affairs (DEA)), IRP2010-2030 (Department of Minerals and Energy (DME) 2011), and REI4P (National Treasury (NT), DME 2011-2014). The implementation of the REI4P on the ground required a joint effort by DME and NT in a special for-purpose office established outside normal DMRE lines of management, namely the IPP office[36].

The IRP/determination-governed system in the ERA only came into effect in 2011. Until then Eskom had effectively decided what generation would be added to its system even though the DOE had unsuccessfully tried to take control in the 2000s. In a radical departure from previous policy, the first detailed[37] IRP under the system imposed an emissions constraint on a least-cost plan to implement South African emissions mitigation policy in line with its Copenhagen pledge. This commitment in 2011 by a developing country to incur substantial additional costs to mitigate emissions demonstrated climate leadership

35 Tyler, E. and Hochstetler, K. (2021) 'Institutionalising decarbonisation in South Africa: navigating climate mitigation and socio-economic transformation', Environmental Politics. Routledge, pp. 1–22. doi: 10.1080/09644016.2021.1947635. page 15.

36 https://www.ipp-renewables.co.za/

37 Two 1-page 'token' IRPs were published in 2010 and 2011 to retrospectively legalize the Medupi and Kusile power stations

and was remarkable at the time. Despite a system where renewable energy generation additions were significantly above least cost at the time, 30 GW of renewable energy generation was incorporated into the IRP2010-2030.

In another radical development, the renewable energy generation was implemented via the renewable energy independent power producer procurement programme (REI4P). A government auction programme with periodic bid windows invited privately owned independent power producers (IPPs) to submit bids. Despite being privately owned, the IPPs are the result of state procurement as Eskom was required in terms of the ERA to sign power purchase agreements (PPAs) with award winners, and thus, their electricity production is state-owned backed by sovereign-guarantees.

From 2011-2014, four bid windows were run resulting in 6GW of new PV[38] and wind generation and fixed investments of some R200Bn. This was from a very low base of renewable energy electricity generation. The projects have been completed and now contribute some 4% of electricity to national generation. The REI4P auctions ceased in 2015. This is viewed as a success because it managed to muster cooperation and support across government and connect foreign policy to mitigation policy and then to electricity policy resulting in substantial investments directly aimed at reducing emissions, it is viewed as small because 4% of electricity is just a start and "mixed" because after only 4 years it stalled owing to a combination of ineffective government by DME and Eskom refusal to sign the PPAs already legally awarded.

A significant unexpected result of the REI4P was the rate of decline in average procurement prices from ZAR 2.79 to ZAR 0.92 from 2012-2014. The crucial, revolutionary impact of this was that by 2015 cost-optimisation modelling showed that renewable energy generation had evolved to providing lower costs for South African system expansion than new coal generation. Emissions mitigation no longer involved a cost trade-off but actually delivered net direct financial benefits.

A paralysing electricity policy impasse from 2014-2021

There has been a seven-year electricity policy implementation impasse in awarding new contracts for constructing or procuring any new utility-scale electricity generation. The electricity shortage has been a central factor in decline of economic growth and de-industrialisation and increases in unemployment and poverty. Several factors explain this impasse.

Firstly, in 2015, in actions of questionable legality, Eskom refused to sign PPAs with IPPs that had been awarded by national government in the REI4P. These were subsequently signed shortly after the removal of President Zuma in 2018.

Secondly, coal IPP projects have been proving to be un-financeable despite strong government support. The DME issued a Determination for 2,500MW of coal and announced a coal IPP programme at the end of 2014. After two awards amounting to 1,500MW in 2016, the selected bidders did not manage to secure financing. These projects are basically unviable owing to their economics, environmental permitting problems and related withdrawal of financiers. It is now becoming unlikely that investments in new coal-fired electricity will be financeable in future without very special state aid.

Thirdly, the gas IPP programme has not managed to get off the ground owing to credibility problems related to the stalling of the REI4P. In 2015, the DME issued a Determination for 3,126MW of gas generation. In 2018, the DOE stated[39] that "Eskom signing of the REIPPPP is a precondition for international investor confidence in the IPPPP and the Gas Programme" and that the bid process would start when the IRP had been updated. However, the IRP2019 shifted new gas to 2024. If it had been implemented as initially envisaged, much of the supply shortage could have been avoided and space would not have been created for the RMIPPP and the current attempts at contracting emergency gas-fired generation mounted on Karpower ships.

Last, Eskom coal procurement contracts have been at the centre of structures and processes-labelled State Capture[40]. President Zuma, cabinet ministers, previous Eskom CEOs, senior Eskom executives and coal mine owners have been implicated. Some of the same people were involved in the stalled REI4P (Eskom refused to sign contracts of awarded bids). These people were also openly part of a high visibility misin-

38 Some CSP plants were also 'procured'.

39 Department of Energy. Presentation on the independent power producer procurement programme (REI4P) to the Portfolio Committee on Energy parliament. Cape Town 06 March 2018.

40 We capitalize it as it has a specific meaning for South Africa – Chipkin, I. *et al.* (2018) *Shadow State: The Politics of State Capture*. doi: 10.18772/22018062125.

formation campaign to discredit renewable energy in general and the REI4P in particular. In December 2016 the South African Public Protector published the "State of Capture" report that provided evidence of coal contracts (allegedly) illegally awarded by Eskom. The evidence implicated individuals, including the then Eskom CEO. Subsequently this evidence has been corroborated in a parliamentary enquiry and judicial commission. These processes also revealed information about the state procurement regulatory capacity at National Treasury (NT) and Finance Ministry National Prosecuting Authority (NPA) being disabled to facilitate such (allegedly) illegal contracts. Evidence leaves little doubt that irregular coal contracts were (and possibly still are) at the centre of a large network called State Capture.

In brief, the REI4P has been limited to existing awards from its first 2011-2014 bid windows. Going forward, Eskom coal procurement contracts are of significant relevance to implementing renewable energy generation policy because a transition to renewable energy will strand coal assets involving trillions of Rands.

The REI4P and the history of distribution of costs and benefits within the broader South African policy context

While the renewable energy independent power producer procurement programme (REI4P) was a success in economic efficiency terms, it has been viewed by crucial stakeholders as highly skewed against economic transformation and a replication of legacy extractive economic arrangements. Serious and deep issues around distribution of costs and benefits and protection of vulnerable communities need to be addressed. This is a central feature of the mission that is developing in the Presidential Climate Commission.

The apartheid-era electricity system was an important component in the social and economic system of gross inequality, exclusion and oppression. South Africa enjoyed 14 years of democratic transition, post-apartheid growth and substantial improvements in socio-economic conditions from the end of the apartheid government in 1994 until 2008. Since the 2007-2008 Great Recession, South Africa has been experiencing an escalating economic, socio-economic and human development crisis. The electricity system has become a central site of policy conflict which is still largely unresolved.

Until 2006, a mass household electricity programme extended electricity access to most urban households but then stalled. Adequate electricity is now too expensive for some 40% of South African households who suffer energy poverty. Transformation and reform of the upstream electricity generation and coal supply sides has been problematic. Conflict in the ANC which has ruled since 1994, between proponents of Washington Consensus-style reforms and anti-privatisation has caused serious policy conflict, uncertainty, and instability. Organised labour, which was a major player in over-throwing apartheid, is the most powerful anti-privatisation proponent in terms both of economic power (industrial action) and in rallying political support inside the ANC and at elections.

The transition to renewable energy generation involves investments in renewable energy generation of a substantial scale in national terms – electricity spending is more than 5% of GDP and the transition involves shifting this quantum of spending from coal to renewable energy. Investments of at least R30Bn per annum in wind and PV will be required each year until 2030 and trillions of Rands over the 2020-2050 transition. At an aggregated level, the national electricity system, national economy and local and global natural environments are direct beneficiaries. This provides the system-wide motivation for the transition. However, at a disaggregated level, benefits and costs of the REI4P have been unevenly distributed. Benefits flow to renewable energy project developers, equipment suppliers, land and renewable energy generation facility owners and operators, and financiers (especially if privately-owned and being rewarded at market rates) and employees of all of these.

This inequitable distribution of benefits has supported resistance to the transition. South Africa has a history of gross inequity of the distribution of costs and benefits involving natural resource exploitation and in energy and electricity production in particular. Therefore, addressing distribution of costs and benefits is crucial for social justice. It is also necessary to garner and maintain political support for the transition.

Addressing the distributional inequality is also techno-economically and politically feasible. Organised labour has consistently stated that it views the contracting of IPPs as privatisation of Eskom through the back door and that they oppose this. Important civil society organisations and NGOs also oppose it or at least demand that the energy transition does not replicate existing severe inequities in the electricity system. There has been a struggle for more than twenty years over regulation and reform of the 100% state-owned vertically integrated electricity monopoly which owns and operates a generation fleet dominated (85%) by coal generation. Government was well on the path to privatising part of the Eskom coal fleet in 2002. However, national strike action put an end to privatisation plans. The first major power shortage in 2008 was the direct result of the policy impasse of combined failed privatisation of coal generation and of government preventing Eskom from building coal power stations as it always had. No plants were built from 1998-2006 despite a known looming supply shortage[41]. Eskom had contracted BEE miners without ensuring performance capabilities and the South African electricity system entered a period of generation capacity shortages and multiple problems in Eskom coal supply contracts that has steadily worsened. Linked to anti-privatisation and coal contracts aimed at BEE transformation, but re-directed and a central driver of State Capture, important constituencies in the ANC have been effective in (intentionally or not) being a major factor in the policy impasse. The REI4P was presented as privatisation and effectively halted. Eskom coal contracts were a mainstay of State Capture and Eskom showed negative interest in contracting utility-scale renewable energy.

In 2018, after the removal of President Zuma, moves were immediately made to sign the REI4P awards. The National Union of Mineworkers South Africa (NUMSA) and Transform RSA (an organisation associated with supporting key state capture figures) mounted a court challenge in March which failed, and contracts worth R57Bn were signed for 27 projects that had been stalled since 2015. The Coal Transporters Forum then launched a court process to nullify the contracts which also failed.

The direct economic and financial beneficiaries were mainly local project developers, foreign renewable energy equipment suppliers and local and foreign financiers. Most of the finance was supplied on commercial terms and was underwritten by state (sovereign) guaranteed PPAs.

Civil society groups mobilised along social justice lines, organised labour with an anti-capitalist stance and state capture cronies, funded by proceeds of coal contract rent-seeking, were allied in their resistance to utility-scale RE-IPPs. The facts that the allies in the anti-IPP cause used were correct: the REI4P did provide rich rewards to project developers and owners and their financiers and mostly foreign renewable energy technology companies. Also, renewable energy would lead to the phase-out of coal, although with the generation shortage all extra generation for some time (still) provides relief for an over-stressed coal fleet and reduces the need to run very expensive diesel peakers and also reduces economically damaging load shedding.

Mobilisation against renewable energy also raised the issue of the impact of a coal phase-out on the coal industry and employment. To garner necessary support for the transition there is a need to distribute benefits from the huge growth in the renewable energy sector fairly and to protect vulnerable coal workers and their communities as coal is phased out. Localising renewable energy equipment manufacture will significantly increase economic benefits and, if well managed, can assist with both distribution of economic benefits and protection of the vulnerable by locating renewable energy manufacturing in coal areas which in many cases are already industrial areas with industrial infrastructure. If effectively integrated with industrial policy, a stable and credible steady demand for renewable energy equipment could drive substantial re-industrialisation through local manufacture of renewable energy equipment which will increase national employment substantially, although jobs will be lost in the coal mining and coal power stations.

Short-term strategic policy recommendations

Policy analysis

The DDS achieves the same emissions reductions as the CPS in the 2020-2030 period. The CPS requires more capital investment because of deviations in the official IRP2019 plan which forces new coal power stations into the plan despite them costing more. Thus, over the 2020-2030 period, if current electricity policy is implemented the resulting emissions will still put South Africa onto a DDS pathway.

41 Froestad, J. Nøkleberg, M. Shearing, C. Trollip, H (2018) 'South Africa's Minerals-Energy-Complex: Flows, regulation, governance and policing', in Omorogbe, Y. and Ordor, A. (eds) Ending Africa's Energy Deficit and the Law Achieving Sustainable Energy for All in Africa Oxford University Press, p. 327.

However, as explained above, implementation of electricity policy has for some time been paralysed by entangled factional politics in the ruling party with fossil-industry rents and corruption centred on coal-based electricity playing a large role. Government has not managed to break the log-jam in energy policy implementation in the electricity policy context. Recently there been signs of policy implementation starting to become un-stuck but to achieve necessary scale policy commitment across government needs to be clearer and much more stable. There are risks that coal and gas interests could force economically irrational amounts of new coal and gas generation into the mix, undermining both short- and long-term emissions reductions as well as the economy.

Therefore, the core and immediate major South African real world decarbonisation challenge is breaking this log-jam and to initiate new investments in renewable energy. Secondly, the grossly economically and financially irrational coal power stations and gas Karpowerships that have been forced into official plans need to be independently reviewed. This will involve implementing existing legal requirements in decision-making to ensure that clear and transparent reasons are made public, particularly when they depart from least cost solutions. Further on, with views to the 2030-2040 period, specific mitigation policy is required to drive reductions in electricity emissions. This will need to be implemented via electricity policy mechanisms.

Intra-government institutional arrangements

Solutions to the policy implementation impasse need to navigate a fragmented state where "…numerous government agencies, generally with poorly defined mandates and inadequate resourcing" and when they disagree "there was often no way to expedite dispute resolution. These factors led to long-running inconsistencies in policies, regulations and implementation." "…only Cabinet, the Presidency and the courts have the power to arbitrate disputes between government agencies." [42] As detailed below, the Presidency has recently demonstrated leadership to break one long running impasse in connecting renewable energy generation to the grid. This might be a model for a practical solution for accelerating renewable energy roll-out until the intra-governmental challenges with contradictory policies and plans are addressed.

In June 2021 President Ramaphosa over-rode[43] his Minerals and Energy Minister via Operation Vulindlela (OV), and directly intervened in electricity policy implementation and lifted the threshold for licensing connections to the grid from 1MW to 100MW. The reasons have been given by OV as the need to get generation onto the grid as fast as possible and that existing DMRE initiatives, even if successful, would not close the power supply gap and continue to cause substantial economic damage. Via OV the Presidency, Finance Ministry and National Treasury have accepted the findings of techno-economic analyses and have been explicit about the damage caused by the protracted and worsening electricity shortage. They have also explicitly stated[44] that even if the current DMRE RMIPPP and REI4P Bid Window 5 go smoothly, "these current interventions will not be sufficient to meet the electricity supply shortfall until at least late 2023 or early 2024". They cite 2020 Eskom and CSIR estimates of the power shortage of 4,000MW and 8,000MW respectively. OV estimates that by 2024 the renewable energy that will be connected to the grid will reduce GDP loss by 1.75% from the "severe electricity shortage" and add 0.5% of GDP through investments in renewable energy by the private sector, yielding a very significant economic benefit of 2.25%. This is through simply lifting a restriction.

This recent policy intervention by the Presidency is a stark example of what has become necessary to break (some of) the policy implementation impasse and the damage and unrealised benefits that would have resulted from not intervening in delays and resistance in DMRE policy implementation. However, there has not been a positive acknowledgement of this by the DMRE. The Energy Minister stated that his "arm had been twisted"[45]. Then, pushed by the president to implement the measure, the DMRE delayed the publication of the regulations lifting this restriction until past the deadline. Then, the first version of the

42 Magetla, N. (2021) *Draft Policy Brief for the Presidential Climate Commission Governance and the Just Transition - October 2021.*

43 https://www.news24.com/news24/southafrica/news/twisting-mantashes-arm-operation-vulindlela-drove-raising-embedded-energy-threshold-to-100mw-20210611

44 South African Presidency Operation Vulindlela (2021). Supporting the implementation of priority structural reforms. Presentation to the Presidential Climate Commission (PCC). 30 July 2021.

45 https://www.businesslive.co.za/bd/national/2021-06-10-ramaphosa-twists-mantashes-arm-to-free-up-new-power-generation/

regulations created much uncertainty and had to be updated. Today there is still uncertainty in poorly drafted regulations that continue to hinder implementation.

Operation Vulindlela (OV) has demonstrated a successful institutional solution to the challenges that the DMRE faces while it continues to carry out both minerals promotion and electricity planning and licensing authorities. This double function exposes it to politically and economically powerful incumbent coal and fossil interests, which have been embroiled in state capture while at the same time the DMRE has to manage the imperatives of a transition that will involve substantial economic losses for these interests. While OV has proven its potential and provided partial compensatory benefits, the intervention does not go to the root cause of the problem. A more permanent institutional solution to the DMRE policy impasse is needed. A starting point would seem to be separating out the energy portfolio from minerals in the Department of Mineral Resources and Energy (DMRE) back into a Department of Energy as structured when the REI4P was launched. This would reverse the decision made in June 2019 to merge the Department of Energy (DOE) and the Department of Mineral Resources, to go back to 2010 when the Department of Minerals and Energy had been divided into two Departments to precisely balance the interests of the coal industry and nascent gas industry[46] vs interests of rational electricity planning which had proved problematic.

In parallel, the president could establish an executive structure in the presidency to extend the advisory structures and processes that have emerged in the Presidential Climate Commission (PCC) and Operation Vulindlela (OV) and empower and hold accountable this executive structure to address inter-agency contradictions and competition that have been delaying implementation and urgently attend to the acceleration of renewable energy deployment to address the power-supply shortage.

Electricity policy implementation also depends on DMRE and Eskom cooperation which has a poor record. This cooperation remains to be far from assured with a current combative relationship evident between the Eskom CEO and energy minister[47] over the issues of the role of renewable energy in national electricity supply and expectations that Eskom will sign PPAs with the Karpower ships. The Presidency-extended structures could enhance the coordination between DMRE and Eskom.

Integrated policy actions

The just transition (JT) can stabilise and re-build the electricity generation sector, which is central and contingent to national security, the success of the democratic transition and addressing poverty and unemployment, as well as achieving net zero by 2050. Coal electricity generation is in inexorable decline. Without effective management this will lead to the rapid collapse of regional economies already in severe distress. A managed electricity system transition in the form of the JT managed by the PCC could turn this around and facilitate decarbonisation of other sectors. Government has to be convincing that plans for the coal phase-out will include measures to address welfare in coal regions to regain/maintain security and social stability as a basis for sufficient support for the constitutionalists to enable investments in the renewable energy roll-out.

A number of academic and technical studies have described the potential requirements and elements of a Just Transition Transaction (JTT) specifically for the power sector[48]. The need for procedural justice is a central feature and a number of proposals have been made. These include social plans for coal regions, retraining of coal sector workers, re-purposing of coal power stations. This involves siting renewable energy generation in coal regions (economically viable despite not being optimal renewable energy resource areas), assistance with economic diversification and establishing renewable energy equipment manufacturers in coal regions within an energy/industrial policy that provides sufficient

46 As well as coal promotion, DMRE is also responsible for upstream oil and gas policy and regulation. There has been a recent condensate discovery categorised by TotalEnergies as *"a new world-class gas and oil play"* (Announced in July 2019, https://totalenergies.com/media/news/press-releases/total-makes-significant-discovery-and-opens-new-petroleum-province-offshore-south-africa).

47 This is not only reported in the press but evident in comments made by these office holders on recorded videos on social media.

48 Burton, J., Marquard, A. and McCall, B. (2019) Socio-Economic Considerations for a Paris Agreement-Compatible Coal Transition in South Africa.; Climate Investment Funds. 2020. Supporting Just Transitions in South Africa: Just Transition Case Study. Washington, DC. www.climateinvestmentfunds.org/sites/cif_enc/files/knowledge-documents/supporting_just_transitions_in_south_africa.pdf; https://www.wri.org/just-transitions/south-africa - World Resources Institute (2021) South Africa: Strong Foundations for a Just Transition.

demand certainty from the renewable energy generation roll-out for local equipment manufacturers. So overall governance and outline proposals for the JTT exist but this needs to be developed now through to implementation using the Presidential Climate Commission (PCC) JTT process.

Localisation of production of renewable energy equipment – A secure state-backed, stable demand for renewable energy can create a 'pipeline of utility scale projects' over the medium term, which in turn, creates a stable demand for renewable energy equipment. This demand can serve as a basis for establishing an industrial policy to establish a large domestic renewable energy equipment manufacturing industry. Policy has been unpredictable and policy implementation stop-go. However, investment in utility scale generation has either been directly through 100% state-owned Eskom, or backed by sovereign guaranteed power purchase agreements (PPAs). It is most likely that even if future PPAs aren't backed by formal sovereign guarantee the counter party will either be state-owned Eskom or a state-owned (transmission) system operator. This will effectively put the state into a guaranteeing situation anyway as has been made clear with the current Eskom debt crisis. Failure of Eskom to honour debt is tantamount to a sovereign default. Thus, whether government creates more certainty by, for example, providing credible commitments to implementing the IRP2019 renewable energy programme or not, it will in effect be committing state resources to backing the programme. A formal credible commitment would create certainty demand for upstream renewable energy equipment that would form the basis for industrial policy integration and investments by renewable energy equipment manufacturers. This will enable investment both in electricity generation and upstream renewable energy equipment manufacturing.

Enable state-owned and independent power producer utility scale investments and household, community, business and municipal participation in investments in electricity generation.

To address major economic and political constituencies, programmes that involve state and community ownership need to be added to the existing REI4P, which has been limited to large private corporate ownership of generation assets. It is unlikely that the struggle between proponents and opponents of state/public/private ownership will be resolved soon. This struggle has been de-stabilising energy policy since initial attempts at sector reform in the early 2000s. In the context of a damaging electricity supply crisis and the need for rapid transition to make a fair contribution to GHG emissions mitigation, progress should not remain hostage to this struggle. A necessary compromise could involve a policy commitment to implement both private and public/community-ownership programmes in parallel. Detailed plans for this for this can be developed in the JT structures being set up in the PCC.

Regarding ownership of generation, decarbonisation pathways offer a range of possibilities. Conflict, since the early 2000's, over resolving one ownership model has been a central cause of the energy shortage. Techno-economic analysis within existing institutions indicates that a number of ownership options have a role to play and these do not have to be exclusive. Possibly all are required to achieve the rate and scale required. REI4P, state-owned utility-scale and household, community, business and municipal ownership of electricity generation can play an effective role to meet energy needs and mitigate emissions and at the same time distribute considerable benefits of the huge roll-out of renewable energy generation across society. For example, state-owned Eskom has recently announced its willing intention to embark on a state-owned utility scale renewable energy generation investment programme. Local government initiatives to implement innovative public/private mixes in own-supply and embedded generation are another example.

Utility-scale, medium-scale distributed and embedded small-scale, public and privately-owned are all elements in an optimally functional system: all need implementation as rapidly as possible, Regardless of the various pathways to ultimate decarbonisation of electricity, and regardless of externalities such as emissions, accelerating a rapid roll-out of renewable energy electricity generation: at utility-scale and small-scale, centralised, distributed, embedded, own-supply, public and privately-owned over the next 5-10 years is techno-economically rational and an imperative to address the electricity supply shortage of between 4,000-8,000MW to arrest and turn around economic stagnation. GHG emissions mitigation and local environmental protection in this case are co-benefits. Localisation through stable policy and commitments to state-backed procurement programmes and integrated industrial policy have huge potential to add substantial economic development, industrial development and employment.

Short-term action agenda

Investments in generation

See graph *"Cumulative electricity capital investment post 2021 in CPS and DDS" at the beginning of the electricity section.*

The following specific policy actions are required to achieve the rapid acceleration and increased scale:

Accelerate REI4P Bid Window 5 implementation: Technocratic policy and implementation institutional capacity and mechanisms for the renewable energy rollout exist but implementation needs to be re-vitalised and accelerated.

Prepare and run an expanded REI4P Bid Window 6 that will be based on an independently reviewed maximum rate of utility-scale renewable energy construction to fill the electricity supply gap as soon as possible.

Both the REI4P and the Bid Windows utilise an existing programme to address an emergency – a utility-scale central-buyer-driven renewable energy rollout. While the well-established REI4P implementation mechanisms are probably best suited to accelerate utility-scale renewable energy generation investments in the short term to most effectively begin to fill the critical supply shortage, they do not necessarily have to be the only or biggest contributor to the renewable energy programme in the medium to longer term. Parallel central buyer programmes can be run and the REI4P-style programme can undergo substantial adjustments to ensure support of costs and benefits distribution consistent with the kind of just transition of which details are beginning to emerge in Presidential Climate Commission processes. Much of the economic benefits would involve equipment for REI4P projects being sourced from local manufacturers. This is dealt with in more detail below, but in the short term it makes sense for the REI4P to continue in its current form to fill the large power supply gap.

To address issues of the REI4P being biased towards privatisation, a similar programme to the REI4P can be established where state-owned Eskom can run auctions to achieve efficiencies and competitive prices but Eskom takes public ownership on a build, operate, transfer system once operation is proven at contracted levels. A renewable energy publicly owned power producer procurement programme: REPOPPP can be run in parallel with the REI4P. This could be a hybrid of the auction and conventional tender systems. Government commitment to this could avoid the conflict and stalemate between supporters of the two approaches delaying action. It must be noted that despite its 100% ownership stake, Eskom is governed at arms' length as a profit making company and government has often been challenged in getting Eskom to implement official policy. The unbundling of Eskom and extraction of the national transmission grid from the Eskom vertically integrated monopoly is an example. This been attempted for twenty years without success so far despite well-resourced reform programmes and a number of official statements over the years including a number of announcements in the annual Presidential State of the Nation Address that it would happen "this year" or soon. The ability of government to 'order' Eskom to implement a policy of replacing its coal stations with renewable energy has not yet been demonstrated. Given the urgency of getting PV and wind onto the grid it would make sense to continue with the REI4P while the success of an Eskom driven programme is investigated.

Last but not least, partially releasing additional demand and supply from the existing command and control approach can be unleashed through mobilising opportunities similar to, for example, the recent amendment to regulations to increase to 100MW the threshold for licensing of own–generation and generation to wheel over the grid. This element will exploit the space opened up by government allowing access to the national grid solely regulated by technical requirements. The potential revolutionary impact needs heavy emphasis. Until this development, in essence, all substantial additions of generation capacity were tightly controlled by the Minister of Energy. In general, electricity generation was either owned by Eskom or procured by Eskom as the 'single buyer' for re-sale, creating an effective monopsony and monopoly. Eskom is saddled with crippling debt and most of the coal-fired generation fleet that supplies >85% of electricity reaching the end of its economic life with serious performance problems (fleet EAF at 63% and steadily declining).

This development, forced by the presidency over the head of the DMRE, is a departure from policy trajectories implemented up until now. However, if and when a potential suppressed supply of some 5,000MW of projects starts connecting with a 4,000MW-8,000MW supply-demand gap, the results could be profound. The amendment to the regulation is very recent and much uncertainty surrounds it not least because of the apparent lack of alignment between presidency interventions in energy policy and established DMRE practices as demonstrated over the past five years even after the Zuma presidency had been terminated and substantial efforts started against state-capture. The main mode of implementation which would substantially alter the electricity generation landscape enabled by the sub-100MW dispensation would be for large investments in generation based on private contracts with one or more customers (who could probably be traders) to wheel power over the grid to these customers. If the regulatory authority NERSA enforced fair and open access this could result in a large parallel market freed from the single buyer constraint and tariff control.

Generation planning

The IRP2019 needs to be updated in at least three important respects. The update should contemplate a publicly review process by a panel of independent analysts. These aspects are:

- Incorporating least-cost pathway modelling analysis reflecting latest relevant technology cost assumptions and removing the irrational coal and nuclear power previously forced in without appropriate backing rationale and analysis;
- Extending it to 2050, and;
- Including scenarios that factor in a successful JTT/JET which mobilises finance to accelerate the phase-out of coal and to address social costs of coal phase out. The REI4P and additional renewable energy investment programmes need to be accelerated to implement the updated IRP.

Rescind the risk mitigation independent power producer programme (RMIPPP) and institute a tender procedure that rationally addresses the short-term power shortage. Currently an emergency IPP programme, launched to address a power supply shortage estimated to be between 4,000MW-8,000MW (of typical maximum demand of ~30,000MW) has been delayed twice, is mired in controversy and could likely flounder. A major problem is the attempt by the DMRE to force into the programme a seemingly irrational 20-year contract for base-load gas-fired power, the Karpower[49] ships, despite this being far from least cost after the initial period when it contributes to filling the 'short supply gap'. Owing to the fundamental irrationality of one attempt after the next, detailed above, by DMRE to forcefully implement projects which are techno-economically not viable into what is turning out to be a fairly robust legislative and regulatory system a huge power shortage is wreaking havoc with the electricity system and economy. Twenty year contracts to cover a short-term power shortage offering take-or-pay 50% baseload contracts to using 'emergency' style reasoning is another of the same and is more likely to exacerbate the shortage by failing.

Industry

From an economy wide perspective, a specific economy-wide mitigation political and policy challenge is to separate out the 78Mt of 'residual' emissions, mainly in industry, so that the current absence of economic/technology solutions to decarbonise these emissions does not compromise policy progress for the large proportion (299 out of 377Mt) of emissions that can be economically decarbonised, with little GDP impact. Industry does have economy-wide interlinkages, especially with the electricity sector, but it has its own particular challenges, especially technological, but also economic and political. Historically, anti emissions mitigation policy initiatives have often mobilised an alliance of coal, electricity and energy intensive industry interests. These particular challenges need to be understood and addressed by policy in a way that does not hinder decarbonisation of sectors which have existing decarbonisation technological and politically and economically feasible policy solutions. Importantly, industrial decarbonisation needs to be addressed in a way that does not compromise the rate and scale of electricity sector decarbonisation.

49 https://www.dailymaverick.co.za/article/2021-10-01-smelly-midnight-lifeline-karpowership-gets-another-extension-for-emergency-power-deal/; https://www.businesslive.co.za/bd/opinion/2021-03-23-nod-to-high-proportion-of-gas-to-power-ships-is-fishy/

Government and industry policy developments

It has been problematic for government as a whole to impose on industry its policy of top-down sector and company emissions budgets. One reason is explained by Meckling et al[50]. Firstly, idealized economic agents in models are often modelled to respond, marginally, to marginal changes. While that might apply to a large number of consumers responding to price signals among a large number of products (if you put taxes on whisky up, they shift to wine…) that's not how investments in lumpy, long economic life major capital investments work. In this case, the effect of a slowly increasing cost, as Meckling *et al indicate:* "*…imposes costs on the powerful few—well-organized energy and energy-intensive manufacturing firms—and provides dispersed benefits to the weak many—the broader public. The few regulatory losers have greater incentives and capacity to organize politically and prevent policy implementation. Therefore, polluters shape the political game more than potential winners.*" This is a decades old story in South Africa, especially with a weak state, which in the State Capture[51] era has become so weak the rule based constitutional democracy has been at risk. Basically, (with some exceptions,) the big corporate incumbents have called the tune[52]. Another cause of the challenge for government to formulate and implement effective mitigation policy for heavy industry is the contradiction of state-owned electricity monopoly and the DMRE persisting with pro-coal and anti-renewable energy actions for electricity generation when mitigation options for electricity are far less costly than for heavy industry. Addressing this policy contradiction will garner support from industry for mitigation policy. Also, international trade and technology developments have over the past three years very quickly changed fundamentals in the business context for many of South African businesses. South African business is now acknowledging that future survival, never mind success, lies in decarbonisation.

Decarbonisation of emissions intensive trade exposed industries (EITEIs) with complex transnational value chains such as chemicals and steel will require global sector decarbonisation to enable early participation of small economies such as South Africa. Specific example of this cooperation would be a combination of access to technology, participation in lead markets that have been created in some large industrialised countries to drive decarbonisation of these industries and open and fair markets for zero/low embodied emissions commodities and goods.

South African Green Iron (GI) concept

The so-called Green Iron concept is the opportunity for South Africa to export renewable energy embedded in beneficiated domestic iron ore, hugely increasing the value of this iron ore and so generating export revenues while facilitating accelerating sector decarbonisation. Such revenues could emerge as a significant foreign exchange earner for the South African economy to become essential to creating the macro-economic conditions needed to support a just transition, including replacing unsustainable coal export revenues and taxes. In addition, green HDRI investments would help enlarge the base for the entire renewable energy value chain in South Africa driving jobs creation. Ultimately, GI could be a foundational stepping stone on the path to accelerating primary steel decarbonisation and a sustainable and profitable revitalization of South African industry.

Primary iron/steel production is the biggest global industrial emitter of greenhouse gasses (GHGs). Most emissions come from the production of primary iron from iron-ore. Many countries and steelmakers have announced net-zero commitments. Technologies to produce zero-emissions "green iron" (GI) exist. Much progress has been made on hydrogen direct-reduced iron (HDRI). It is not yet proven at commercial scale but there are strong indications it will be in the next 5-10 years. Though it will cost more than conventional/current technologies at first, demand is anticipated in some markets and end-uses such as voluntary supply chain decarbonisation, markets regulated by end-use standards, government procurement or

50 Meckling, J. et al. (2015) 'Winning Coalitions for Climate Policy How Industrial Policy Builds Support for Carbon Regulation', Science. doi: 10.1126.

51 Baker, Lucy. Burton, Jesse. Trollip, Hilton. (2020) 'The Energy Politics of South Africa', in Hancock, K. J. and Allison, J. E. (eds) §The Oxford Handbook of Energy Politics. Oxford University Press. doi: 9780190861360.001.0001.

52 Tyler, E. and Hochstetler, K. (2021) 'Institutionalising decarbonisation in South Africa: navigating climate mitigation and socio-economic transformation', Environmental Politics. Routledge, pp. 1–22. ; Trollip, H. et al. (2020) Linking the international climate regime to the political economy barriers of raising ambition. H2020 COP21 Ripples. Available at: www.cop21ripples.eu/wp-content/uploads/2020/02/RIPPLES_D4.4a_Main-Report.pdf.

car-buyers prepared to pay 1-2% more for vehicles with zero embodied emissions steel.

Commercial-scale GI plants have been announced to begin operating in the EU from 2024-2030. Policy-created “Lead Markets” with decarbonisation targets, R&D support, market protection, and (public and private sector) policy-driven “market-pulls” are driving competitive innovation. These include voluntary commitments (e.g. Orsted & Volvo) and government actions such as regulations for environmental footprints of buildings and direct government green procurement mentioned in formal policy documents such as the EU New Industrial Policy. Lead Markets are a core element of EU Industrial Policy.

As decarbonisation accelerates, it is likely that it will be less costly to produce GI in South Africa than in the EU. This is mainly because of the abundant, very low-cost renewable energy potential in South Africa and the predicted high demand for low-carbon electricity and hence higher electricity price in the EU, which has more limited renewable energy resources. A commercially competitive South African GI plant would have a dedicated solar PV supply, electrolysers and hydrogen storage for a continuous feed of hydrogen.

South African GI plants could feed into the ‘second phase’ of the establishment of HDRI, namely global diffusion, from around 2027-~2030, when the technology has been proven at scale in the initial EU lead market. GI could become a certified commodity feedstock for steelmaking.

Overall, the result of this research was that considerations of the potential for decarbonisation of iron and steel production underwent a fundamental shift from being viewed as ‘impossible to abate’ to developing a transition as detailed below, using innovations in technology and global value chain configurations. The final modelling result was that by 2035 green iron production is ‘chosen’ in the model under a 8Gt emissions cap as the preferred technology.

Production of GI at a South African location, for export to the EU, could have substantial financial and economic benefits for both South Africa and Europe. Such an arrangement could reduce the overall costs of EU decarbonisation while making its steel industry more competitive. To facilitate timely green HDRI investments, cooperation is required between South Africa, the EU and steelmakers in terms of technology accessibility and market access. This is possible within current policy frameworks but will require specific policy implementation mechanisms and efforts. It will need to navigate WTO, international trade, EU-single market, state-aid, level playing field etc. policies and rules within the context of the SA-EU Free Trade Agreement and Strategic Partnership. South African GI export plants will be feasible on purely commercial terms. The investment will be on basis of exports but product will be available for local markets. South Africa is not in the same position as the EU when it comes to creating a domestic market to warrant the large lumpy investment involved in a GI plant. However, GI will become more competitive with conventional iron across markets over time, as economies of scale and technology learning reduces costs and climate policy induces carbon pricing worldwide. Southern African markets will then be in a position to consider it for local use.

INTERNATIONAL ENABLERS

One primary enabler of South African emissions mitigation policy will be ongoing credible commitments and progress in other countries, and rich countries in particular, in implementing the Paris Agreement.

The second primary enabler flows from the first and regards means of support to South Africa for implementing a Just Transition (JT[53]). The history of South Africa’s extractive economy and current socio-economic conditions make it especially critical to attend to uneven distribution of costs and benefits, social costs and the potential for renewable energy to make a substantial contribution to economic development. The Presidential Climate Commission (PCC) has adopted the JT as a core organising principle for climate policy. A South African version of the just transition concept was mentioned in the Climate Change Response White Paper (DEA 2011). This was integrated by the National Planning Commission (NPC) with procedural and distributive justice elements within the just transition (JT) concept. The NPC has handed over the results of its engagement

53 For more detail on the JT and the PCC see Trollip, H. (2021) *“Climate emission mitigation policy ambition”* at pp139-144 of *“Climate ambition beyond emission numbers - Taking stock of progress by looking inside countries and sectors”* https://www.iddri.org/en/publications-and-events/report/climate-ambition-beyond-emission-numbers-taking-stock-progress

process (Vision and Pathways for a Just Transition to a low carbon, climate resilient economy and society[54]) to the Presidential Climate Commission (PCC). Integrated policy is only beginning to develop solutions to the institutional and governance processes involved in the rise of renewable energy technologies and demise of coal.

The Presidential Climate Commission has begun formulating the details for a Just Transition (JT) with a first set of concrete results in a report scheduled for completion in December 2021. Developing politically feasible solutions to structural issues in the economy that have resulted from centuries of extractive economic development is a complex challenge. The PCC has stated that: "…and one of the first tasks of the PCC is to understand the impacts of climate change on jobs, both positive and negative."

Thirdly, support to break through the electricity policy implementation impasse is critical, as a core national political challenge to getting onto a deep decarbonized emissions pathway. The urgent next steps involve construction and connection of as much new renewable energy electricity generation as is practicably possible firstly to fill the economically crippling electricity generation supply gap and then to implement (at least) some 20GW of new wind and PV generation specified in the IRP2019. In turn, addressing the very uneven distribution of costs and benefits linked to substantial expansion of renewable energy generation capacity, and phasing out of coal generation is one core requirement of addressing social justice issues and the associated legitimate[55] political challenge. Key stakeholders have made it clear that expansion of the renewable energy capacity, mainly through the REI4P mechanism, will not adequately distribute financial and economic benefits. At the same time, this expansion involves costs and losses among a separate group of stakeholders mainly related to coal electricity generation.

The benefits of the transition to renewable energy electricity generation can be substantially increased through integrating electricity policy with upstream renewable energy equipment manufacturing and downstream industrial utilisation of South Africa's comparative advantage in renewable energy generation costs. Although DDS does not require additional capex over CPS in the 2020-2030 decade, commitment to addressing social costs is a central aspect of the JT. In terms of international enablement, it would be necessary for South Africa to be convinced that there was credible international support for South Africa to commit to addressing these costs. Also, in line with Paris Agreement principles, it would be reasonable for SA to seek international support to address these costs. Last, in the 2030-2040 period although DDS is also GDP-neutral compared with CPS, in addition to social costs, very substantial additional investment costs will be required in electricity capital plant in DDS (R1518Bn) above those in CPS (R1118Bn), a difference of R400Bn. Also, over this period, in DDS existing coal power stations will be retired early and/or operated below the levels of CPS, yielding substantially lower revenues for these assets. International policy enablement will be necessary in terms of credible international commitments to Paris Agreement principles, both commitments to emissions reductions and international support to address these social costs, for finance for additional investments and to address substantial revenue losses. To assist with costs outlined above JT Plans involving international climate finance are being formulated within a Just Transition Transaction (JTT) [56]

The Just Transition Transaction (JTT)

President Ramaphosa communicated an initial sum of US$11Bn to the UNFCCC. Eskom, at the centre of the national JT is the monopoly, state-owned coal-based state-owned electricity utility at the centre of the 'creative destruction' and 'utility death spiral' that can't cover interest on its debt which has been major factor in downgrade of sovereign debt to junk and has announced its own Just Energy Transition (JET) which it has announced that it plans to present at COP26[57].

54 https://www.nationalplanningcommission.org.za/assets/Documents/Vision_and_Pathways_for_a_Just_Transition_to_a_low_carbon_climate.pdf

55 Legitimate in terms of core principles of South Africa's constitutional democracy

56 Winkler, H. et al. (2021) 'Just transition transaction in South Africa: an innovative way to finance accelerated phase out of coal and fund social justice', Journal of Sustainable Finance & Investment. Taylor & Francis, pp. 1–24. doi: 10.1080/20430795.2021.1972678.

57 https://www.news24.com/fin24/economy/eskom-in-talks-with-lenders-foreign-governments-to-fund-clean-energy-projects-20210806

Open and fair international trade in low-embodied emissions commodities and goods

A third priority area is energy-intensive trade-exposed industries (EITEIs). There is growing acknowledgement that global sector decarbonisation cooperation and associated policies could be more effective than purely national decarbonisation policies. This would require short-term action informed by long-term perspectives and trade policy cooperation to enable participation of countries with small markets for these industries. This is further detailed in the Industry section above.

The DDP is an initiative of the Institute for Sustainable Development and International Relations (IDDRI). It aims to demonstrate how countries can transform their economies by 2050 to achieve global net zero emissions and national development priorities, consistently with the Paris Agreement.. The DDP initiative is a collaboration of leading research teams currently covering 36 countries. It originated as the Deep Decarbonization Pathways Project (DDPP), which analysed the deep decarbonization of energy systems in 16 countries prior to COP21 (deepdecarbonization.org). Analyses are carried out at the national scale, by national research teams. These analyses adopt a long-term time horizon to 2050 to reveal the necessary short-term conditions and actions to reach carbon neutrality in national contexts. They help governments and non-state actors make choices and contribute to in-country expertise and international scientific knowledge. The aim is to help governments and non-state actors make choices that put economies and societies on track to reach a carbon neutral world by the second half of the century. Finally, national research teams openly share their methods, modelling tools, data and the results of their analyses to share knowledge between partners in a very collaborative manner and to facilitate engagement with sectoral experts and decision-makers.
www.ddpinitiative.org

The Institute for Sustainable Development and International Relations (IDDRI) is an independent, not-for-profit policy research institute based in Paris. Its objective is to identify the conditions and propose tools to put sustainable development at the heart of international relations and public and private policies. IDDRI is also a multi-stakeholder dialogue platform and supports stakeholders in global governance debates on the major issues of common interest, such as actions to mitigate climate change, protect biodiversity, strengthen food security, and to manage urbanisation. The institute also participates in work to build development trajectories that are compatible with national priorities and the sustainable development goals.

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