4SM

Mitigation and Development Pathways in the Near to Mid-term

Supplementary Material

Coordinating Lead Authors:
Franck Lecocq (France), Harald Winkler (Republic of South Africa)

Lead Authors:
Julius Partson Daka (Zambia), Sha Fu (China), James S. Gerber (the United States of America), Sivan Kartha (the United States of America/India), Volker Krey (Germany/Austria), Hans Lofgren (the United States of America/Sweden), Toshihiko Masui (Japan), Ritu Mathur (India), Joana Portugal-Pereira (Brazil), Benjamin K. Sovacool (Denmark), Maria Virginia Vilariño (Argentina), Nan Zhou (the United States of America)

Contributing Authors:
Michel den Elzen (the Netherlands), Reuben Dlamini (eSwatini), Noel Healy (the United States of America), Niklas Höhne (Germany), Angel Hsu (the United States of America/Singapore), Nina Khanna (the United States of America), Claire Lepault (France), Carlisle Ford Runge (the United States of America), Dimakatso Sebothoma (Republic of South Africa)

Review Editors:
Marzio Domenico Galeotti (Italy), Roque Pedace (Argentina)

Chapter Scientist:
Kaleem Anwar Mir (Republic of Korea/Pakistan)

This chapter should be cited as:
Lecocq, F., H. Winkler, J.P. Daka, S. Fu, J.S. Gerber, S. Kartha, V. Krey, H. Lofgren, T. Masui, R. Mathur, J. Portugal-Pereira, B. K. Sovacool, M. V. Vilariño, N. Zhou, 2022: Mitigation and development pathways in the near- to mid-term Supplementary Material. In IPCC, 2022: *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Available from https://www.ipcc.ch/report/ar6/wg3/.

Table of Contents

Table 4.SM.1 | Overview of methods used for projected emissions of NDCs and/or current policies. Adapted from Kuramochi et al. (2020); den Elzen et al. (2019).

Study	Policy cut-off[a] (month/year)	Regions	Sectors	Emissions[b]/ GWP (if applicable)	Scenarios[c]	Policies	Methods[d]	References
Climate Action Tracker	11/2018	Global (38 countries in detail)	Energy, AFOLU	Kyoto/AR4	CP, NDC	All policies	Literature review (official, national, international sources), supplemented by additional bottom-up analysis	Climate Action Tracker (2019) method: https://climateactiontracker.org/methodology/
PBL Netherlands Environmental Assessment Agency	11/2018	Global (G20 countries with policy detail, NDCs for 78 countries, covering 91% of 2012 GHG emissions)	Energy, AFOLU	Kyoto/AR4	CP, NDC	Expert-selected policies based on comprehensive policy inventory	CP: literature review (official, national, international sources), global IAM (IMAGE), ILM (GLOBIOM/G4M), NDC: FAIR model	Kuramochi et al. (2019) online tool: www.pbl.nl/indc
ADVANCE	4/2017*	Global	Energy, AFOLU	Kyoto/AR4	NDC	NDC: GHG targets	Set of global IAMs (AIM/CGE, IMAGE, IMACLIM, GCAM, GEM-E3, MESSAGE-GLOBIOM, POLES, REMIND, WITCH-GLOBIOM)	Luderer et al. (2018); Vrontisi et al. (2018) online database: https://db1.ene.iiasa.ac.at/ADVANCEDB/
CD-LINKS global	12/2016	Global, with regional detail	Energy, AFOLU	Kyoto/AR4	CP, NDC	CP: Comprehensive policies; NDC: GHG targets, additional policies	Set of global IAMs (AIM/CGE, IMAGE, GEM-E3, MESSAGEix-GLOBIOM, POLES, REMIND-MAgPIE, WITCH-GLOBIOM)	McCollum et al. (2018); Roelfsema et al. (2020) online database: https://db1.ene.iiasa.ac.at/CDLINKSDB/
JRC GECO 2019	03/2020	Global G20 countries with policy detail	Energy, AFOLU	Kyoto/SAR	CP, NDC	Expert-selected policies based on comprehensive policy inventory	CP: literature review (official, national, international sources), global IAM (POLES), ILM (GLOBIOM/G4M)	EU Joint Research Centre (2020)
NDC & INDC Factsheets	11/2016	Global (195 countries)	Energy, AFOLU	Kyoto/AR4	NDC	NDC: Emissions pathways	Literature review, IPCC scenario database	Meinshausen and Alexander (2017) http://climatecollege.unimelb.edu.au/ndc-indc-factsheets
Kuramochi et al. (2020)	11/2020	Non-G20 countries: Chile, Colombia, Democratic Republic of the Congo (DRC), Iran, Kazakhstan, Morocco, the Philippines, Thailand, and Ukraine	Energy, AFOLU	Kyoto/AR4	CP, NDC	CP: Comprehensive policies; NDC: GHG targets, additional policies	Literature review (official, national, international sources), supplemented by additional bottom-up analysis	Kuramochi et al. (2021, 2019)
Keesler et al. (2019)	11/2019	National (Argentina)	Energy, AFOLU	Kyoto/AR4	CP, NDC	CP: Comprehensive policies; NDC: GHG target	National ESM	Keesler et al. (2019)
Climateworks Australia	2018	National (Australia)	Energy, AFOLU	Kyoto/AR4	CP, NDC	CP: Comprehensive policies; NDC: GHG target	National ESM	ClimateWorks Australia (2018)
Commonwealth of Australia 2019	2019	National (Australia)	Energy, AFOLU	Kyoto/AR4	CP, NDC	CP: Comprehensive policies; NDC: GHG target	National ESM	Commonwealth of Australia (2019)

Study	Policy cut-off[a] (month/year)	Regions	Sectors	Emissions[b]/ GWP (if applicable)	Scenarios[c]	Policies	Methods[d]	References
Rochedo et al. (2018); Koberle et al. (2020)	12/2016	National (Brazil)	Energy, AFOLU	Kyoto/AR4	CP, NDC	CP: Comprehensive policies, NDC: GHG target	National ESM (BLUES)	Rochedo et al. 2018; Köberle et al. (2020)
Fu et al. (2017, 2018)	11/2017	National (China)	Energy	CO_2/NA	CP, NDC	NDC	National ESM (China)	Fu et al. (2017; Fu (2018)
Li et al. (2019)	12/2018	National (China)	Energy	CO_2/NA	CP, NDC	NDC: Emission peak by 2030	National ESM (China TIMES)	Li et al. (2019) Method: Shi et al. (2016)
Yang et al. (2018)	1/2017	National (China)	Energy	CO_2/NA	NDC	NDC: Emission peak, emission intensity	National ESM (China MAPLE), MACCs	Yang et al. (2018)
China Renewable Energy Outlook	4/2017*	National (China)	Energy	CO_2/NA	CP	CP: Stated policies and extrapolation of current policies	National ESM (CNREC scenario modeling tools)	ERI/CNREC (2017)
European Commission 2018	11/2018	Regional (EU)	Energy, AFOLU	Kyoto/AR4	CP, NDC	CP: Comprehensive policies; NDC: GHG target	Modeling tools for EU analysis (PRIMES, GAINS, GLOBIOM/G4M, CAPRI, GEM-E3, E3ME)	European Commission (2018) Method: https://ec.europa.eu/clima/policies/strategies/analysis/models_en
Vrontisi et al. (2019)	12/2016	Regional (EU)	Energy	Kyoto/AR4	CP, NDC	CP: Comprehensive policies; NDC: GHG target	Regional ESM and CGE model (PRIMES, GEM-E3)	Vrontisi et al. (2019)
Dusbash et al. (2018)	2011–2015	National (India)	Energy	CO_2/NA	CP, NDC	CP: Comprehensive policies; NDC: GHG target	Set of 15 national ESM studies with a base-year of current policies pre-2015 and 2015	Dubash et al. (2018)
Vishwanathan et al. (2018)	12/2016	National (India)	Energy	CO_2/NA	CP, NDC	CP: Comprehensive policies, NDC	National ESM (AIM/Enduse 3.0)	Vishwanathan et al. (2018); Vishwanathan and Garg (2020)
Mathur et al. (2019)	12/2016	National (India)	Energy	CO_2/NA	CP, NDC	CP: Comprehensive policies, NDC	National ESM (India MARKAL)	Mathur and Shekhar (2020)
Oshiro et al. (2019)	12/2016	National (Japan)	Energy, AFOLU	Kyoto/AR4	CP, NDC	CP, NDC	National ESM (AIM/Enduse, DNE21+)	Oshiro et al. (2019)
JMIP/EMF35	3/2018	National (Japan)	Energy, AFOLU	CO_2/NA, Kyoto gases/ AR4	NDC	NDC: GHG target	National ESMs (AIM/Enduse-Japan, AIM/Hub-Japan, DNE21-Japan, IEEJ-Japan)	Sugiyama et al. (2021)
Safonov et al. (2020)	12/2016	National (Russia)	Energy	CO_2/NA	CP, NDC	CP: Comprehensive policies, NDC	National energy systems models (Russia-TIMES)	Safonov et al. (2020)
Rhodium Group	11/2019	National (USA)	Energy	Kyoto/AR4	CP, NDC	CP: Comprehensive policies; NDC: GHG target	National ESM (USA)	Pitt et al. (2019)
EIA Annual Energy Outlook 2019	6/2018*	National (USA)	Energy	CO_2/NA	CP	CP: Current laws and regulations	National ESM (NEMS)	EIA (2019)
ENGAGE Global	07/2019	Global, with regional detail	Energy, AFOLU	Kyoto/AR4	CP, NDC	CP: Comprehensive policies; NDC: GHG targets, additional policies	Set of global IAMs (AIM/CGE, COFFEE, IMAGE, GEM-E3, MESSAGEix-GLOBIOM, POLES, REMIND-MAgPIE, TIAM-ECM, WITCH)	Riahi et al. (2021); Bertram et al. (2021a); Drouet et al. (2021); Hasegawa et al. (2021)
ENGAGE National Asia	03/2020	National (China, India, Japan, Korea, Thailand)	Energy, AFOLU	Kyoto/AR4	NDC	NDC: GHG targets	Set of national IAMs (AIM/Hub China, India, Japan, Korea, Thailand, Vietnam)	Fujimori et al. (2021)

Study	Policy cut-off[a] (month/year)	Regions	Sectors	Emissions[b]/ GWP (if applicable)	Scenarios[c]	Policies	Methods[d]	References
COMMIT	7/2019	Global with regional detail, National (Australia, Brazil, Canada, EU, India, Japan, Korea, Russia, USA)	Energy, AFOLU	CO_2/NA, Kyoto/AR4	CP, NDC	CP: Comprehensive policies; NDC: GHG targets, additional policies	Set of global and national ESMs/IAMs (global: AIM/CGE, COFFEE, IMAGE, MESSAGEix-GLOBIOM, POLES, PROMETHEUS, REMIND-MAgPIE, TIAM-Grantham, WITCH; national: AIM/CGE-Korea, AIM/Enduse-Japan, BLUES-Brazil, GCAM-USA, PRIMES, TIMES-Australia)	van Soest et al. (2021)
REMIND 2.1	06/2020*	Global with regional detail	Energy, AFOLU	Kyoto/AR4	CP, NDC for SSP1/2/5	CP: Stylized policies; NDC: GHG targets, stylized policies	Global IAM (REMIND)	Baumstark et al. (2021)
PEP1p5	08/2017*	Global with regional detail	Energy, AFOLU	Kyoto/AR4	CP, NDC	CP: Comprehensive policies; NDC: GHG targets, additional policies	Global IAM (REMIND-MAgPIE)	Kriegler et al. (2018)
CEMICS	05/2017	Global with regional detail	Energy, AFOLU	Kyoto/AR4	CP, NDC	NDC: GHG targets	Global IAM (REMIND)	Strefler et al. (2018)
van der Zwaan et al. 2018	11/2016*	National (Ethiopia)	Energy, AFOLU	CO_2/NA	CP		National IAM embedded in global IAM (TIAM-ECN ETH)	van der Zwaan et al. (2018)
Dalla Longa and van der Zwaan 2017	05/2016*	National (Kenya)	Energy, AFOLU	CO_2/NA	CP, NDC		National IAM embedded in global IAM (TIAM-ECN KEN)	Dalla Longa and van der Zwaan (2017)
Nogueira et al. (2020)	05/2019*	National (Madagascar)	Energy, AFOLU	CO_2/NA	CP, NDC		National IAM embedded in global IAM (TIAM-ECN MDG)	Nogueira et al. (2020)
Fortes et al. (2019)		National (Portugal)	Energy	CO_2, CH_4, N_2O/NA	NDC		National ESM (TIMES-Portugal)	Fortes et al. (2019)
Climate Equity Reference Calculator		Multi-national (91 countries and regions)	Energy, AFOLU	Kyoto/SAR	NDC		Literature review (NDC targets, emission inventories, exogenous emission pathways), spreadsheet calculation	Holz et al. (2018)
EMF36		Global with regional detail	Energy. AFOLU	CO_2/NA	NDC		Set of global CGEs (C-GEM, CGE-MOD, DART, EC-MSMR, EDF-GEPA, ENVISAGE, ICES-EMF, SNOW, TEA, WEGDYN)	Böhringer et al. (2021)
Wei et al. (2018)		National (China)	Energy	CO_2/NA	NDC (3 variants)		National IAM embedded in global IAM (C3IAM)	Wei et al. (2018)
NGFS	12/2020	Global with regional detail	Energy, AFOLU	Kyoto/AR4	CP/NDC	CP: Comprehensive policies; NDC: GHG targets, additional policies	Set of global IAMs (GCAM, MESSAGEix-GLOBIOM, REMIND-MAgPIE)	Bertram et al. (2021b)
Paris Reinforce		Global with regional detail, EU	Energy, (AFOLU)	CO_2/NA, Kyoto/AR4	CP/NDC	CP: Comprehensive policies; NDC: GHG targets, additional policies	Set of global IAMs (E3ME, GCAM-PR, GEMINI-E3, ICES-XPS, MUSE, NEMESIS) and regional IAM (E4SMA-EU-TIMES)	Sognnaes et al. (2021); Nikas et al. (2021)
van de Ven et al. (2021)		Global	Energy, AFOLU	Kyoto/AR4	NDC	NDC: GHG targets, additional policies	National IAM embedded in global IAM (GCAM-USA)	van de Ven et al. (2021)
Le Treut et al. (2020)		National (Argentina)	Energy	CO_2/NA	NDC	NDC: GHG targets, additional policies	National IAM (IMACLIM-ARG)	Le Treut et al. (2021)

Study	Policy cut-off[a] (month/year)	Regions	Sectors	Emissions[b]/ GWP (if applicable)	Scenarios[c]	Policies	Methods[d]	References
Panos et al. (2021)	2018	National (Switzerland)	Energy	CO_2/NA	CP	CP: Comprehensive policies	National ESM (Swiss TIMES Energy Systems Model)	Panos et al. (2021)
Rogelj et al. (2017)		Global	Energy, AFOLU	Kyoto/AR4	NDC	NDC: GHG targets, additional policies	Global IAM (MESSAGE-GLOBIOM)	Rogelj et al. (2017)
Benveniste et al. (2018)		Global	Energy, AFOLU	Kyoto/SAR	NDC	NDC: GHG targets, additional policies	Monte Carlo analysis of GHG emissions	Benveniste et al. (2018)

Notes: [a] In case policy cut-off date is not explicitly specified in the publication or accompanying information, the study submission date minus six months is used as proxy; [b] CO_2 = CO_2 only, Kyoto = Kyoto GHGs, SAR = IPCC Second Assessment Report, AR4 = IPCC Fourth Assessment Report; [c] CP = Current Policies, NDC = Nationally Determined Contribution; [d] IAM = Integrated Assessment Model, ESM = Energy Systems Model, ILM = Integrated Land Model, CGE = Computable General Equilibrium Model.

Table 4.SM.2 | Comparison of post-COVID and pre-COVID 2030 emissions projections. The comparison is based on current policy scenario projections for all GHG emissions, unless otherwise noted. All results rounded to .5%-point precision.

	Emissions[a]/Sectors[b]	Min	Max	References
Climate Action Tracker	Kyoto/all	–4%	–7%	Climate Action Tracker (2020)
IEA World Energy Outlook 2020[c]	CO_2/energy	–4%	–10%	IEA (2020)
UNEP Emissions Gap Report 2020	Kyoto/all	–3%	–7.5%	(UNEP 2020)
Dafonomilis et al. (2020)	Kyoto/all	–4%	–7.5%	Dafnomilis et al. (2020)
Dafonomilis et al. (2021[d])	Kyoto/all	–6%	–7.5%	Dafnomilis et al. (2021)
Kikstra et al. (2021[e])	Kyoto/all	–1.5%	–8.5%	Kikstra et al. (2021)
ENGAGE[f]	Kyoto/all	–3%	–6.5%	Riahi et al. (2021)
Pollitt et al. (2021[g])	CO_2/all	–3.5%	–3.5%	Pollitt et al. (2021)

Notes: [a] CO_2 = CO_2 only, Kyoto = Kyoto GHGs [b] all = all sectors including AFOLU emissions, energy = energy related emissions [c] Stated Policies Scenario, scenario 'incorporates our assessment of all the policy ambitions and targets that have been legislated for or announced by governments around the world' (IEA 2020), and 'assumes that significant risks to public health are brought under control over the course of 2021, allowing for a steady recovery in economic activity'. [d] Dafnomilis et al. (2021) range includes estimates from three models E3ME, GEM-E3, and IMAGE. [e] Kikstra et al. (2021) range based on four different recovery scenarios. [f] Riahi et al. (2021) range includes estimates from four models GEM-E3, MESSAGEix-GLOBIOM, POLES, REMIND-MAgPIE based on sensitivity analysis. [g] Pollitt et al. (2021) Green Recovery Plan scenario not included in range.

References

Baumstark, L. et al., 2021: REMIND2.1: transformation and innovation dynamics of the energy-economic system within climate and sustainability limits. *Geosci. Model Dev.*, **14(10)**, 6571–6603, doi:10.5194/gmd-14-6571-2021.

Benveniste, H. et al., 2018: Impacts of nationally determined contributions on 2030 global greenhouse gas emissions: Uncertainty analysis and distribution of emissions. *Environ. Res. Lett.*, **13(1)**, 014022, doi:10.1088/1748-9326/aaa0b9.

Bertram, C. et al., 2021a: Energy system developments and investments in the decisive decade for the Paris Agreement goals. *Environ. Res. Lett.*, **16(7)**, 074020, doi:10.1088/1748-9326/ac09ae.

Bertram, C. et al., 2021b: *NGFS Climate Scenarios Database - Technical Documentation V2.2*. 90 pp. https://www.ngfs.net/sites/default/files/ngfs_climate_scenarios_technical_documentation__phase2_june2021.pdf (Accessed November 1, 2021).

Böhringer, C., S. Peterson, T.F. Rutherford, J. Schneider, and M. Winkler, 2021: Climate policies after Paris: Pledge, Trade and Recycle: Insights from the 36th Energy Modeling Forum Study (EMF36). *Energy Econ.*, **103**, 105471, doi:10.1016/j.eneco.2021.105471.

Climate Action Tracker, 2019: *Warming Projections Global Update December 2019*. Climate Action Tracker (Climate Analytics, NewClimate Institute), 33 pp. https://climateactiontracker.org/documents/790/CAT_2020-09-23_Briefing_GlobalUpdate_Sept2020.pdf.

Climate Action Tracker, 2020: *Pandemic recovery: Positive intentions vs policy*. Climate Action Tracker (Climate Analytics, NewClimate Institute), 25 pp. https://climateactiontracker.org/documents/790/CAT_2020-09-23_Briefing_GlobalUpdate_Sept2020.pdf.

ClimateWorks Australia, 2018: *Tracking progress to net zero emissions: National progress on reducing emissions across the Australian economy and outlook to 2030*. ClimateWorks Australia, 21 pp.

Commonwealth of Australia, 2019: *Australia's Emissions Projections 2019.* Department of the Environment and Energy. https://industry.gov.au/sites/default/files/2020-07/australias-emissions-projections-2019-report.pdf (Accessed November 1, 2021).

Dafnomilis, I. et al., 2020: *Exploring the impact of COVID-19 pandemic on global emission projections: Assessment of green vs. 'not green' recovery*. PBL Netherlands Environmental Agency, The Hague, The Netherlands, and New Climate Institute, Koln, Germany, 44 pp.

Dafnomilis, I. et al., 2021: Targeted green recovery measures in a post-COVID-19 world enable the energy transition. (submitted for publication) doi.org/10.21203/rs.3.rs-667715/v1.

Dalla Longa, F. and B. van der Zwaan, 2017: Do Kenya's climate change mitigation ambitions necessitate large-scale renewable energy deployment and dedicated low-carbon energy policy? *Renew. Energy*, **113**, 1559–1568, doi:10.1016/j.renene.2017.06.026.

den Elzen, M. et al., 2019: Are the G20 economies making enough progress to meet their NDC targets? *Energy Policy*, **126**, 238–250, doi:10.1016/j.enpol.2018.11.027.

Drouet, L. et al., 2021: Net zero-emission pathways reduce the physical and economic risks of climate change. *Nat. Climate Chang.*, **11**, 1070-1076, doi: 10.1038/s41558-021-01218-z.

Dubash, N., R. Khosla, N.D. Rao, and A. Bhardwaj, 2018: India's energy and emissions future: an interpretive analysis of model scenarios. *Environ. Res. Lett.*, **13(7)**, 074018, doi:10.1088/1748-9326/aacc74.

EIA, 2019: *Annual Energy Outlook*. US Energy Information Administration, Washington, DC, USA, 83 pp. https://www.eia.gov/outlooks/aeo/pdf/aeo2019.pdf (Accessed November 1, 2021).

ERI/CNREC, 2017: *China Renewable Energy Outlook*. Energy Research Institute of the Academy of Macroconomic Research/NDRC, and China National Renewable Energy Centre, 681 pp. https://www.dena.de/fileadmin/dena/Dokumente/Themen_und_Projekte/Energiesysteme/CREO-2017-EN-20171113-1.pdf (Accessed November 1, 2021).

European Commission, 2018: *In-depth analysis in support on the COM(2018) 773: A Clean Planet for all – A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy*. European Commission (EC), Brussels, Belgium.

European Commission, Joint Research Centre, Keramidas, K., Tamba, M., Diaz-Vazquez, A., et al., *Global energy and climate outlook 2019 : electrification for the low-carbon transition : the role of electrification in low-carbon pathways, with a global and regional focus on EU and China*, Publications Office, 2020.Fortes, P. et al., 2019: *Trabalhos de base para o Roteiro para a Neutralidade Carbónica 2050*.

Fu, S., 2018: Personal communication. National Center for Climate Change Strategy and International Cooperation (NCSC).

Fu, S., J. Zhou, and L. Liu, 2017: *An analysis of China's INDC (Updated analysis 2017).* MILES report. China National Center for Climate Change Strategy and International Cooperation (NCSC).

Fujimori, S. et al., 2021: A framework for national scenarios with varying emission reductions. *Nat. Clim. Change*, **11(6)**, 472–480, doi:10.1038/s41558-021-01048-z.

Hasegawa, T. et al., 2021: Land-based implications of early climate actions without global net-negative emissions. *Nat. Sustain.*, **(4)**, 1052–1059, doi:10.1038/s41893-021-00772-w.

Holz, C., S. Kartha, and T. Athanasiou, 2018: Fairly sharing 1.5: National fair shares of a 1.5°C-compliant global mitigation effort (D1500, Trans.). *Int. Environ. Agreements Polit. Law Econ.*, **18(1)**, 117–134, doi:10.1007/s10784-017-9371-z.

IEA, 2020: *World Energy Outlook 2020*. International Energy Agency (IEA), Paris, France.

Keesler, D., L. Orifici, and G. Blanco, 2019: *Situación actual y proyección de emisiones de gases de efecto invernadero en la Argentina*. Universidad Nacional del Centro de la Provincia de Buenos Aires, Buenos Aires, Argentina.

Kikstra, J.S. et al., 2021: Climate mitigation scenarios with persistent COVID-19-related energy demand changes. *Nat. Energy*, **(6)**, 1114–1123, doi:10.1038/s41560-021-00904-8.

Köberle, A.C., P.R.R. Rochedo, A.F.P. Lucena, A. Szklo, and R. Schaeffer, 2020: Brazil's emission trajectories in a well-below 2°C world: the role of disruptive technologies versus land-based mitigation in an already low-emission energy system. *Clim. Change*, **162(4)**, 1823–1842, doi:10.1007/s10584-020-02856-6.

Kriegler, E. et al., 2018: Short term policies to keep the door open for Paris climate goals. *Environ. Res. Lett.*, **13(7)**, 074022, doi:10.1088/1748-9326/aac4f1.

Kuramochi, T. et al., 2019: *Greenhouse gas mitigation scenarios for major emitting countries. Analysis of current climate policies and mitigation commitments: 2019 update*. New Climate Institute, Koln, Germany, PBL Netherlands Environmental Agency, The Hague, The Netherlands, and IIASA, Laxenburg, Austria, 155 pp. https://www.pbl.nl/en/publications/greenhouse-gas-mitigation-scenarios-for-major-emitting-countries-2019-update.

Kuramochi, T. et al., 2020: *Global Emissions Trends and G20 Status and Outlook.* Emissions Gap Report 2020, Kenya, Nairobi.

Kuramochi, T. et al., 2021: Greenhouse gas emission scenarios in nine key non-G20 countries: An assessment of progress toward 2030 climate targets. *Environ. Sci. Policy*, **123**, 67–81, doi:10.1016/J.ENVSCI.2021.04.015.

Le Treut, G., J. Lefèvre, F. Lallana, and G. Bravo, 2021: The multi-level economic impacts of deep decarbonization strategies for the energy system. *Energy Policy*, **156**, 112423, doi:10.1016/j.enpol.2021.112423.

Li, N. et al., 2019: Air Quality Improvement Co-benefits of Low-Carbon Pathways toward Well below the 2°C Climate Target in China. *Environ. Sci. Technol.*, **53(10)**, 5576–5584, doi:10.1021/acs.est.8b06948.

Luderer, G. et al., 2018: Residual fossil CO_2 emissions in 1.5–2 °C pathways. *Nat. Clim. Chang.*, **8(7)**, doi:10.1038/s41558-018-0198-6.

Mathur, R. and S. Shekhar, 2020: India's energy sector choices—options and implications of ambitious mitigation efforts. *Clim. Change*, **162(4)**, 1893–1911, doi:10.1007/S10584-020-02885-1.

McCollum, D.L. et al., 2018: Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals. *Nat. Energy*, **3(7)**, doi:10.1038/s41560-018-0179-z.

Meinshausen, M. and R. Alexander, 2017: NDC & INDC Factsheets – Climate and Energy College, University of Melbourne, Australia.

Nikas, A. et al., 2021: Where is the EU headed given its current climate policy? A stakeholder-driven model inter-comparison. *Sci. Total Environ.*, **793**, 148549, doi:10.1016/J.SCITOTENV.2021.148549.

Nogueira, L.P., F.D. Longa, and B. van der Zwaan, 2020: A cross-sectoral integrated assessment of alternatives for climate mitigation in Madagascar. *Clim. Policy*, **20(10)**, 1257–1273, doi:10.1080/14693062.2020.1791030.

Oshiro, K. et al., 2019: Mid-century emission pathways in Japan associated with the global 2°C goal: National and global models' assessments based on carbon budgets. *Clim. Change*, doi:10.1007/s10584-019-02490-x.

Panos, E., T. Kober, K. Ramachandran, and S. Hirschberg, 2021: *Long-term Energy Transformation Pathways: Integrated Scenario Analysis with the Swiss TIMES Energy Systems Model*. Paul Scherrer Institute, Villigen, Switzerland, 146 pp. https://sccer-jasm.ch/JASMpapers/JASM_results_stem.pdf.

Pitt, H. et al., 2019: Taking Stock 2019. US Climate Service, Rhodium Group, New York, NY, USA, https://rhg.com/research/taking-stock-2019/ (Accessed November 1, 2021).

Pollitt, H., R. Lewney, B. Kiss-Dobronyi, and X. Lin, 2021: Modelling the economic effects of COVID-19 and possible green recovery plans: a post-Keynesian approach. *Clim. Policy*, 1–15, doi:10.1080/14693062.2021.1965525.

Riahi, K. et al., 2021: Implications of avoiding temperature overshoot for the attainability and costs of stringent mitigation targets. *Nat. Clim. Change*, **11**, 1063-1069, doi: 10.1038/s41558-021-01215-2.

Rochedo, P.R.R. et al., 2018: The threat of political bargaining to climate mitigation in Brazil. *Nat. Clim. Change*, **8(8)**, 695–698, doi:10.1038/s41558-018-0213-y.

Roelfsema, M. et al., 2020: Taking stock of national climate policies to evaluate implementation of the Paris Agreement. *Nat. Commun.*, **11(1)**, 2096, doi:10.1038/s41467-020-15414-6.

Rogelj, J. et al., 2017: Understanding the origin of Paris Agreement emission uncertainties. *Nat. Commun.*, **8**, 15748, doi:10.1038/ncomms15748.

Safonov, G. et al., 2020: The low carbon development options for Russia. *Clim. Change*, **162(4)**, 1929–1945, doi:10.1007/s10584-020-02780-9.

Shi, J., W. Chen, and X. Yin, 2016: Modelling building's decarbonization with application of China TIMES model. *Appl. Energy*, **162**, 1303–1312, doi:10.1016/J.APENERGY.2015.06.056.

Sognnaes, I. et al., 2021: A multi-model analysis of long-term emissions and warming implications of current mitigation efforts. *Nat. Climate Chang.*, **11**, 1055–1062, doi: 10.1038/s41558-021-01206-3.

Strefler, J. et al., 2018: Between Scylla and Charybdis: Delayed mitigation narrows the passage between large-scale CDR and high costs. *Environ. Res. Lett.*, **13(4)**, 044015, doi:10.1088/1748-9326/aab2ba.

Sugiyama, M. et al., 2021: EMF 35 JMIP study for Japan's long-term climate and energy policy: Scenario designs and key findings. *Sustain. Sci.*, **16(2)**, 355–374, doi:10.1007/s11625-021-00913-2.

UNEP, 2020: *Emissions gap report 2020*. Unite Nations Environment Programme (UNEP), Kenya, Nairobi.

van de Ven, D. et al., 2021: The Impact of U.S. Re-engagement in Climate on the Paris Targets. *Earth's Future*, **9(9)**, doi:10.1029/2021EF002077.

van der Zwaan, B., A. Boccalon, and F. Dalla Longa, 2018: Prospects for hydropower in Ethiopia: An energy-water nexus analysis. *Energy Strateg. Rev.*, **19**, 19–30, https://doi.org/10.1016/j.esr.2017.11.001.

van Soest, H.L. et al., 2021: Global roll-out of comprehensive policy measures may aid in bridging emissions gap. *Nat. Commun.*, doi: 10.1038/s41467-021-26595-z.

Vishwanathan, S.S. and A. Garg, 2020: Energy system transformation to meet NDC, 2 °C, and well below 2°C targets for India. *Clim. Change*, **(162)**, 1877–1891, doi:10.1007/s10584-019-02616-1.

Vishwanathan, S.S., A. Garg, V. Tiwari, and P.R. Shukla, 2018: India in 2°C and well below 2°C worlds: Opportunities and challenges. *Carbon Manag.*, **9(5)**, 459–479, doi:10.1080/17583004.2018.1476588.

Vrontisi, Z. et al., 2018: Enhancing global climate policy ambition towards a 1.5°C stabilization: A short-term multi-model assessment. *Environ. Res. Lett.*, **13(4)**, doi:10.1088/1748-9326/aab53e.

Vrontisi, Z., K. Fragkiadakis, M. Kannavou, and P. Capros, 2019: Energy system transition and macroeconomic impacts of a European decarbonization action towards a below 2°C climate stabilization. *Clim. Change*, doi:10.1007/s10584-019-02440-7.

Wei, Y.-M. et al., 2018: An integrated assessment of INDCs under Shared Socioeconomic Pathways: an implementation of C^3IAM. *Nat. Hazards*, **92(2)**, 585–618, doi:10.1007/s11069-018-3297-9.

Yang, X., F. Teng, X. Xi, E. Khayrullin, and Q. Zhang, 2018: Cost–benefit analysis of China's Intended Nationally Determined Contributions based on carbon marginal cost curves. *Appl. Energy*, **227**, 415–425, doi:10.1016/j.apenergy.2017.08.016.