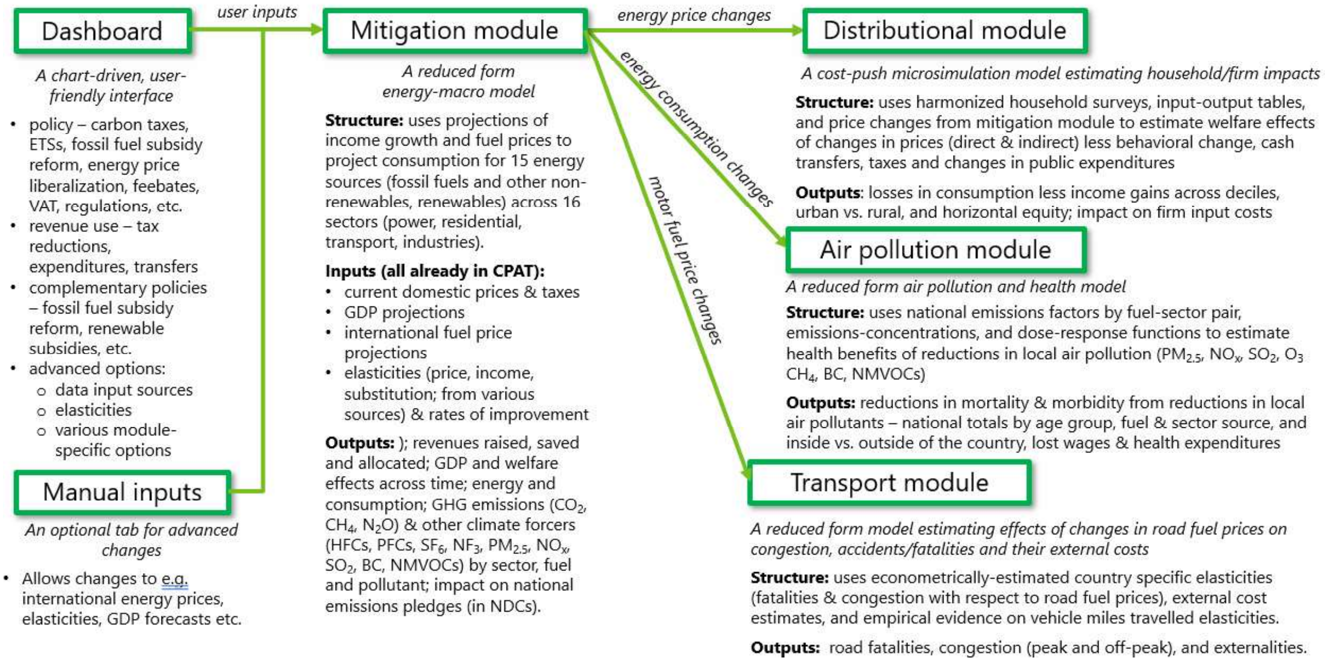
2. Overview of CPAT Structure

CPAT is a spreadsheet-based 'model of models' with four key components ('modules'; Figure 2):

1. **Mitigation module –** a reduced-form macro-energy model for estimating impacts of climate mitigation policies on energy consumption, prices, GHGs, local air pollutants, revenues, GDP, and welfare;
2. **Distribution module –** a cost-push microsimulation model for estimating impacts of energy and non-energy price changes on industries and households (by consumption decile and region), net of revenues used ('revenue recycling') for public investment, transfers, or personal income tax (PIT) cuts;
3. **Air pollution module –** a reduced-form air pollution and health model for estimating impacts on premature deaths and disease from local air pollutants like fine particles (e.g., $PM_{2.5}$) and ozone; and
4. **Transport module –** a reduced-form model for estimating the impacts of motor fuel price changes on congestion and road accidents/fatalities as well as their external costs.

Figure 2. Overview of CPAT Structure



Source: IMF and WB staff.

The user interacts primarily with the 'Dashboard' without the need to input external data (Figure 3). The Dashboard is a chart-driven, user-friendly interface. The user selects the country of interest, mitigation 'policy scenario' (e.g., carbon or energy taxes), the strength/coverage of the policy (across fuels and sectors), and complementary policies (e.g., fossil fuel subsidy reform, energy price liberalization, and feed-in subsidies for renewables). Any revenues raised or saved can be allocated to tax reductions, current spending, public investment, or transfers. Key parameters (e.g., price and income elasticities) can be customized by the user. Within seconds, the user sees the main results in six key charts[26] and over 100 more detailed charts. CPAT does not require any external data to function for the countries covered, but users can input such data (e.g., on domestic energy prices) in the 'Manual Inputs' tab.

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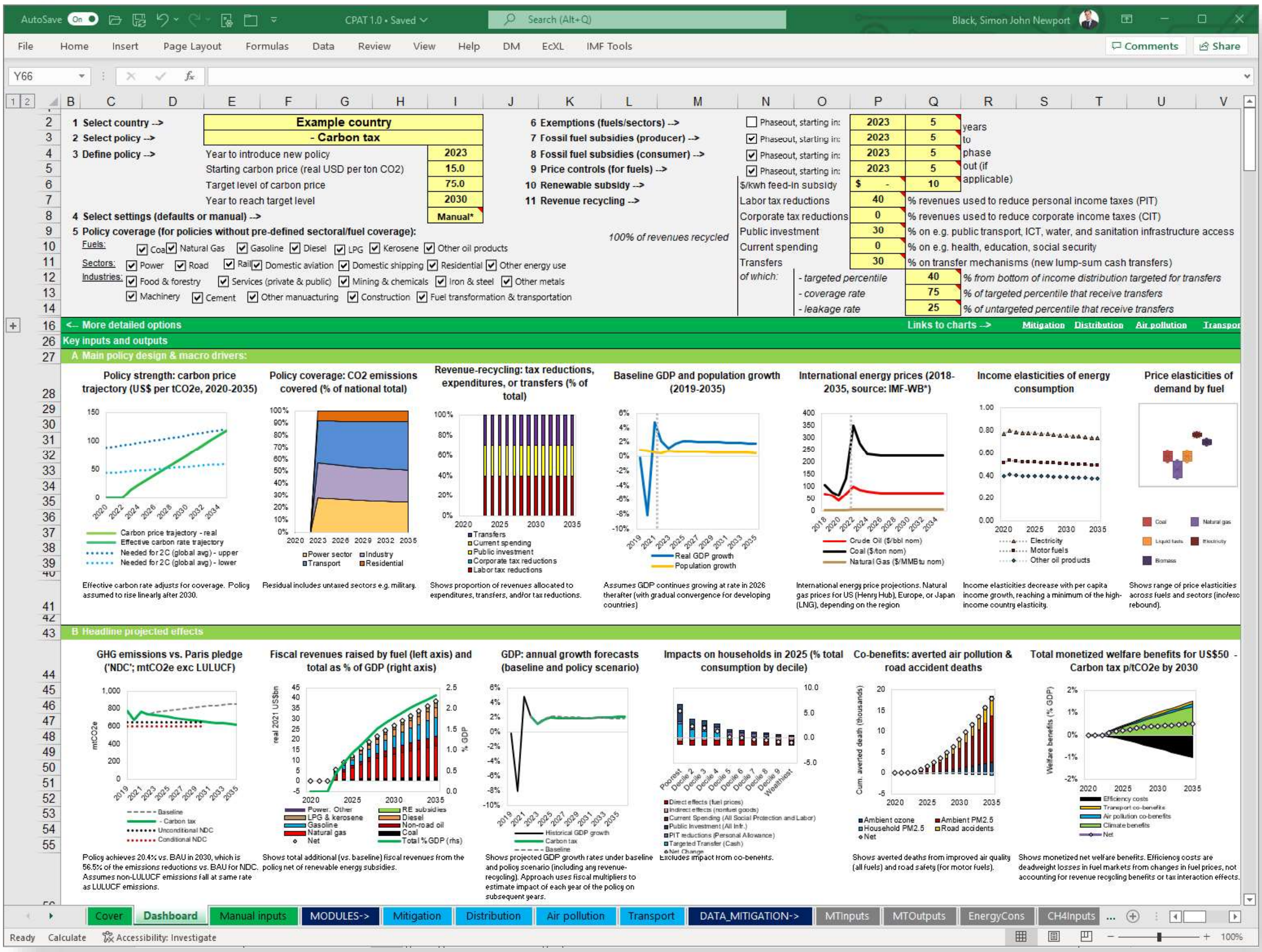
[26] Key charts include: GHG emissions projections compared with NDCs in the BAU and policy scenarios, net changes in fiscal revenues by fuel source in the policy scenario, GDP impacts by component, incidence impacts on household consumption deciles, averted premature deaths from improvements in air quality and road safety, and net changes in welfare by component (abatement costs less monetized externality benefits from climate and health/transport co-benefits).

Figure 3. CPAT Main Interface ('Dashboard')



1 Select country --> Example country
2 Select policy --> - Carbon tax
3 Define policy -->
Year to introduce new policy: 2023
Starting carbon price (real USD per ton CO2): 15.0
Target level of carbon price: 75.0
Year to reach target level: 2030
4 Select settings (defaults or manual) --> Manual*
5 Policy coverage (for policies without pre-defined sectoral/fuel coverage):
Fuels: ☑ Coal ☑ Natural Gas ☑ Gasoline ☑ Diesel ☑ LPG ☑ Kerosene ☑ Other oil products
Sectors: ☑ Power ☑ Road ☑ Rail ☑ Domestic aviation ☑ Domestic shipping ☑ Residential ☑ Other energy use
Industries: ☑ Food & forestry ☑ Services (private & public) ☑ Mining & chemicals ☑ Iron & steel ☑ Other metals ☑ Machinery ☑ Cement ☑ Other manuacturing ☑ Construction ☑ Fuel transformation & transportation

6 Exemptions (fuels/sectors) --> ☐ Phaseout, starting in: 2023 5
7 Fossil fuel subsidies (producer) --> ☑ Phaseout, starting in: 2023 5
8 Fossil fuel subsidies (consumer) --> ☑ Phaseout, starting in: 2023 5
9 Price controls (for fuels) --> ☑ Phaseout, starting in: 2023 5
years to phase out (if applicable)
10 Renewable subsidy --> $/kwh feed-in subsidy $ - 10
11 Revenue recycling -->
100% of revenues recycled
Labor tax reductions: 40 % revenues used to reduce personal income taxes (PIT)
Corporate tax reductions: 0 % revenues used to reduce corporate income taxes (CIT)
Public investment: 30 % on e.g. public transport, ICT, water, and sanitation infrastructure access
Current spending: 0 % on e.g. health, education, social security
Transfers: 30 % on transfer mechanisms (new lump-sum cash transfers)
of which:
- targeted percentile 40 *% from bottom of income distribution targeted for transfers*
- coverage rate 75 *% of targeted percentile that receive transfers*
- leakage rate 25 *% of untargeted percentile that receive transfers*

<-- More detailed options
Links to charts --> Mitigation Distribution Air pollution Transpor

Key inputs and outputs

A Main policy design & macro drivers:

Policy strength: carbon price trajectory (US$ per tCO2e, 2020-2035)
Effective carbon rate adjusts for coverage. Policy assumed to rise linearly after 2030.

Policy coverage: CO2 emissions covered (% of national total)
Residual includes untaxed sectors e.g. military.

Revenue-recycling: tax reductions, expenditures, or transfers (% of total)
Shows proportion of revenues allocated to expenditures, transfers, and/or tax reductions.

Baseline GDP and population growth (2019-2035)
Assumes GDP continues growing at rate in 2026 therafter (with gradual convergence for developing countries)

International energy prices (2018-2035, source: IMF-WB*)
International energy price projections. Natural gas prices for US (Henry Hub), Europe, or Japan (LNG), depending on the region

Income elasticities of energy consumption
Income elasticities decrease with per capita income growth, reaching a minimum of the high-income country elasticity.

Price elasticities of demand by fuel
Shows range of price elasticities across fuels and sectors (incl/exc rebound).

B Headline projected effects

GHG emissions vs. Paris pledge ('NDC'; mtCO2e exc LULUCF)
Policy achieves 20.4% vs. BAU in 2030, which is 56.5% of the emissions reductions vs. BAU for NDC. Assumes non-LULUCF emissions fall at same rate as LULUCF emissions.

Fiscal revenues raised by fuel (left axis) and total as % of GDP (right axis)
Shows total additional (vs. baseline) fiscal revenues from the policy net of renewable energy subsidies.

GDP: annual growth forecasts (baseline and policy scenario)
Shows projected GDP growth rates under baseline and policy scenario (including any revenue-recycling). Approach uses fiscal multipliers to estimate impact of each year of the policy on subsequent years.

Impacts on households in 2025 (% total consumption by decile)
Excludes impact from co-benefits.

Co-benefits: averted air pollution & road accident deaths
Shows averted deaths from improved air quality (all fuels) and road safety (for motor fuels).

Total monetized welfare benefits for US$50 - Carbon tax p/tCO2e by 2030
Shows monetized net welfare benefits. Efficiency costs are deadweight losses in fuel markets from changes in fuel prices, not accounting for revenue recycling benefits or tax interaction effects.

Source: IMF and WB staff.

The mitigation module, which is the core of CPAT, is a reduced-form macro-energy model. It provides, on a country-by-country basis, projections of energy demand and supply, prices, CO_2 and other GHG emissions by fuel and sector, revenues, GDP, abatement costs and welfare impacts, as well as several other metrics. These are estimated under the BAU scenario and for many different mitigation policies, including: carbon taxes, ETSs, fossil fuel subsidy reform, fuel/electricity taxes, energy price liberalization, renewables subsidies and feed-in tariffs, VAT harmonization, energy efficiency and emission rate standards, feebates, methane fees, and combinations of these policies ('policy mixes').

Figure 4 shows example outputs from the mitigation module. There are around 50 other charts available to the user with outputs including: energy demand and prices (including gaps to socially optimal price levels[27]); national emissions and electricity capacity, investment and generation by energy source; impacts on trade of energy goods; sectoral decarbonization targets (in NDCs); impacts on revenues from changes in taxes and subsidies on fuels, electricity, and renewables; impacts on GDP over time and by policy change (taxes, expenditures, investments, or transfers); GHG emissions by sector, gas, and fuel; and, finally, energy-related CO_2 emissions by sector, industry, and fuel. Additionally, key inputs are displayed graphically, including growth forecasts, global energy prices, and price and income elasticities.

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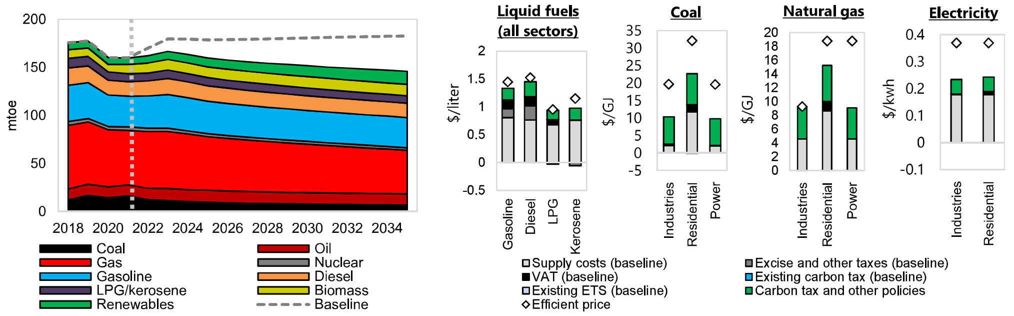
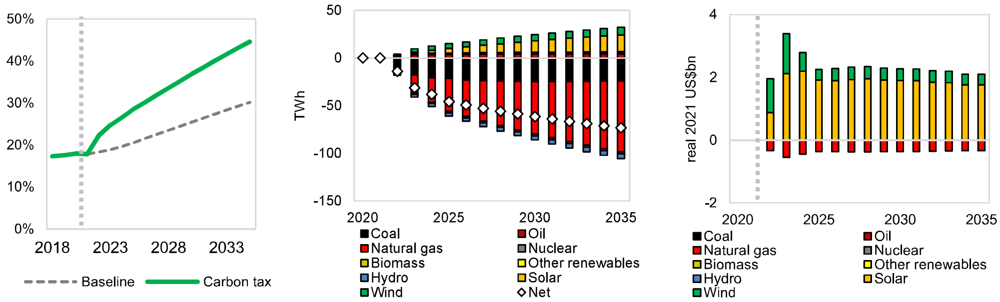
[27] See Parry and others (2021c)

Figure 4. Example Outputs from CPAT Mitigation Module
(for US$50 Carbon Price/ton CO$_2$e by 2030, Unspecified Country)

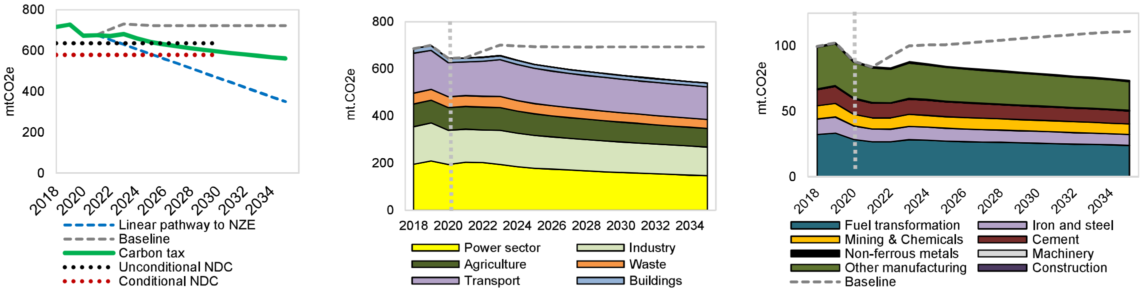
Panel A. Energy – Modelled total energy demand by fuel (left) and impacts on 2030 energy prices (right)



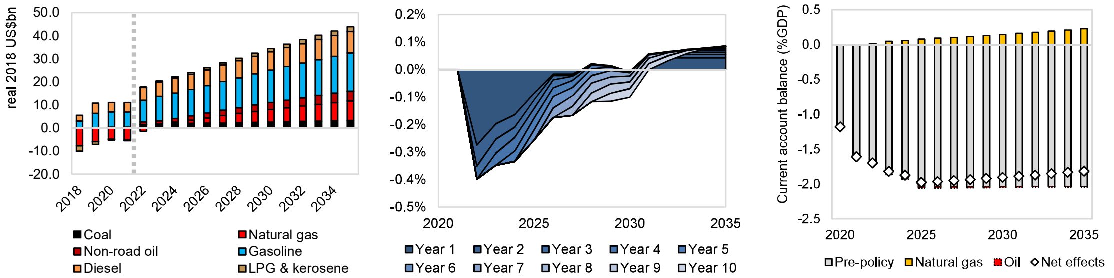
Panel B. Electricity – renewable shares of power generation (left), changes in generation by source (middle), and changes in annual investment in power capacity (right)



Panel C. Emissions – GHGs vs. targets (left), GHG by sector (middle), and industrial CO$_2$ emissions (right)



Panel D. Economic – revenues raised by fuel (left), net impacts on GDP levels by reform year (middle) and current account balance from reduced fuel imports (right)

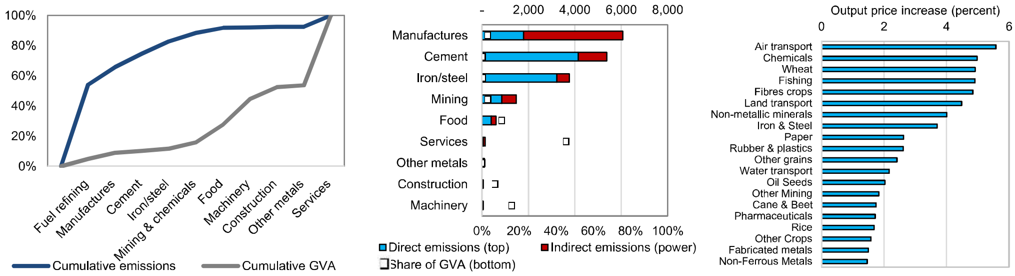


Source: IMF staff using CPAT.

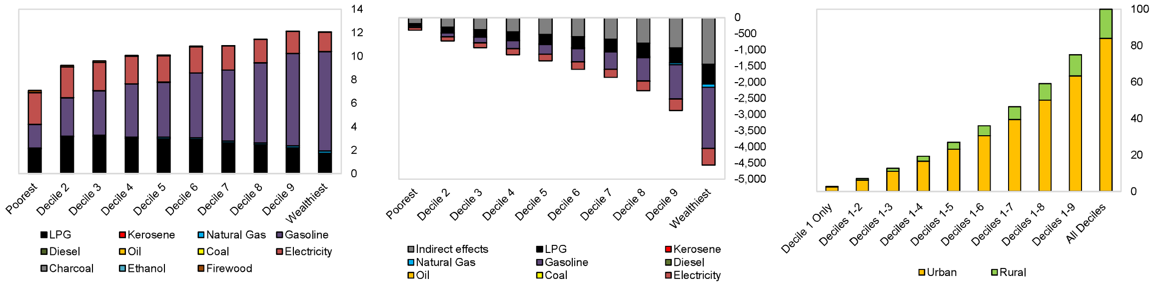
The distribution module estimates incidence impacts from climate mitigation policy on industries (for many sectors) and households (across and within deciles). Changes in energy prices affect industry input and, hence, production costs. Impacts are estimated for 59 non-energy sectors (e.g., steel, cement, chemicals). For households, detailed information on budget shares is used to estimate effects across consumption deciles, both ‘direct’ (from changes in energy prices) and ‘indirect’ (from changes in prices of non-energy goods and services), and on net (accounting for revenue recycling). Effects are estimated at the decile level and between urban and rural regions for a growing set of countries.[28]

Figure 5. Example Outputs from CPAT Distribution Module

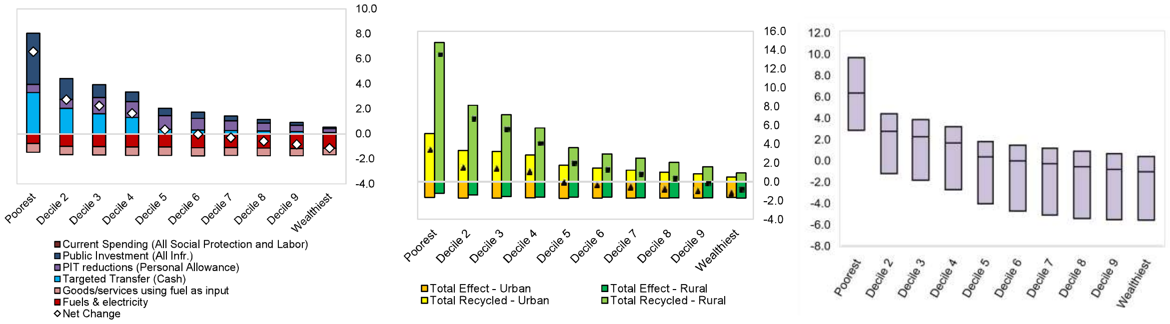
Panel A. Industry impacts – cumulative CO_2 emissions and gross value added (GVA) (left), emissions intensity of production (tCO_2 per $m GVA; middle), and price (cost) impacts on 20 of 59 most affected industries (right)



Panel B. Households – BAU energy consumption (percent of total by decile; left), initial impact on household consumption (absolute LCU by decile; middle), and cumulative revenues needed to compensate given household deciles (right)



Panel C. Net household incidence – mean consumption effect (percent pre-policy consumption; left), between urban and rural sub-samples (middle); and horizontal equity (for 25th-75th percentiles and median; right)



Source: IMF staff using CPAT. Note: LCU = local currency units.

Figure 5 illustrates some example outputs from the distribution module. These include impacts on industry, direct and indirect effects on households from changes in energy and other goods’/services’

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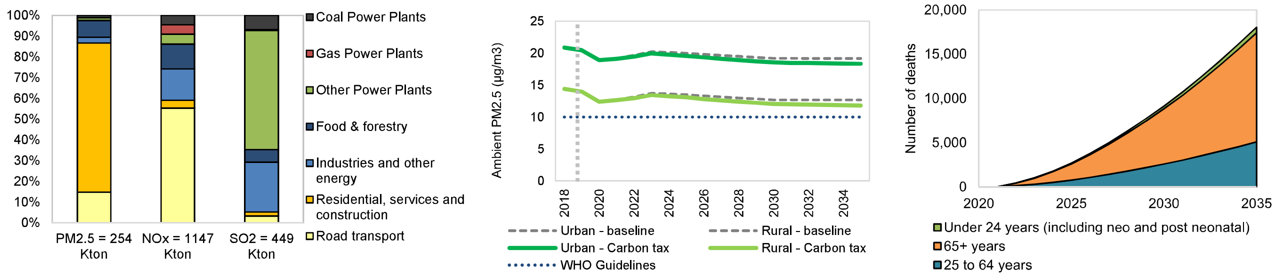
[28] Industry analysis requires input-output (IO) tables, which have been harmonized for 120 countries to date. Household analysis requires household budget surveys (HBSs), which have been harmonized for over 65 countries to date.

prices, and net incidence impacts (accounting for ‘revenue recycling’ i.e., use of revenues raised or saved for, e.g., PIT cuts or cash transfers). Around 25 figures are available, including: impacts on industrial input and output prices (for 59 sectors); composition of household consumption of energy and non-energy goods/services by decile; absolute consumption effects before and after revenue recycling by decile and between urban and rural sub-samples; cumulative share of revenues required for compensating given household deciles (e.g., bottom 10 percent); changes in inequality and horizontal equity (median, 25th, and 75th-percentile impacts within each decile for all, urban, and rural households).

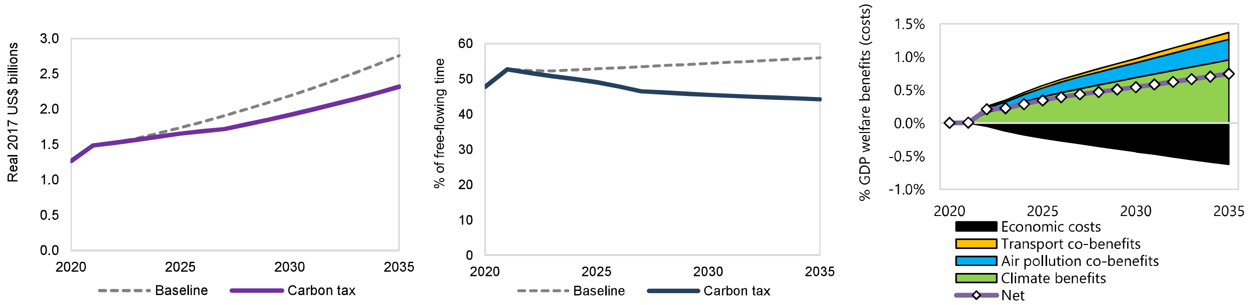
The two remaining modules (air pollution and transport) capture the welfare spillovers from climate policy on health, congestion, and road safety (known as ‘development co-benefits’). Fossil fuel combustion creates emissions of local air pollutants like fine particulate matter ($PM_{2.5}$, produced directly and indirectly from atmospheric reactions) and low-lying ozone (O_3). These contribute to the 4.5 million premature deaths (in 2019) from outdoor air pollution and many more instances of diseases like asthma and stroke (IHME 2020). Cuts in fuel combustion can, therefore, help improve human health. The air pollution module estimates these benefits by disease, age group, location, and source using several methods. Lastly, increases in road fuel prices tend to cut road accidents, congestion, and their associated external costs which, alongside other road sector impacts, are estimated by the transport module.

Figure 6. Example Outputs from CPAT Air Pollution and Transport Modules (for US$50 Carbon Price/ton CO_2e by 2030, Unspecified Country)

Panel A. Air Pollution – Baseline emissions of local air pollution by source and pollutant (left), changes in local air pollution concentrations (middle), and cumulative avoided deaths by age (right)



Panel B. Transport & Welfare – Congestion as a share of travel time (left), total road maintenance costs (middle), and annual monetized welfare benefits from reform (right)



Source: IMF staff using CPAT.

Example outputs from the air pollution and transport modules are shown in Figure 6. These include baseline emissions of $PM_{2.5}$, NO_x and SO_2 by source, impacts on urban and rural $PM_{2.5}$ concentrations, avoided deaths by age group, changes in congestion and road maintenance costs, and finally total net welfare impacts from the policy. There are around 50 other charts available, including: relative risk of diseases; emissions factors; baseline and changes in deaths by type (indoor, outdoor, ozone), sector, disease, and age group (infants, children, working age, and 65+); changes in morbidity (years lived with disease and disability adjusted-life years); GDP losses due to air pollution; avoided lost wages; savings in health expenditures by payee (government, private, and donors); and changes in external costs from reduced congestion, road accidents, and maintenance. These and other data on co-benefits can help governments fully appraise social, health, and welfare changes of different climate mitigation policies.

3. Mitigation Module

This section describes the mitigation module, including how the BAU and policy scenarios are modelled and impacts on key metrics of interest (energy demand, emissions, revenues, GDP, and welfare). For more technical details, see Annex I – Technical Details: Mitigation Module.

Modeling the BAU and Policy Scenario

To estimate the impacts of climate policy on metrics of interest, the mitigation module contains a 'business-as-usual' (BAU) and policy scenario. In both cases energy consumption is split into 15 fuels and electricity sources produced or consumed by 17 sectors:

- Energy sources – coal, natural gas, gasoline, diesel, kerosene, liquified petroleum gas (LPG), jet fuel, other oil products, electricity, wind, solar, hydro, other renewables, nuclear, and biomass.
- Sectors – consistent with UNFCCC, these include power generation, transport (road, rail, shipping, and aviation, including domestic and international), buildings (residential, food & forestry, public & private services), industries (mining & chemicals, iron & steel, other metals, machinery, cement, other manufacturing, construction, fuel transformation & transport), other energy use and non-energy use.

These are projected forward from a base of recently observed fuel and electricity consumption using:

- GDP projections (see Annex I: GDP for details);
- Domestic energy prices and projections of future international energy prices (See Annex I: Energy prices and International and domestic energy price projections);
- Assumptions about the income elasticity of demand and own-price elasticity of demand for fuels and electricity (see Annex I: Own-price elasticities of demand for energy products consumed by households and firms and Income elasticities of energy demand); and
- Assumptions on rates of technological change due to exogenous efficiency improvements in fuel-consuming assets and in the cost and productivity of key low-carbon technologies like renewables.

For more information on the energy sector see Energy Demand, Energy Supply and Energy Sector: Key Assumptions sections in Appendix I.

The model is parameterized using data compiled from various sources by country and sector. Energy demand and production data is from the International Energy Agency (IEA 2022a), Enerdata (2022), and other sources. GDP projections are from the latest IMF forecasts.[29] Data on energy taxes, subsidies, and prices by energy product has been compiled from publicly available and IMF sources, with inputs from proprietary and third-party sources.[30] International energy prices are projected forward using an average of WB and IMF projections for coal, oil, and natural gas prices, which are then used to project domestic prices using empirical estimates of pass-through by country.[31] Elasticities are calibrated to empirical evidence through an extensive literature review (Annex I) and yield estimates that are broadly in line with the mid-range of BAU emissions and policy scenario responsiveness implied by other models.

Given the power sector's importance for decarbonization, CPAT contains two power supply models. Climate mitigation requires decarbonizing electricity generation while electrifying end-uses of energy across sectors and for all countries. Power supply is estimated using two models: an elasticity-based model and a hybrid technology-explicit ('technoeconomic') model. The former uses elasticities which

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[29] Based on the IMF's World Economic Outlook for initial years, followed by assumptions of steady growth, including gradual convergence for developing countries to developed country GDP growth rates (estimated using the IMF-ENV CGE model): no country can sustain negative or high GDP growth in the long run. However, it should be noted these effects exclude the negative growth effects of global climate change. Adjustments in emissions projections are also made to account for partially permanent structural shifts in the economy caused by the pandemic.

[30] See Parry and others (2021c).

[31] These are empirically estimated and bucketed by the CPAT team, though are unity for most fuels and sectors. Pass-through rates less than 1 are assumed to imply that the government imposes price controls (e.g., government-imposed fuel pricing formulas) through subsidization. See Annex for further elaboration. For an alternative approach for projecting pass-through rates for motor fuels, see Kpodar and Abdallah (2016)

estimate changes in the generation mix in response to relative price changes (from fuel and other costs). The latter incorporates an explicit stock of power generation assets with an investment and dispatch decision. Projections of levelized costs of electricity (LCOE) for generation are combined with assumptions on retirement rates, capacity factors, physical or economic limitations, and the increasing need for storage. The system makes forward-looking investments in new capacity while dispatching existing assets. Electricity prices vary for industrial and residential users, which determines electricity demand.

In the BAU, current fuel taxes/subsidies and carbon pricing are held constant in real terms. This assumes countries do not add to or strengthen existing mitigation policies.[32] For fuels, it is assumed that international energy supply is able to meet demand with exogenous international fuel prices.

In the policy scenario, the user selects from a broad range of mitigation policies, including:

- Price-based policies **–** such as carbon pricing (carbon taxes and ETSs[33]), fuel and electricity taxes, fossil fuel subsidy reform, energy market reform such as price liberalization[34], VAT reform.
- Renewable subsidies **–** feed-in tariffs (equivalent to a renewable production tax credit) for renewable power generation (to accelerate adoption of wind and solar).
- Regulatory policies **–** emission rate standards, energy efficiency standards, and their 'fee and rebate' analogues ('feebates'; taxes on carbon intensive goods or production used to fund subsidies on low-carbon intensity goods or production).
- Policy mixes **–** the above can be combined, e.g., a carbon tax with fossil fuel subsidy reform, energy price liberalization, VAT harmonization and renewable subsidies.

Impacts of Policies on Energy, Emissions, and Achievement of NDCs

The impacts of price-based mitigation policies such as carbon pricing on fuel use and emissions depend on: (i) impacts on energy prices, and (ii) the price responsiveness of fuels by sector. In the industry, buildings, and transport sectors, price changes impact demand for fuels by incentivizing shifts to more efficient and cleaner technologies along with direct reductions in fuel demand (e.g., from reduced driving or reduced demand for steel). In the power sector, investments in new generation (to replace retirements or meet rising electricity demand) shift from fuels like coal and natural gas plants towards low-carbon technologies like solar and wind[35], subject to physical or economic limitations on scaleup alongside an increasing need for electricity storage. Dispatch depends based on the generation mix, with fuel-based power becoming more expensive, partially raising electricity prices and dampening power demand and, hence, overall generation. See Annex I: Impacts of Policies and Targets for more details.

Non-price policies such as regulations are modelled using a shadow pricing approach. Regulatory policies such as emission rates or energy efficiency standards enhance the efficiency of energy-consuming capital goods but generally have limited impacts on consumer prices. Given the large plethora of design choices for regulations, they are modelled similarly to price-based policies through a shadow price. This impacts the efficiency of energy-consuming capital goods without impacting direct demand for energy like a price-based policy would. This allows for comparisons of policies on energy consumption and emissions.

Total GHGs and local air pollutants are estimated via emissions factors by fuel, country, and sector. These are provided by the International Institute for Applied Systems Analysis (IIASA)[36] for:

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[32] This is comparable with the IPCC's 'current policies' scenario, which is SSP2-4.5 (Shared Socioeconomic Pathway; see IPCC 2022). The closest IEA equivalent is the Stated Policies Scenario – see IEA (2022a).

[33] Behavioral responses are assumed to be slightly lower for ETSs compared with carbon taxes as evidence suggests that the price uncertainty of permits impedes their relative cost effectiveness – see e.g., Aldy and Armitage (2020).

[34] Energy market reforms such as automatic pricing schemes reinforce the effectiveness of price-based policies such as ETSs in electricity markets. However, these need not be precursors to pricing – see Acworth and others (2020) for discussion.

[35] In default settings, hydroelectric capacity is assumed to be fixed as it is assumed that countries have already exhausted these opportunities. Nuclear is allowed to be phased-up (with a lag) in countries which already have fission reactors.

[36] Based on the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model; see Wagner and others (2020). Emissions factors for local air pollutants in the future are estimated using an average of current and planned policies.

- Greenhouse gases – the ‘Kyoto gases’ of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and F-gases (HFCs, PFCs, SF_6, NF_3). These are included in UNFCCC inventories except for NF_3.[37]
- Fine particulate matter ($PM_{2.5}$) and ozone (O_3) – includes PM sources from black carbon (BC), organic carbon (OC), volatile organic compounds (VOCs), carbon monoxide (CO), nitrous oxide (NO_x), and sulphur dioxide (SO_2). Ozone is formed when local air pollutants react in the presence of sunlight. $PM_{2.5}$ and, to a smaller degree, ozone cause millions of premature deaths globally, and are estimated by the air pollution module. They can also have localized warming or cooling effects, which are also estimated.[38]

CPAT’s mitigation module also includes non-energy emissions from: land use, land use change and forestry (LULUCF); agriculture; industrial processes; waste; and other sources. Historical GHGs are compiled by IMF staff using data from the UNFCCC, the Emissions Database for Global Atmospheric Research (EDGAR),[39] the Food and Agriculture Organization of the United Nations (FAO), and national sources.[40] LULUCF emissions are assumed to decline steadily for countries with positive emissions and be flat for countries with negative emissions.[41] Industrial process emissions scale with energy-CO_2. Agricultural CO_2 emissions scale with population and per-capita income while waste emissions scale with population. Methane emissions from agriculture, waste, and extractives are estimated using country-specific emissions factors, assuming autonomous technical change, GDP growth and, in the policy scenario, marginal abatement cost curves. Under default settings, non-CO_2, non-methane GHGs are assumed to change at the same rate as energy emissions.[42] See Annex I: Non-Energy Sectors for details.

Using this approach, mitigation pledges in NDCs can be estimated and compared. The mitigation module converts all quantifiable, economy-wide mitigation pledges into percent reductions vs. BAU in 2030 defined in terms of GHGs excluding LULUCF.[43,44] This allows for estimation of whether a country’s target is likely to be met under the policy scenario (or baseline in the case of non-binding pledges) as well as comparisons of mitigation ambition across countries. The latest forecasts for these NDCs, alongside emissions projections from CPAT, can be found on the IMF’s Climate Indicators Dashboard.[45]

Impacts on Revenues, GDP, and Welfare

Revenues are estimated by comparing total revenue from fuel and electricity taxes, net of outlays on fuel or renewable subsidies, in the BAU versus the policy scenario. This captures both increases

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[37] Global warming potentials to convert non-CO_2 GHGs into CO_2-equivalent are based on 100-year Global Warming Potentials (GWP100), though Global Temperature Potentials (GTPs) are also available. GWP is a measure of the heat absorbed over a period, whereas GTP is a measure of the temperature change at the end of that period, relative to CO_2. Total energy-related emissions are adjusted to match what countries submit to UNFCCC (where available) by adjusting emission factors. Local air pollutants such as particulate matter (PM) are not covered by UNFCCC but can still have warming or cooling effects (see footnote below), and hence are also included in CPAT for informational purposes.

[38] The impacts of local air pollutants on local warming and cooling generally counteract each other in many cases. For example, SO_2 has a local cooling effect while BC has a local warming effect. Hence, reducing combustion of fuels that emit PM sources will have a local warming effect (via SO_2) and cooling effect (via BC). In most cases, net effects are small compared with reducing GHGs from cutting fossil fuel combustion, though this varies at the subnational level.

[39] EDGAR is a joint project of the European Commission Joint Research Center (EC-JRC) and the Netherlands Environmental Assessment Agency (PBL). See https://edgar.jrc.ec.europa.eu/methodology.

[40] See IMF Climate Change Indicators Dashboard, available at: https://climatedata.imf.org/

[41] Per the latest Coupled Model Intercomparison Project (CMIP6) exercise used by IPCC, most scenarios assume emissions from LULUCF will be flat between 2020 and 2040 – see IIASA (2021).

[42] This is equivalent to turning a carbon tax into a GHG tax assuming a similar responsiveness of non-energy consuming sectors to that of energy consuming sectors. Estimating impacts of non-energy sector responses is, however, difficult, and this assumption does not currently yield impacts on revenues, prices, and GDP, and can also be switched off.

[43] LULUCF emissions are commonly excluded from assessments of NDCs. This is due, in part, to uncertainties in land-based emissions of agriculture amounting to 4 to 5.5 gtCO2 or roughly 7 to 10 percent of total annual global GHGs (Grassi and others, 2018). Recent work has made progress on reconciling differences (Schwingshackl and others, 2022).

[44] Sectoral parts of NDCs (e.g., renewables shares) are excluded from target emissions levels. This is because a country with an unambitious NDC that achieves an ambitious sectoral target could increase emissions in other sectors and still achieve its target, hence economy-wide components of NDCs are the most important from a mitigation perspective.

[45] See https://climatedata.imf.org/

in revenues from new fuel taxes as well as cuts in revenues from base erosion for pre-existing energy taxes. Leaving aside base erosion, revenue-raising policies include carbon taxes, ETSs with auctioned allowances, increases in energy excises, VAT harmonization, and reductions in fossil fuel subsidies. Revenue-reducing policies include expenditures (e.g., on renewable subsidies), green public investments, and most regulations. Regulations, like tradable emission rate standards, are revenue-neutral while feebates can be revenue-raising, neutral or reducing, depending on their design. Users can recycle revenues towards increases in public investment, (targeted) transfers, current spending, cuts in personal income and/or corporate taxes, or a mix thereof. For revenue-reducing reforms, users can choose tax bases to raise taxes from to ensure overall revenue-neutrality. See Revenue section in Annex I for details.

GDP impacts are estimated for each country and year.[46] Fiscal multipliers are common macroeconomic parameters, usually stated in terms of the impact on output in the years following the reform.[47] These are extracted from external models and empirical studies and used to estimate the deviation from projections. Policies such as carbon pricing impact GDP over time depending notably on how revenues are recycled.[48] Reductions in PIT and increases in public investment tend to be more supportive to GDP (either minimizing GDP losses or yielding a net gain, one version of the 'double dividend' hypothesis[49]) than increasing transfers or current government expenditures.[50] Net effects also vary over time, though in aggregate both ex ante and ex post empirical evidence suggests that GDP impacts of mitigation policies are small (slightly positive or negative) or ambiguous in sign.[51] GDP impacts can have second-order effects on energy consumption and emissions, for example with small increases (decreases) if GDP rises (falls), though these rebound effects are not material in practice.[52] See GDP impacts in Annex I for details.

The impacts of policy reforms on welfare are estimated in several ways. Welfare effects are estimated applying long-established formulas from the public finance literature[53] and reflect integrals under marginal abatement cost schedules as well as efficiency effects due to compounding/offsetting pre-existing distortions from fuel taxes/subsidies. At present, (to be conservative) CPAT does not capture additional welfare effects from revenue recycling and other interactions with the broader fiscal system (see Box A1.1 in Annex I). The domestic benefits from reduced environmental costs of fuel use ('development co-benefits') such as reductions in premature mortality from local air pollution, traffic accidents, and congestion are estimated separately by the air pollution and transport modules—external costs from these factors are used in welfare calculations.[54] See Welfare or efficiency costs and net economic benefits section in Annex I for more details.

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[46] The climate mitigation policy impacts on GDP (due to higher energy prices) described here are consistent with the industry/sector-level cost increase simulations of the CPAT distribution module (see discussion in Section 4 and relevant Annexes below), which are based on the same set of energy price changes generated by the CPAT mitigation module.

[47] For a discussion of fiscal multipliers' use and estimation, see Batini and others (2014).

[48] The supply of fossil fuels is assumed to be flat in CPAT. In effect, when examining the policies of individual countries, it is assumed that their mitigation policies do not significantly affect global prices and supply of fuels.

[49] For an extensive discussion of the double dividend hypothesis regarding the effects of environmental tax reforms such as carbon pricing as it relates to GDP, welfare, and employment, refer to Heine and Black (2019).

[50] The design of PIT reductions and country context, such as prevalence of informality, affect growth impacts of reform. Some design nuances, such as reducing differences in compliance between labor and capital taxes, are not captured.

[51] Multipliers are from the WB's Macro-Fiscal Model (MFMod; Burns and others 2019) and Schoder (2022). GDP effects are uncertain and vary with country and policy reform. The ex-ante modelling literature tends to find that revenue-neutral environmental tax reforms raise employment but have ambiguous impacts on GDP and welfare (Heine and Black 2019). However, empirical studies have found little evidence of a negative impact from carbon pricing policies on GDP or employment – see, for example, Bretscher and Grieg (2020) and Metcalf and Stock (2020).

[52] Because the impacts of mitigation policies on GDP tend to be small (see above footnote), the rebound effects also tend to be small. This rebound through GDP should not be confused with the separate rebound of policy-induced energy efficiency, which would result in a small offsetting increase in energy demand due to lower marginal costs of energy.

[53] See Harberger (1964).

[54] Based on IMF methodologies in the default case (Parry and others 2014, 2015, 2021c), though other approaches to estimating air pollution mortality effects are available in the tool.

Box 1. Planned Improvements in CPAT Mitigation Module

Several enhancements are presently envisaged for future iterations of the mitigation module.

In implementing mitigation policies, countries are increasingly adopting a sectoral approach (Black and others, 2022a). The tool would benefit from more granular representation of energy-consuming sectors, their technologies, and sectoral policies. Models with dynamic capital turnover have been developed separately for transport and buildings and will be incorporated in future versions. These models include a dynamic capital stock which allows for better modelling of sectoral policies, such as a tightening of emission rate standards (for new or existing vehicles and buildings) and green industrial policies such as subsidization of newer technologies.[55] This can also allow for quantification of the spillover impact of technology policies on costs due to learning curve effects[56] and the impact of capital vintages on optimal mitigation strategies.[57] Other, more refined, industry- and activity-specific sectoral models, such as for industrial sectors like steel, chemicals, and cement, alongside agriculture, and forestry, are planned.

Additionally, economic impacts, policy coverage, and international linkages will be enhanced. GDP and international trade effects will be better modelled, notably for industrial sectors and for fossil fuel exporting countries. Incorporation of planned policies – for example for nuclear in power and efficiency in buildings – will enhance the representation of governments' existing plans. The representation of the production structure tables will be improved through use of the IMF's forthcoming Multi-Analytical Regional Input-Output (IMF-MARIO) database. Lastly, welfare effects estimates could be improved through incorporation of distortions in the fiscal system (Parry and others, 1999) as well as informality and other relevant channels (Bento and others, 2018; Heine and Black, 2019).

Lastly, it is envisioned that CPAT will increasingly allow for linkages with external models, either to give outputs to or consider inputs from. These models could include, for example, macroeconometric models such as the Macro-Fiscal Model (MFMOD; Burns and others 2019), computable general equilibrium (CGE) models like IMF's ENVISAGE (IMF-ENV; Chateau and others 2022), sectoral models such as the Future Technology Transformations models (FTT; Mercure 2012, Mercure and others 2018, Knobloch and others 2019, Vercoulen and others 2019), the IMF's Fiscal Analysis of Resource Industries model (FARI; Luca and Mesa Puyo 2016), and others.

Caveats

There are several caveats to CPAT's mitigation module (though some of these will be addressed in future improvements to CPAT – see Box 1). First, the module abstracts from the possibility of:

- **Non-linear responses to large policy changes**. For example, a large increase in emissions prices could facilitate a rapid adoption of carbon capture and storage (CCS) or direct air capture technologies, though the future costs of these technologies are uncertain.[58] Additionally, the model does not capture the impacts of widescale technological change which may be induced by climate policy and could imply higher price elasticities (alongside more positive impacts on GDP[59])
- **Learning-by-doing spillovers in low-carbon technologies**. Renewables have sharp learning curves, with the costs of solar declining 90 percent between 2010 and 2020, for example.[60] The model includes assumptions on learning rates for key technologies, but these are not endogenized at present (policy in one country is not assumed to impact global learning rates) and may be too conservative (implying lower BAU emissions and potentially higher price responsiveness).

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[55] For a discussion of green industrial policies, see Hallegatte and others (2013).

[56] Wright's law relates the impact of cumulative production of technologies with the change in unit costs: as firms get better at producing technologies (e.g., via learning-by-doing) average total costs decline – refer to Grubb and others (2021).

[57] The need for rapid decarbonization and the long-lived nature of some energy-consuming capital goods as buildings (in addition to market failures) justifies additional policy effort in these sectors – see Vogt-Schilb and others (2018).

[58] Cost projections for CCS, while highly speculative, are around \$75 to \$175 per ton CO_2e (see Gillingham and others 2018, Keith and others 2019).

[59] See Heine and Black (2019).

[60] See Way and others (2021).

- **Feedback from fuels markets.** The possibility of upward-sloping fuel supply curves[61] and other changes in international fuel prices that might result from simultaneous climate or energy price reform in large countries would impact results. Parameter values are, however, chosen such that the results from the model are broadly consistent with those of more detailed energy models that, to varying degrees, account for these types of factors (see Annex I).

Other caveats for the initial iteration of the mitigation module ('CPAT 1.0') include:

- **International linkages across countries are limited.**[62] CPAT accounts for changes in fuel and electricity imports and exports (e.g., due to decarbonization) and changes in trade are accounted for in GDP estimates, but the coverage of traded products is limited. This prevents explicit analysis of the implications of border carbon adjustments (BCAs), for example, which are receiving increasing attention, though additions are planned.
- **Impacts from policy changes on GDP are simplified.** GDP impacts are estimated as described above to account for general equilibrium effects of climate policy changes (e.g., from changes in employment, balances of payments, monetary factors, etc.) to adjust the forecasted growth path. In general, this is a reasonable approach.[63] However, it should be noted that fiscal multipliers are currently aggregated at the region and income-group level, while country-specific circumstances (e.g., debt distress) are not currently included.[64] Economic effects also do not account for interactions between climate mitigation policies and distortions in the economy created by the broader fiscal system, which can reduce policy costs (e.g., through recycling carbon pricing revenues in broader tax reductions). GDP impacts from changes in informality, induced technical change, or local air pollution (for example on productivity) are also not included but could be substantive.[65]
- **Sectors are de-coupled at present but will become increasingly integrated in future updates (Box 1).** Global decarbonization requires cutting emissions in power generation while electrifying end-uses of energy, creating inter-sectoral linkages. For example, electric vehicles will add modestly to electricity demand while hydrogen is likely to become more readily available for decarbonizing industry (though the share of hydrogen in industry energy consumption is likely to remain small this decade). As a result, future updates will add interactions between electrified sectors and power demand.
- **Lastly, price elasticities used may be too high in the short term and too low in the long term.** CPAT assumes the impacts of prices on energy use are fully realized within one year.[66] This may somewhat overstate responsiveness in the short-term, as firms and households take time to adjust, but it is a reasonable approximation as the focus is on policies that are phased in over several years. [67] Also, there is initial evidence that price elasticities used may be too low in the long run. Empirical elasticity studies tend to examine responses to price changes induced by market fluctuations. However, policy-induced price changes may elicit responses that can be much larger than market-induced changes (e.g., due to higher salience and expected permanence of tax-induced changes).[68] Users can, however, adjust price elasticities.

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[61] The assumption of flat fuel supply curves is reasonable for countries that are price-takers in international fuel markets and for coal over the longer run (given its vast reserves). Large producers may, however, have some market power in international markets for oil and natural gas, implying that changes in domestic supply may have some domestic price effects.

[62] The bulk of empirical evidence thus far suggests that leakage effects (alongside competitiveness, see below) from climate mitigation policies are small or statistically insignificant (Eskander and Fankhauser 2023). However, these may be due to low prices and exemptions, while some empirical studies find larger effects (see e.g., Wingender and Misch 2021). Simulation-based studies find high or low impacts depending on parameters.

[63] See, e.g., IMF Staff Guidance Note (IMF 2022h).

[64] However, improvements to the representation of GDP in CPAT to account for country-specific circumstances are in development. Simulation and empirical studies indicate that GDP effects of mitigation policies remain quite uncertain, though current evidence suggests they are small or, in some cases, positive. See footnote 51.

[65] For a more detailed discussion, see Heine and Black (2019).

[66] In substance, this only affects the energy intensity component of elasticities, accounting for roughly half of the responsiveness. Additionally, one of the power sector supply models in CPAT accounts for short-term limits on new investment in response to mitigation policy. Lastly, dynamic models of capital turnover for the transport and building sectors have been developed to distinguish policies that only affect new (as opposed to new and existing) capital.

[67] Previous versions included short- and long-term elasticities but results were not significantly affected by this distinction.

[68] See, for example, Li and others (2014), Anderrson (2019) and Moore and others (2021).

4. Distribution Module

Income inequality and poverty are increasingly important in discussions of climate mitigation policies. Given the need for a 'just transition' as recognized by Parties to the UNFCCC, distributional impacts of climate policy have become more relevant to policymakers. Public acceptability can be strongly driven by the level of fairness of reforms, notably their impact on (low-income) households. In addition, policymakers are increasingly interested in the impact of policies on exporting or import-competing firms, especially those in energy intensive, trade exposed (EITE) sectors. The impact of policy-induced price changes and use ('recycling') of revenues raised or saved on households and industries are crucial design considerations. This section describes the distribution module (for technical details, see Annex II **–** Technical Details: Distribution Module).

The Distributional Impact of Climate Mitigation Policies

Changes in energy prices from climate mitigation policies can have a regressive or progressive effect on households, depending on the country. Broadly, in low- and middle-income countries, carbon pricing policies (before revenue recycling) tend to be moderately progressive, since grid access and ownership of energy-intensive goods, such as cars and appliances, tend to be more concentrated towards the top of the income distribution (Mercer-Blackman and others, 2022). In high-income countries, changes in energy prices tend to be regressive because, for example, ownership of energy-intensive goods tends to be broader than in developing countries (Heine and Black 2019, Ari and others, 2022).

However, for all countries, revenues raised or saved can make reforms pro-poor and equity-enhancing overall. Climate mitigation policies can have negative absolute impacts on the vulnerable, even when incidence effects are progressive (affecting wealthy households more as a share of pre-policy consumption). In the case of revenue-raising policies such as carbon pricing and fossil fuel subsidy reform, revenues can be used to compensate (or more than compensate) vulnerable households. Cash transfers, social safety nets, and investments in education and health can disproportionately benefit the poor. This could help countries make progress towards achieving Sustainable Development Goals (SDGs) and is especially relevant for lower-income countries where domestic revenue mobilization is constrained by informality. By contrast, non-pricing mitigation policies, such as regulations, do not have a first-order impact on energy prices, and hence do not affect households in the same way pricing policies do. However, non-pricing policies also do not raise revenues (and erodes the base for existing energy taxes). In such cases, it may be more difficult to influence the net distributional effect of the policy (e.g., via revenue recycling).

Additionally, countries are increasingly interested in the impact of climate mitigation policies on firms. As countries scale up mitigation policies, policymakers may be concerned about impacts on firms that compete in international markets (exporting or import-competing firms), such as those operating in EITE industries like steel, cement, and chemicals. Governments may fear these industries will lose market share through an increase in input costs relative to firms in other countries. Firms could also move production overseas, partially offsetting the policy impact on global emissions ('carbon leakage'). These fears may be overstated given empirical evidence,[69] but impacts on EITE firms remain a concern for policymakers nonetheless.[70]

CPAT's distribution module estimates impacts of climate mitigation policies on 59 non-energy economic sectors across 120 countries. Impacts are quantified as changes in firms' input costs and output prices, presented by industry/sector and the share of each industry/sector in gross value added (GVA), total output, household demand, and exports. This can aid policymakers in estimating impacts on firms, especially in EITE industries, and can inform countries considering policies to protect firms such as BCAs (Parry and others 2021c) or, ideally, an international carbon price floor (Parry and others 2021a).

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[69] On competitiveness, a meta-study of 103 publications finds that strict but flexible environmental policies increase competitiveness of firms and countries overall (a 'strong version' of the 'Porter hypothesis'; see Cohen and Tubb 2018). A systematic review finds that two thirds of 54 studies show no negative impacts on firms from taxes and ETSs (Peñasco and others 2021). On leakage, most empirical studies so far find statistically insignificant effects – see footnote above.

[70] For example, evidence suggests that a country with a larger share of industry in GDP is less likely to adopt a carbon price, which could be due to policymaker fears of losses in competitiveness (Dolphin and others 2020).

Impacts before Revenue Recycling and Responses

The CPAT distribution module quantifies impacts of mitigation policies on firms and households. It models the impact of rising energy prices on firm production costs and on household consumption of energy goods ('direct effects') and non-energy goods and services ('indirect effects'). For households, net impacts are estimated accounting for revenue recycling through PIT reductions, transfers, and public expenditures. The module also allows for the estimation of these impacts across (vertical distribution) and within (horizontal distribution) consumption deciles, and between households in rural and urban areas.

The distribution module follows a standard, cost-push microsimulation approach, common in the literature.[71] This combines HBSs (scaled such that total HBS-estimated consumption matches household consumption in national accounts) with input-output (IO) table data. This allows for estimation of impacts of changes in prices (from the mitigation module) on the input costs of affected industries, increases in expenditures for households, and losses in consumer surplus ('burdens') of households.[72] The user can vary several assumptions and policy design, such as whether and how to target poorer households for compensation. The module also adjusts for changing energy product budget shares over time, improvements in the energy efficiency of production, and for behavioral responses to higher energy/non-energy prices.

Data on household budget shares is obtained from HBSs for, so far, over 65 countries. Data is aggregated into CPAT-compatible good/service categories[73] and households are grouped into population-weighted, per-capita consumption deciles. Budget shares are computed by dividing total expenditure on each good/service by each household's total consumption expenditure across all goods/services. Sector-specific price increases for each energy source and sector from the policy scenario are obtained from the mitigation module. This allows for estimation of increases in expenditures and losses in consumer surplus from changes in the price of energy and other goods/services.

For 'direct' and 'indirect' effects, price increases for energy and other goods/services (due to higher energy input prices) are calculated within the module. In the default case, it is assumed that price changes are fully passed forward onto consumer prices (i.e., flat/perfectly elastic energy supply curves). Energy price changes are obtained from the mitigation module and affect households' consumption of fuels and electricity (direct effect; see Equation (16) in Annex II). Non-energy sector price increases are obtained as the sum-product of: i) each sector's energy intensity (see Annex II for details); and ii) the change in energy prices induced by the policy. Sectoral energy intensities are derived from global IO tables[74] that are mapped to CPAT non-fuel consumption good/service categories mentioned above. Summing the estimates across all non-fuel goods/services yields the increase in expenditures (e.g., on food, housing, etc.; indirect effect).

Impacts on expenditures can be converted into welfare-equivalent measures, i.e. losses in consumer surplus ('burdens'). While households can face losses in consumption from increased prices (not accounting for the benefits of revenue recycling), they also incur additional losses in utility from the presence of a tax wedge. Total welfare-equivalent losses ('burdens') which include deadweight losses are estimated in CPAT (see Annex II for more details).

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[71] See, for example, Fabrizio and others (2016).

[72] Consumer surplus here is defined as the portion of the Marshallian aggregate surplus that is captured by consumers, with the remainder captured by firms. Marshallian aggregate surplus can be thought of as the utility gained from consumption of a good less its production costs. Graphically, consumer surplus is the area between the demand curve and equilibrium prices for goods. See Mas-Collell (1995, p.326). Burdens are measured by losses in consumer surplus, which include: i) extra household expenditures on goods due to their higher prices (a first-order effect); and ii) the value to households of forgone consumption induced by price changes, net of reduced spending (a second-order effect).

[73] To facilitate relative cross-country comparability of results, CPAT uses a standardized classification of goods and services across all countries, distinguishing among 8 energy goods (coal, electricity, natural gas, oil, gasoline, diesel, kerosene, LPG) and 14 non-energy goods/services (appliances, chemicals, clothing, communications, education, food, health services, housing, other, paper, pharmaceuticals, recreation and tourism, transportation equipment, public transportation).

[74] At present, from the Global Trade Analysis Project (GTAP)-10 database which includes data for year 2014 across 65 sectors. These cover the following five fossil fuels: coal, electricity, oil, natural gas, and petroleum products. See: https://www.gtap.agecon.purdue.edu/databases/v10/index.aspx. IO tables will be updated to incorporate any periodic updates to the GTAP database vintages (e.g., from GTAP-10 to GTAP-11), or alternatively may shift to the IMF's forthcoming MARIO database.

The above approach also allows for estimation of impacts on industries. This analysis is particularly important when examining international competitiveness impacts (e.g., for EITE industries).[75] Cost increases are calculated as simple sectoral averages or weighted/ranked by sectoral output, exports, final household demand, and gross value-added (GVA). The user can make a distinction between input (i.e., producer) and output (i.e., final, consumer) price changes by applying imperfect pass-through coefficients from the literature.[76] Results are available for 59 sectors as well as 8 aggregated CPAT sectors.

However, by not considering effects of revenue recycling or behavioral responses, these first-order impacts do not capture welfare effects. Households and firms respond to price changes by adjusting consumption bundles and input mixes, both of which reduce net impacts on households. Additionally, revenues raised or saved from the reform can be recycled, with varying impacts across households.

Impacts after Revenue Recycling and Responses

The distribution module accounts for behavioral responses in two ways. The first approach adjusts for 'behavioral and structural change' in the economy. It does this by uniformly scaling downwards impacts across deciles by the ratio of revenues raised per the mitigation module to revenues raised based on the HBS data. This scaling implicitly adjusts the estimated effects from changes in the carbon intensity of the economy implied by the (older) IO tables and that of the (newer) energy consumption balances. The second approach adjusts for behavioral responses by considering decile and product-specific price elasticities of demand. These elasticities are derived from country-level data (by income group) sourced from the United States Department of Agriculture (USDA)[77] and applied assuming households behave according to a constant elasticity of substitution (CES) utility function. See Annex II for technical details.

Use of revenues raised or saved is important for comprehensively evaluating the distributional impacts of climate mitigation policies. Revenue recycling through cash transfers, PIT reductions, and creating or scaling-up existing social assistance programs can make reforms that appear initially regressive (i.e., relatively more burdensome for the bottom of the income distribution), in fact, both progressive (enhancing the equity of the fiscal system) and pro-poor (raising the absolute welfare of the poorest deciles).

Four 'modes' of revenue recycling can be simulated. i) new or existing targeted transfers (for which the user can decide the targeted percentiles and targeting inefficiency); ii) transfers towards public investment in infrastructure; iii) scaling up an existing social protection scheme; and iv) reducing effective PIT liabilities. Infrastructure transfers are assumed to target parts of the income distribution without initial access to clean water, electricity, sanitation, information technologies, or public transport. Increases in current spending are assumed to benefit households proportionally to existing social protection schemes (e.g., social assistance, insurance, or in-kind benefits). Revenue recycling via PIT reforms can take the form of proportional or lump-sum reductions in household consumption decile-specific PIT liabilities or to exempt deciles entirely. Finally, transfer schemes are also available for population segments below international poverty lines . Lastly, the module estimates the share of revenues required to compensate parts of the income distribution (e.g., the bottom two deciles). See Annex II for technical details.

Both (negative) consumption effects as well as (positive) revenue recycling effects are expressed as shares of pre-policy consumption and in absolute (monetary) per-capita terms. This is done at the household decile level and separately for rural and urban sub-samples. For vertical distribution impact outputs (between groups), the user can further choose between decile mean and median HBS data inputs. Horizontal impacts (within groups) are estimated for the 25th and 75th percentile within each decile.

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[75] In this case, the assumption of flat supply curves (i.e., households bearing the entire incidence of the policy) may not be valid: domestic firms competing in international markets may not be able to pass forward cost increases onto consumers.

[76] Users can use coefficients from Ganapati and others (2020), Neuhoff and Ritz (2019) and Abdallah and others (2020) – refer to Annex II for further details.

[77] See: https://data.ers.usda.gov/reports.aspx?ID=17825

Caveats

The distribution module is subject to several limitations:[78]

- **Changes in economic structure may not be fully accounted for.** In calculating the indirect effects of policy, the share of each sector in total consumption and output remains constant over time (they are, nonetheless, scaled in gross terms with GDP). However, the relative production structure is likely to change, especially with longer time horizons and more aggressive mitigation policies.
- **The impacts of imperfect pass-through of changes in input costs to output costs are only partly accounted for.** The module assumes, by default, full pass-through of producer price increases onto consumers or, equivalently, flat supply curves at the domestic market level (see Annex II for options to relax this assumption). However, higher energy prices could be passed backwards into lower producer prices (e.g., assuming upward-sloping supply curves). If this impacts profits, some of the incidence could be borne by firm owners (via lower capital returns) or workers (via lower wages).
- **Various other channels, not commonly accounted for in cost-push microsimulation models, can affect incidence estimates (including regressivity or progressivity).** To the extent that fossil fuel-intensive industries are capital-intensive, climate policies may increase returns to labor. This could, in turn, mean that (wealthier) households deriving a larger share of their income from capital could be disproportionately hurt by climate mitigation policies (relative to poorer households that derive most of their income from wages). Additionally, to the extent that poorer households live in more polluted areas (within cities), they may benefit relatively more from reductions in local air pollution induced by climate policies. More research on these channels is required to ascertain their relative importance.

5. Development Co-Benefits Modules: Air Pollution and Transport

Climate mitigation policies have broad impacts beyond carbon emissions, including ancillary benefits ('co-benefits') for human health and welfare. CPAT contains two modules for estimating two of the key co-benefits of climate policy: i) health improvements from reductions in local air pollution; and, ii) welfare benefits from reductions in vehicle use in response to higher road fuel prices, via reduced congestion, accidents, and road maintenance costs.[79] These modules are briefly described below. Further details can be found in Annex III.[80] For more details on the development co-benefits modules, see Annex III **–** Technical Details: Co-Benefits Modules (Air Pollution & Transport).

Air pollution co-benefits module

Burning fossil fuels and biomass emits pollutants that damage human health. Outdoor ('ambient') air pollution mortality and morbidity occur through people inhaling $PM_{2.5}$ (particulate matter with diameter up to 2.5 micrometers, fine enough to penetrate the lungs and bloodstream) and low-lying ozone (O_3). $PM_{2.5}$ is emitted directly from fuel combustion or formed indirectly from atmospheric reactions involving precursors (SO_2, N_2O, BC, other organic matter, and ammonia (NH_3)) emitted from burning fuels. Low-lying ozone can inflame and damage airways and aggravate lungs. Ozone is formed indirectly through atmospheric reactions among precursors (volatile organic compounds (VOCs), CH_4, CO, N_2O, and/or SO_2).

The associated social and health costs are substantial. The Global Burden of Disease (GBD) reported 4.5 million deaths from outdoor air pollution in 2019, with 92 and 8 percent due to $PM_{2.5}$ and ozone, respectively, and 60 percent from burning of fossil fuels. Indoor air pollution caused a further 2.3 million

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[78] For a discussion of general limitations of cost-push distributional analyses, see Heine and Black (2019) and Shang (2023).

[79] While there are other co-benefits from reducing fuel use, such as improved energy security, they are generally smaller, more difficult to quantify, and better addressed through other policies (see NRC 2010, Chapter 2).

[80] Further details, including on options not commonly used in the IMF but available to users can be found in more in-depth documentation available on the WB's accompanying website (linked to from www.imf.org/cpat).

deaths.[81] As with climate damages, outdoor air pollution is principally an externality, since individuals and firms do not consider the risks to others from emissions released when fossil fuels are combusted.

CPAT quantifies the mortality, morbidity, and economic costs of local health damages stemming from fossil fuel use for each country in four main steps. First, local air pollutant emissions ($PM_{2.5}$, SO_2, N_2O, BC, CO, VOCs and CH_4) are estimated using energy use by fuel, sector, and scenario, as described in the mitigation module section above. Second, emissions of pollutants are translated into concentrations of $PM_{2.5}$ and ozone and population exposure. There are two main approaches used for this in CPAT: intake fractions and the TM5-FASST approach, which are then averaged.[82]

The intake fraction method estimates the portion of $PM_{2.5}$ that, on average, is inhaled by exposed populations. This approach was first used in Parry and others (2014) and has since been refined in collaboration with the WB. For coal, natural gas, and oil power plants, intake fractions are derived using spatial data on power plant locations matched to granular data on population density at different distances from each plant (within and across borders) and regression coefficients describing the fraction of emissions ingested given population density at different distances.[83] For vehicle, building, industry, and other emissions (released generally closer to ground level), intake fractions were extrapolated nationwide from a database of (ground-level) intake fractions for over 3,000 urban areas. Intake fractions tend to be higher in densely populated areas and lower where emission sources are coastally located and a large portion of emissions dissipate over the ocean without harming local populations.[84]

The TM5-FASST is an emulator of the full TM5-Chemical Transport Model (CTM) that relates emissions from a source to air quality ($PM_{2.5}$ and ozone) at that and other locations ('receptors'). The results in CPAT are based on this 'source-receptor' approach downscaled at the country level and augmented by local source apportionment studies.[85] The air quality modelling approach is more sophisticated than the intake fraction approach in that it accounts for local meteorological and topographical factors influencing ambient pollution concentrations. On the other hand, air quality modelling is less granular for the application of fossil-fuel related sources like power plants, implying less precision in estimating populations potentially exposed to fossil fuel-related pollution.

The third step is to map population exposure to $PM_{2.5}$ and low-lying ozone to health burdens. This is done using, by age class, baseline mortality rates for illnesses whose prevalence is increased by air pollution exposure and exposure-response curves from the 2019 GBD study. For $PM_{2.5}$, CPAT assesses jointly the impacts of outdoor and indoor air pollution (although it does not explicitly model policies that affect indoor air pollution). Outputs include mortality and disability-adjusted life years (DALYs).

Fourth, the two approaches are averaged and changes in mortality risk valued. The monetization of mortality risks is contentious, but necessary to factor health risks into estimates of efficient energy prices and determine tradeoffs among policies. The approach draws on an OECD (2012) meta-analysis of several hundred studies on health risk valuations, which (after updating for inflation and income growth) implies a value of around US$4.6 million per death avoided for 2020 in the average OECD country. This is extrapolated to other countries based on incomes relative to the OECD and an assumed mortality risk elasticity.[86] Lost wages from morbidity are included, but account for a small portion of total costs.

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[81] See IHME (2020).

[82] Other methods are also available in CPAT, including machine learning-based methods.

[83] Data is available for 164 countries. Intake fractions for other countries are inferred from comparable countries in each region.

[84] The intake fraction is converted to a pollution concentration by scaling by the breathing rate.

[85] TM5-FASST (the TMF-FAst Scenario Screening Tool, see Van Dingenen and others, 2018) is based on a linearized version of TM5, a detailed atmospheric chemistry model. The original source-receptor matrices in TM5-FASST are separated into 56 regions which are then downscaled to country-specific matrices and supplemented with local source apportionment studies which estimate the contribution of sources such as fossil fuels to baseline concentrations.

[86] See Parry and others (2014), and Table 7 in Viscusi and Masterman (2017). Extrapolations are based on purchasing power parity, which more accurately reflects people's willingness to pay for risk reductions out of income. Mortality valuations may also differ across countries with differences e.g. in life expectancy, health, economic and social support and so on, though effects of these factors are not well understood (Robinson and others 2019). Some argue for an income elasticity above 1 to reflect lower income households' relatively higher utility from spending (e.g., as more spending is on essentials) but Viscusi and Masterman (2017) fail to reject an elasticity of 1. CPAT allows for adjustments to the income elasticity.

Caveats

The air pollution co-benefits estimates are subject to several caveats.

- **Temporal and geographical scope**. CPAT provides an estimate of annual health co-benefits averaged over the population. In reality, there can be significant variation in pollution exposure during both the course of the year and across urban and rural areas. Information on this temporal and spatial variation could inform the design of fine-tuned air emissions fees.
- **Uncertainty in the relationship between emissions, concentrations, and health impacts**. While there is consensus that $PM_{2.5}$ and ozone impact health significantly, there is uncertainty on the exact relationship between the emissions of pollutants and concentrations of $PM_{2.5}$ and ozone, and between concentrations and the incidence of specific illnesses. While the above describes the default approach, CPAT provides five methods in total to estimate this relationship, all of which have been cross-checked against more complex air quality models, allowing for sensitivity analysis.

Road transport co-benefits module

Climate policies can impact human welfare by affecting congestion, road accidents, and road damage. By raising the costs of gasoline and diesel, climate policies can reduce vehicle kilometers travelled (VKT), by incentivizing public transport, carpooling, trip chaining, and reducing overall travel demand. This has impacts on economically costly congestion, as well as road accidents and wear and tear on roads. Some of these costs are borne by individuals while others are borne by others. External costs are relevant for assessing the welfare impacts of climate policies and the extent to which these policies are in countries' own domestic interests before counting global climate benefits.[87] Policymakers may also be interested in other metrics like total travel delays and road fatalities, not least because they are easier to explain. As discussed below, CPAT estimates all of these metrics, with further details provided in Annex III.

Congestion is a major problem in cities across the world. Congestion is measured as the time lost due to the actual travel speed being slower than a 'free-flowing' speed (i.e., the speed under no congestion), mostly in urban areas. Despite a marked reduction in congestion in 2020-2021 from changes in urban mobility and work patterns due to the COVID-19 pandemic, congestion rose in 2022 in most cities.[88]

In the baseline, CPAT forecasts congestion delays using historic congestion growth rates, adjusted for GDP and population growth, and in the policy scenario using elasticity estimates. The baseline forecast for congestion is calculated using the last available year of data (from TomTom) projected forward using historic congestion growth rates, adjusted for GDP and population growth. As congestion applies mainly to urban, working-age populations, we calculate the time lost in traffic due to congestion for the VKT of this share of the population. The policy forecast calculates how much time would be lost in congestion when fuel prices change due to new policies, using an econometrically estimated fuel price elasticity.

Road accidents cause about 1.3 million deaths per year (94 percent in low- and middle-income countries[89]) and various other costs including injuries, medical burdens, and property damage. CPAT provides estimates of total road accident fatalities in the baseline scenario and how they are affected by mitigation policies using empirical estimates of the link between road fuel prices and road fatalities. The accident fatality baseline forecast (in the BAU) is projected forward using the latest available data from external data sources (OECD, IRF, and United Nations Economic Commission for Europe (UNECE)) as well as average past growth rates adjusted for GDP and population growth. This baseline forecast is compared to a policy forecast (if fuel was taxed more heavily), calculated using the abovementioned fuel price elasticities and the fuel price change due to the policy.

CPAT also provides estimates of the marginal external costs of congestion and accidents and associated welfare benefits. The marginal external cost of congestion is the impact of motorists adding to

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[87] Parry and others (2015). Total external costs from all road externalities are estimated at almost $1 trillion in 2020, with two-thirds coming from congestion alone (Parry and others 2021c).

[88] See https://www.tomtom.com/newsroom/explainers-and-insights/the-most-congested-cities-in-the-world-2022/

[89] See https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries

congestion and costly delays for other road users. Changes in total external costs are the product of the reduction in fuel induced by the policy and the marginal external costs per liter. It is estimated by multiplying average travel delays per VKT by: (i) the relationship between marginal and average travel delays based on traffic speed-flow curves; (ii) vehicle occupancy (averaging over cars and buses); (iii) people's value of travel time (VOT, assumed to be 60 percent of the nationwide average market wage in 2020); (iv) fuel economy (to convert costs per VKT into costs per liter of fuel); and (v) the portion of the fuel demand elasticity that comes from reduced driving (and therefore affects congestion) versus the portion that comes from improved fuel economy/shifting to EVs (which does not affect congestion).[90]

CPAT also includes estimates of marginal accident externalities per liter of fuel use. A portion of accident costs are commonly viewed as internal to drivers (e.g., own-driver injuries) while other costs are external (e.g., injury risks to pedestrians, elevated risks to occupants of other vehicles from multi-vehicle collisions, and property and medical costs borne by third parties). Accident externalities per liter are measured[91] by apportioning country-level data on traffic fatalities into external versus internal risks, monetizing them using the above approach for mortality valuation, extrapolating estimates of other components of external costs from several country case studies to other countries, and dividing by fuel use, scaling by the portion of the fuel price elasticity that reflects reduced driving.

The road transport module also estimates the impacts of changes in VKT on road damage as measured by road maintenance costs. The baseline forecast of road maintenance costs is projected from the latest available data (from the International Road Federation (IRF)) and for future years using average historic road maintenance cost growth and an empirically derived relationship between road maintenance costs and GDP and population growth. Externalities are assumed to be 50 percent of total maintenance costs, with the other half attributed to weather and natural deterioration. The entire externality is attributed to diesel consumption, since damage is caused by high axle-weight vehicles that primarily use diesel as a fuel (again, scaled by the driving portion of the diesel fuel price elasticity).

Finally, VKT itself may be a metric of interest. The base value for VKT comes from the IRF, while changes in subsequent years are a function of average VKT growth, GDP and population growth as well as changes in fuel prices (both due to international commodity fluctuations and changes in prices following climate mitigation policy adoption).These relationships are estimated econometrically (at the country level, where data is available) and differentiate between short- and long-run responses, as some responses materialize more slowly (e.g., purchases of fuel-efficient vehicles and moving closer to population centers).

Caveats

The road transport co-benefits estimates are subject to some caveats:

- **Fuel price elasticity estimates are assumed to be causal.** The estimated relationship between changes in fuel prices and VKT may not be well-identified. In the empirical approach, country and year fixed effects control for unobserved heterogeneity across countries and global trends. However, endogeneity cannot be entirely ruled out (e.g., there may be unobserved, time-varying factors correlated with both the explanatory variable and the error term).[92] Results are, nonetheless, consistent with more detailed, country-level studies from the relevant literature.
- **Data quality may affect the results.** Changes in key indicators, such as VKT and accidents, are estimated econometrically and, thus, impacted by the quality of historical data. Where data is not available for a given country, IMF region and income group averages are used to infer the relationships between GDP growth, population, price responsiveness, and driving-related indicators.
- **The impacts of electrification of road transport (through plug-in and hybrid electric vehicles, EVs) are not currently modelled explicitly.** EVs also create driving-related externalities, but

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[90] Further adjustments are made to account for the relatively weaker responsiveness of driving on congested roads (which is dominated by commuting) to fuel taxes than driving on free-flowing roads and the share of buses and trucks in the vehicle fleet (which contribute more to congestion per VKT). See Parry and others (2014), Ch. 5.

[91] See Parry and others (2014), Ch 5.

[92] For a discussion of these issues, see Angrist and Pischke (2009).

consume less or no gasoline or diesel, so a tax on petroleum products would not effectively price externalities from EVs. However, future iterations of CPAT are expected to address this (see Box 1).

- **Proxy taxes on driving-related externalities in the future may be preferable to road fuel duties for pricing road externalities.** Driving-related externalities are more effectively taxed through policies that directly target external costs (e.g., per-VKT charges related to prevailing congestion). CPAT currently allows for taxes imposed on an energy consumption basis. Future updates of the model could include targeted policies, which are becoming more viable with better technologies.

6. Conclusion

Stabilizing the global climate requires climate mitigation policy reforms across countries. Global GHG emissions must be cut by 25 to 50 percent this decade to be on track with limiting warming to well below 2ºC, and ideally 1.5ºC, above pre-industrial levels. Such a rate of decarbonization is unprecedented, necessitating new policies and a strengthening of existing policies. This includes carbon pricing (carbon taxes and ETSs), fossil fuel subsidy reform, energy market reform and price liberalization, renewable energy subsidies, feebates, green public investments, regulations, VAT harmonization, and mixes thereof. Analytical tools are required to help policymakers design and assess reform packages which accelerate decarbonization (including in high-cost sectors) while supporting other government objectives.

CPAT can help policymakers in over 200 countries assess, design, and implement reforms that cut GHG emissions while supporting other objectives. CPAT allows for the rapid quantification of impacts of climate mitigation policies. It can therefore help governments identify, design, communicate, and implement reforms that decarbonize economies while supporting other objectives such as growth, poverty alleviation, equity, environmental quality, and energy access. While some tradeoffs are inevitable in policymaking, a variety of welfare-enhancing climate mitigation reforms are both desirable and feasible across countries.

To ensure reforms are durable, policymakers should also consider political economy factors. While CPAT can inform assessments of the likely political acceptability of reform, for example by quantifying incidence impacts on industries and households, varying national contexts can mean varying preferences for mitigation policy design.[93,94] As such, separate qualitative analyses (e.g., public opinion surveys) can help inform both the design of policies and in the communication of their benefits.[95]

Reforms should include measures to facilitate a ‘just transition’ and ‘deep decarbonization’. To ensure that vulnerable households are not left behind, policies focused on retraining, relocation, and financial support for displaced workers (e.g., in coal mining regions) will be needed. In addition, broader policies beyond CPAT’s scope are needed to facilitate abatement in the highest-cost sectors, notably to address technology-related market failures.[96] Such policies could include prizes, support for basic research, and advance market commitments for newer, more expensive technologies.

The need for policy packages that accelerate decarbonization has never been so universal nor urgent. By making CPAT available to policymakers, its developers at the IMF and WB hope to help countries implement needed climate mitigation policies, stabilize the climate, and achieve a more sustainable future.

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[93] There is a relationship among the policies of different countries: evidence suggests policies can diffuse across borders. Linsenmeier and others (2022b) find that one country implementing mitigation policies increases the chances that other countries adopt the same policies. The emissions reductions from such positive policy externalities may be even larger than domestic emissions reductions. However, types of mitigation policies may vary in the extent they cross international borders (Dolphin and Pollitt 2021) and within countries over time (Linsenmeier and others 2022a).

[94] Some reform designs appear generalizable from a political acceptability standpoint. For example, evidence suggests that public attitudes towards carbon taxes and fossil fuel subsidy removal are similar and that recycling revenues through per-capita transfers, labor tax reductions, or expenditures towards climate mitigation or adaptation projects can enhance acceptability (Carattini and others 2019, Harring and others 2023).

[95] Effective communications and transparency are important for reform durability – see Coady and others (2018).

[96] For example, firms are unable to internalize all the benefits of innovation, due to learning-by-doing spillovers. As a result, private investment in low-carbon R&D may lie below what is socially optimal, even in the presence of a robust carbon price.