Carbon Transparency Initiative

Methodology for the power and transport sectors

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AUTHORS

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The Carbon Transparency Initiative

The Carbon Transparency Initiative (CTI) is a project of ClimateWorks that seeks to create a transparent and granular Current Development Scenario that is based on policies, decarbonization trends, and energy related investments. The CTI reveals progress toward building a low-carbon economy through an indicator-led methodology that is based on an analysis of the drivers that shape emission trends. This allows for analysis of medium-term decarbonization, sensitivity analysis based around policy and technology shifts, and identification of macro trends and how regional targets compare. The time period covered is from 2005 to 2030. An annually updated dashboard will display these driver metrics, monitor their year-to-year changes, allow sectoral and regional comparisons, and track progress toward emissions targets. Thus far, models have been developed for China, the EU, India, Mexico, and the USA with plans to expand to other countries in 2016.

The following document describes the methodology used to calculate the greenhouse gas (GHG) emissions trajectories projected from the CTI model for two sectors – power and transport. A uniform methodology is used for all countries for which the model was developed and across 11 sectors: power, transportation, oil & gas, buildings, iron & steel, cement, chemicals, 'other industries', agriculture, forestry, and waste. Data sources are also uniform across regions and rely upon a number of trusted sources, e.g., International Council on Clean Transportation (ICCT), Bloomberg New Energy Finance (BNEF), International Energy Agency (IEA), and other databases. The CTI models have been peer-reviewed by Instituto Nacional de Ecología y Cambio Climático, Lawrence Berkeley National Laboratory, Grantham Institute, Stockholm Environment Institute, the Council on Energy, Environment and Water, and California Environmental Associates. The McKinsey Center for Business and Environment supported models built for the four countries and the EU.

Detailed analysis of the results obtained from the CTI for these two sectors are described in Faster & Cleaner. A future document, to be released next year, will include the methodology for the other sectors. Results and analysis will be hosted on ClimateWorks' website.

Leading Indicator Approach

Overview

The CTI model measures leading indicators made up of driver and outcome metrics at the sector and sub-sector level for each country. This approach helps lend a higher degree of performance pressure and transparency to the global debate on decarbonization. The intention is to allow for comparisons both between regions and over time at multiple levels of the economy. By moving from macro to micro-level metrics included in the CTI model, one can highlight where and how progress toward decarbonization occurs. For example, common macro-level metrics include comparisons of emissions per unit of GDP or per person. Both are valid metrics for comparison, but if one is comparing economies that are developed versus developing, large versus small, or industrial as opposed to service based, these metrics might not capture some of the finer details. Instead, one might want to make comparisons of just industrial productivity in the steel sector, penetration rates of electric drive vehicles, or renewable generation capacity and so on. In this way the CTI adds nuance to the debate on decarbonization by illuminating how underlying decarbonization metrics compare with each other.

Throughout the CTI analysis we refer to various types of indicator metrics. A unit of measure that is used in calculating emissions or energy consumption is referred to as a **driver metric**. These driver metrics are classified into two groups: **activity metrics** that refer to changes in population, demand for goods, services, and energy and **intensity metrics** that are measures of the amount of energy or emissions resulting from one unit of that activity. The **outcome metrics** are the total emissions and related statistics in each sector which are the result of a series of calculations that depend on the driver metrics. For example, population growth is a driver metric of a number of activities: as population increases, so does the demand for goods, services, and energy (all of which are designated as activity metrics), which in turn results in changes in emissions. Another example is the electricity demand in megawatt hours. This activity metric requires an intensity metric – an emission factor or amount of emissions per unit of energy produced – in order to calculate the outcome metric of the resulting emissions. For the power sector, emission factors are dependent on both the make-up of the generation fleet and how that supply is utilized; it is not just the existence of a coal generating facility that results in emissions but how that facility is utilized and changes over time.

Comparisons between regions and time periods are possible for a variety of indicator metrics. Furthermore, since population and GDP are key drivers for emissions growth, the CTI model incorporates five different scenarios by using the Shared Socioeconomic Pathways (SSPs) developed for the climate change modeling community (Moss et al. 2010).[1] These pathways provide a range of GDP and population growth projections for each of the countries/regions. This allows for a range of sensitivity analyses as these metrics drive changes through several sectors in the model. Again, this allows for comparisons over a large host of metrics ranging from macro-level outcome to micro-level activity and intensity metrics.

Figure 1 displays how this works. The CTI model is a bottom-up model that constructs a national inventory of emissions from sector-based activity and intensity metrics. Metrics are placed in the broader context both for their contributions to a national inventory and in comparison with other countries/regions.

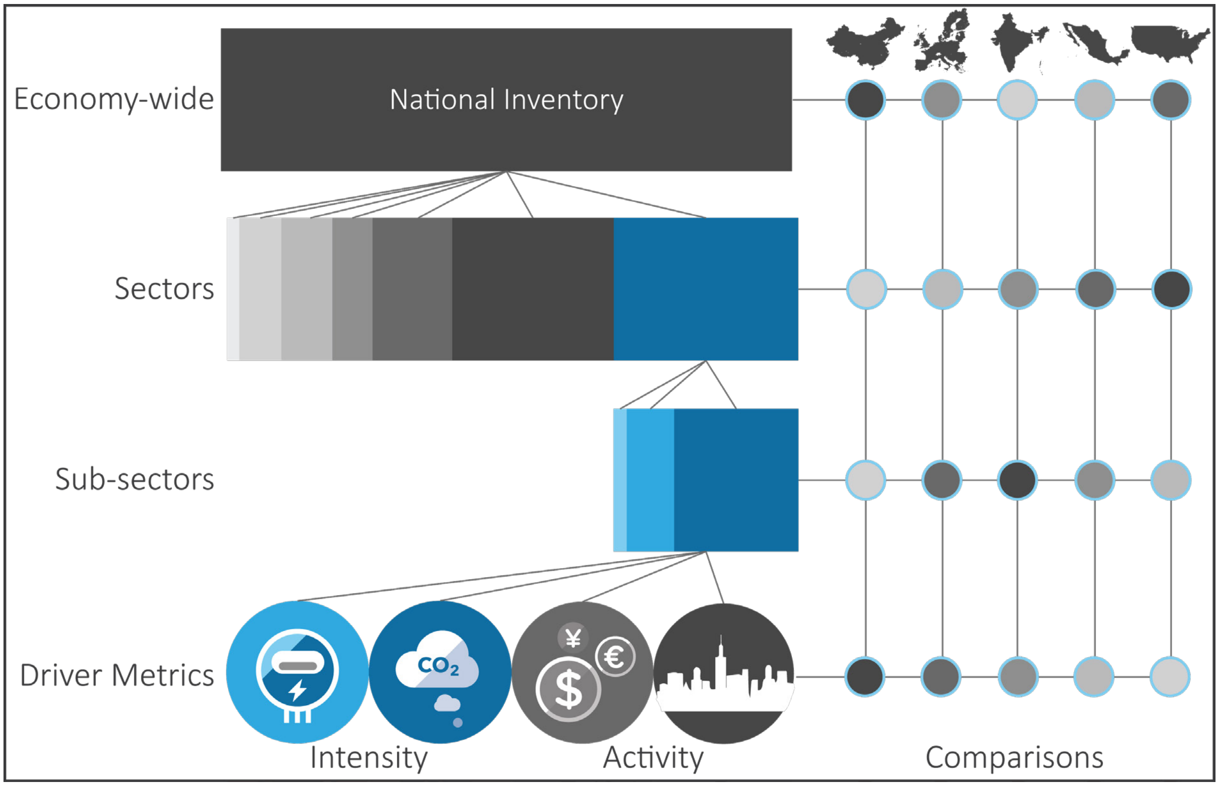

Figure 1: Pathway from macro to micro-level metrics. This is an illustrative example of a bottom-up model moving from driver metrics – both intensity and activity – through to a national inventory. Moving up the figure, comparisons are available at each level. For example, for the power sector one can examine the activity metrics of the demand for electricity (TWh), how this activity is met in sub-sector detail (generating technologies), how the sum of emission for this generating activity for the sector compares to other sectors, and finally how at each level these metrics compare to conditions in other countries/regions.

[1] The Shared Socioeconomic Pathways (SSPs) identify a number of socioeconomic, policy, and demographic conditions for each country. Created as a uniform set of scenarios for the integrated assessment modeling community, the five scenarios contain assumptions for economic activity and the interaction between countries. However, the CTI model uses only population and GDP estimates and does not attempt to model the qualitative aspects of the scenarios. SSP2, the Middle of the Road scenario, is used as the default in the CTI model, though users may switch between all scenarios.

Table 1 provides a list of the leading indicators grouped by driver and outcome metrics. This is not meant to be an exhaustive list of the metrics used in the CTI models, but represents some of the most significant metrics.

Table 1: *Leading indicator metric list by sector*

Sector	Driver Metrics	Outcome Metrics
Overarching	Population - 5 scenarios GDP - absolute and per capita – 5 scenarios	Carbon intensity of GDP Emissions per capita Total emissions
Power	Fraction of technology in mix - % of capacity New build capacity - per technology and fuel Capacity factor - per tech and fuel Auxiliary consumption, transmission and distribution losses Carbon intensity of generation by fuel Estimated cost of MWh	Total power sector emissions Average carbon intensity of generation Emissions per capita Total electricity generated Total electricity per capita
Transport	Size of vehicle fleet and car ownership per 1000 people Average distance driven per vehicle/ per capita Passenger kilometers traveled by all modes Internal combustion engine efficiency - fuel economy Electric vehicle penetration rate - fleet % and new sales # Modal freight and passenger split	Total transport sector emissions Carbon intensity - emissions per passenger km Transport emissions per capita Emissions gCO_2e/km Public transport penetration rate
Oil & Gas	% of gas extracted, vented and/or flared Crude oil refined, exported or imported Share of conventional and unconventional production Total volume extracted	Total emissions for Oil & Gas sector Emissions intensity of extraction Emissions per BOE extracted, distributed, and processed % of emissions from upstream, midstream, and downstream
Buildings	Total square meter building area per capita (res. and services) % of total energy by major usage category % of building area by asset class % of direct energy use by fuel type Electric efficiency factor	Total emissions from buildings sector Direct energy per square meter building area (res & serv) Electricity per square meter building area (res & serv) Emissions per square meter building area (res & serv)
Industry - iron & steel	% of EAF and BOF % of coal/natural gas/renewables/oil for direct energy Electric efficiency factor	Total emissions from iron & steel sector Emissions per ton generated Emissions per capita Total tons of steel generated
Industry - cement	% of coal/ natural gas/renewables/oil for heat generation % of Dry vs. Wet Clinker generation % of Clinker Substitution Electric efficiency factor	Total emissions from cement sector Emissions per tons generated Emissions per capita Total tons generated (and per capita)

Sector	Driver Metrics	Outcome Metrics
Industry - chemicals	% of coal/natural gas/renewables/oil for direct energy Electric efficiency factor	Total emissions from chemicals sector Emissions per unit GDP generated Added value per capita Total economic added value of sector Volume and % of emissions from F-gases
Industry - other	% of coal/natural gas/renewables/oil for direct energy Electric efficiency factor	Total emissions from other industry sector % of emissions from top three highest emitting sectors Emissions per unit GDP generated Emissions per capita
Agriculture	Number of Animals (absolute) Meat consumption per capita Fraction of managed manure facilities with biodigester Efficiency of nutrient use (crop yield/N fertilizer)	Total emissions from agriculture sector Emissions from agriculture per capita Emissions share of livestock, fertilizer, and other Emissions share of Methane, N_20 and CO_2 Emissions per Ha agricultural land
Forests	Net changes in protected areas (all IUCN categories) Total land forest & peat land area	Net emissions from forestry sector Mean carbon content per Ha
Non-CO_2	Share of diesel vehicles Share of waste incinerated % of gas extracted vented and/or flared Methane leakage rates in gas processing & distribution	Emissions of methane, nitric oxide and nitrogen oxide, and F-gases
Waste	Amounts of solid waste generated per capita % of collected waste recycled % of collected waste incinerated % Methane recovered from landfills	Total emissions from solid waste & wastewater sector Emissions per capita Emissions per ton of waste

Power Sector Module

Overview

The CTI model contains eleven sectors for each country/region. Each sector is itself composed of a module and contains data for the driver and outcome metrics of a sector. Further, there are linkages across the modules so that changes in one sector dynamically affect other sectors. The power sector is of chief importance for such linkages as it both receives input from demand sectors (all other sectors except forestry) and provides an input to other sectors through its calculation of the average carbon intensity of generation – the amount of emissions produced per unit of electricity generated. The CTI model combines data from different sources to calculate total emissions from the power sector using total power consumption and the average carbon intensity. Data for this sector is primarily obtained through Bloomberg New Energy Finance's (BNEF) New Energy Outlook, but also incorporates a few data points from the International Energy Agency's (IEA) World Energy Outlook.

Figure 2 shows the logic tree for the power sector. Starting from the top-left of the figure, the model takes the existing generating fleet (current capacity) and adds and subtracts according to planned capacity investments and retirements. The model then multiplies the installed capacity of each type of electricity source (coal, oil, gas, wind, solar, etc.) by the appropriate capacity factor (the utilization factor for a generating technology) and a representative amount of full-load hours to estimate the yearly power generation by fuel type. The intensity indicator "Carbon Intensity of Fuel" is an input based on electricity production data and emission factors from both the IEA and BNEF. The share of power generation from different fuel types is then determined by combining technology-specific data for installed capacity to calculate the average carbon intensity for a country or region. Power demand from the sectors are modeled individually and then aggregated for the total power consumption activity indicator (lower left-hand side of Figure 2). As demand changes, the model uses its own merit order, informed by analysis from BNEF and McKinsey, for the different fuel types to balance electricity demand and supply for energy (more on the optimization using this merit order below). The total power consumption and the average carbon intensity together are used to determine emissions from the power sector. Additional outputs include the carbon intensity of GDP, emissions per capita, electricity generation shares by technology, and emissions by demand sector.

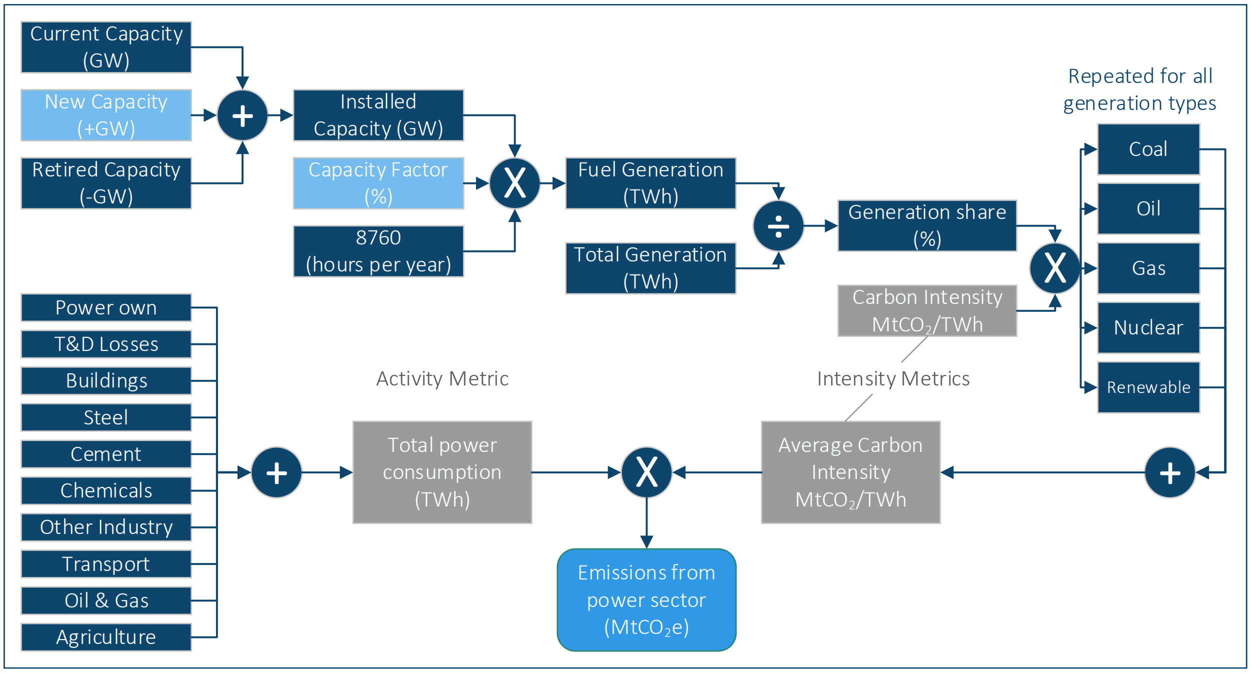

Figure 2: Power Sector Emissions Logic Tree. The CTI model calculates emissions from the power sector based on factors that include activity metrics and intensity metrics (indicated in grey) accounting for various fuel types and energy demand from the sectors (dark blue) as well as the generation necessary to cover own power consumption and transmission and distribution losses. Data are based on BNEF, IEA, and CTI's own demand forecast from the various other sectors. Light blue indicates where optimization takes effect.

Optimizing for the power sector

The CTI model also allows for a recalculation of the emissions based on a new electricity demand condition. This either occurs as a user identifies a different SSP which changes the population and GDP trajectories for a region, or by performing a sensitivity analysis in one of the demand sectors resulting in an increase or decrease in demand. When this occurs, an optimization macro will recalculate the supply of electricity based on a number of parameters that are available for the user to change. In Figure 2 we have highlighted in light blue where the changes occur for this macro. In Figure 3 we explain the detailed logic tree that underlies how this macro works.

The power sector macro recalculates the average carbon intensity by changing the amount of capacity for each of the generating technologies and how these technologies are utilized through their capacity factors for each year modeled. It does this in a multi-step function for two time periods (in the near term from 2016-2017, and the medium term from 2018 onward). The parameters for each step are accessible to a user and include the merit order for changes to capacity factors and capacity additions, and the amount of change allowed. There are a total of four steps for each time period (identified in the figure as changes to the capacity factor and then capacity additions). Before these steps the macro identifies whether or not the new condition is an increase or decrease in electricity demand as there are differing sets of parameters for both cases. Then the macro looks at the parameters identified for the first time period and applies these parameters in an iterative step order and repeats for the later period based on its own set of parameters.

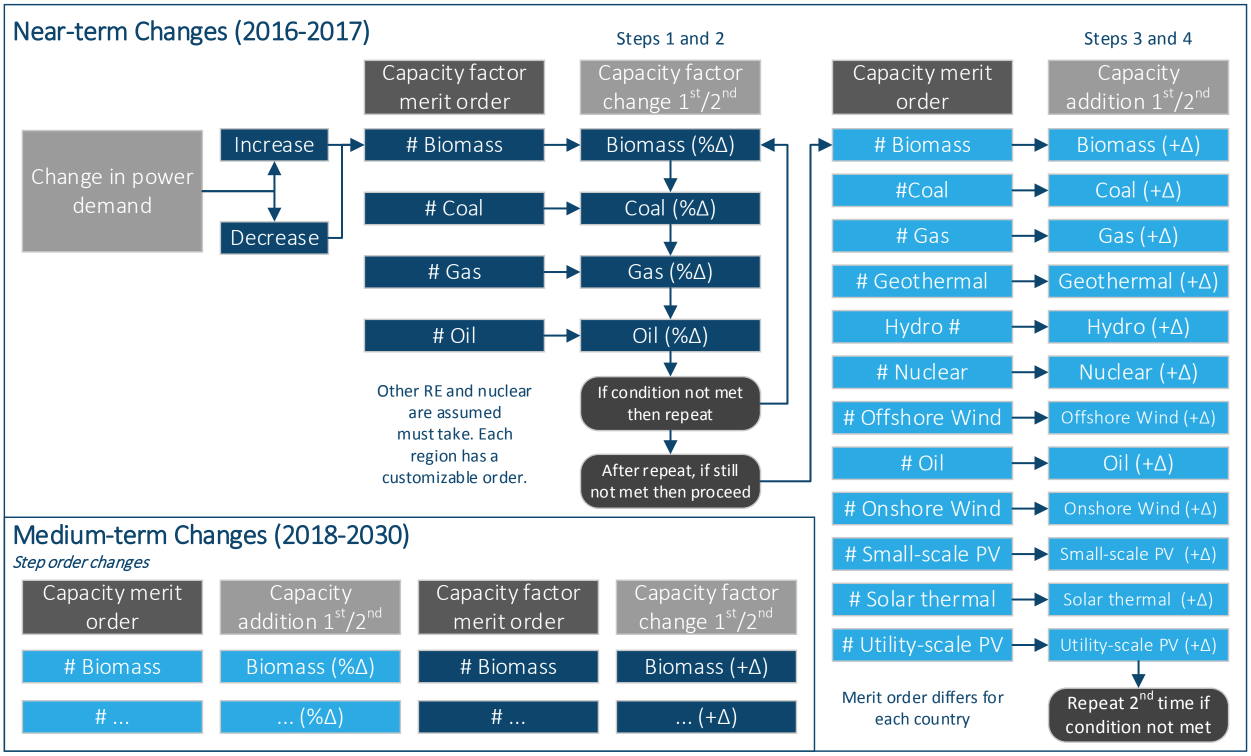

Figure 3: The CTI model recalculates emissions from the power sector when a change in electricity demand occurs via a macro. This macro changes the amount of capacity coming online in a given year (indicated in dark blue) and how that capacity is utilized through a change to capacity factors (indicated in light blue). Changes to capacity occur by incrementally adding or subtracting 0.1 GW while changes to capacity factors add and subtract 0.1%. This generates a new average carbon intensity metric that is used for calculating emissions.

The step order changes as you move from the near term (2016-2017) to the medium term (2018-2030). For the near term, the macro identifies the merit order for changes to capacity factors. In **Step 1**, the macro incrementally increases or decreases the capacity factors (according to the defined merit order) for Coal, Gas, Oil and Biomass. These technologies are considered dispatchable, as renewable energy (RE) and nuclear are assumed as a must take and already utilized (a user can add or subtract technologies based on their own analysis and identify the order in which changes occur). If the new electricity demand condition is met, the macro stops this incremental increase or decrease to the capacity factors. Otherwise this step is repeated a second time (**Step 2**). There are two steps for this such that increased utilization of the fleet can be tailored to local conditions. For example, a user might want to allow for higher utilization of gas in both steps while allowing oil to increase only in the second step.

If adjustments to capacity factors do not meet the new demand condition the macro moves to the second set of steps. In **Step 3,** the macro looks to capacity additions to meet the new electricity demand condition by either adding or subtracting from planned capacity additions. Unlike changes to the capacity factors, capacity additions are allowed for all generating technologies and not just the dispatchable technologies. As with the capacity factor adjustments there are two steps and a merit order. The macro will apply the merit order to incrementally add capacity until the new electricity demand is met or repeat this process in **Step 4** if the capacity additions in Step 3 prove insufficient. Again, this two-step process allows for the user to tailor how new capacity (or a reduction to planned capacity) changes according to local conditions.

In the medium term (2018 onwards) the step order changes. For this time period the two steps for capacity additions occur before the two steps that change capacity factors. This is important for reconciling differences between the CTI model and the BNEF model. The CTI model projects its own electricity demand based on sector analyses that differ from BNEF demand projections. In the near term, by prioritizing changes to capacity factors we allow for better continuity with BNEF projections of changes in the fleet capacity due to currently scheduled additions and retirements. In the medium term this is reversed, allowing the fleet capacity to be shaped by the projected changes in demand. Since fleet capacity additions or retirements are capital and time intensive, changes over longer time periods are important to capture. Together, this macro allows for a retention in the intelligence originally gathered by our research partners at BNEF on the investment flows impacting the planned addition and retirement of capacity and how fleets are utilized.

Transport Sector Module

Overview

The transport sector module contains substantial data on both the activity and intensity of different types of vehicles – light duty vehicles (LDVs), 2-wheeled and 3-wheeled vehicles, trucks, buses, freight, aviation, marine and rail. The module further breaks down the passenger vehicles based on type of vehicle and fuel. For indicators related to vehicle activity, data is primarily obtained from the International Council on Clean Transportation's (ICCT) Roadmap model, with a few exceptions such as the electric drive vehicle (EDV) penetration rate, aviation-freight emissions, and the total number of vehicles per 1000 people. Each mode of transportation and each fuel type has separate emission intensity calculations based on a combination of the activity metric (the amount of kilometers travelled, or tons transported in the case of freight), the energy intensity of the vehicle (the amount of energy it takes to travel a kilometer), and the emissions intensity (the amount of emissions per kilometer travelled based on the efficiency of the vehicle and the carbon content of the fuel). The module captures changes to economy or efficiency standards through changing these intensity metrics.

Activity metrics for the various modes include total number of vehicles within the particular type of vehicle mode, passenger activity as it relates to certain modes of travel (e.g. aviation, marine and rail) and freight activity for trucks, rail, marine, and aviation. As mentioned above, the CTI model deviates somewhat from the ICCT model, including in the expected number of vehicles of all types by 2030 per 1000 people which is a function of GDP per capita (Dargay, Gately, & Sommer, 2007), and the penetration rate of EDVs expressed by the percent of new car sales and in total. Important output metrics from the sector include total emissions from transport, emission intensity per passenger km and per vehicle km, total km travelled per capita, emissions per capita, and penetration rates by mode including public transport and EDVs.

Figure 4 shows the emissions logic tree for the transport sector. On the left-hand side are the activity (in dark blue) and intensity (in gray) metrics used for calculating emissions for four groupings: **Road Vehicles** including public and private passenger transport modes via LDVs, two-wheeled vehicles (2W), three-wheeled vehicles (3W), and buses, as well as three weight categories of trucks primarily engaged in freight transport; **Passenger Rail & Aviation** transport; **Freight Rail & Aviation** transport; and international **Marine Freight**. The sum of all groupings results in total emissions. In each grouping there is further granularity. For example, LDVs are broken down into gasoline, diesel, compressed natural gas/liquefied petroleum gas (CNG/LPG), fuel cell and electric drive vehicles. Biofuel emission intensities and penetration rates are also important for emissions calculations and alter the emissions intensities of the modes. In this way emission outcomes are a product of both the overall mode activity, the efficiency of the fleet, and fuel use for a given activity. The diversity of metrics in this sector provides numerous opportunities for comparisons between countries/regions.

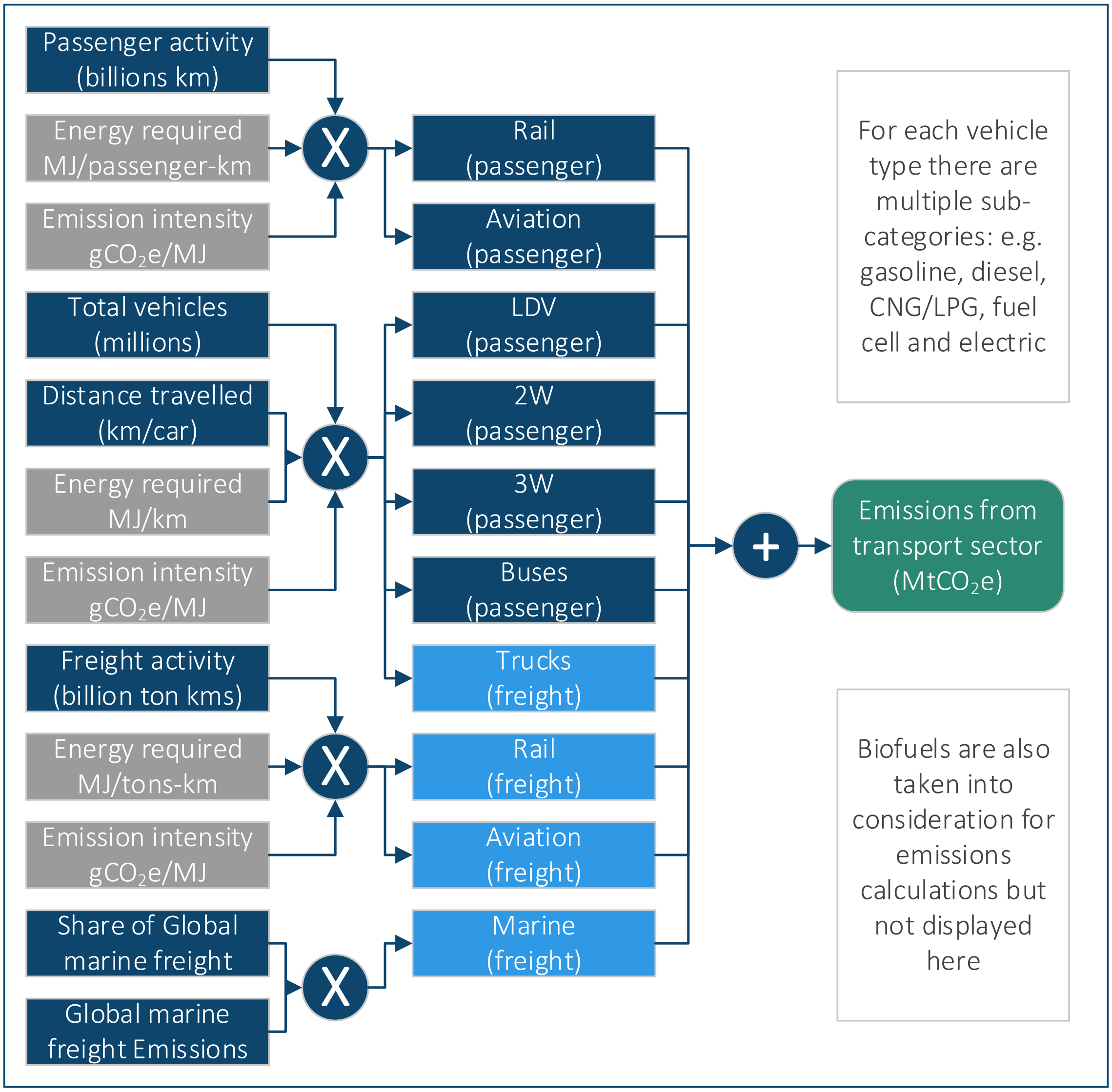

Figure 4: Transport Sector Logic Tree. The CTI model calculates emissions from the transport sector based on various factors that include activity metrics (indicated in dark blue) and intensity metrics (in gray) accounting for various transport modes, distance travelled, energy required per km travelled and energy intensity of fuel used for the particular transport mode. Data are based on ICCT's Roadmap model and CTI's own assumptions on patterns of growth.

Sources

Overview

The CTI relies on a number of trusted sources. In many cases the source data includes historical inventories that were used for calibrating the model – meaning that projections are based on a combination of analyses of trends of technologies, policies, and investments that affect the trajectory of a given sector. In other cases, the source data also included projections. However, the CTI model does not always take these projections at face value, and instead alters projections based on our own understanding of how a sector is trending, reacts to new policies, and/or changes according to differing pathways of population and GDP growth. Therefore, data sources fall into three categories:

1. **Historical Inventories** – sources that only included historical data for a given sector and required development of a methodology for projections;
2. **Historical Inventories with Projections** – sources that included historical and projected data for the time period covered and are incorporated at face value; and
3. **Historical Inventories with Altered Projections** – sources that included historical and projected data but were altered according to methodologies developed from additional analysis.

Both the power and transport sector data fall into the third category. BNEF provided the initial data for the power sector while the CTI methodology alters this to fit demand projections. ICCT similarly provided the initial data for the transport sector but the CTI methodology changed projections according to additional analyses of certain indicators. Table 2 highlights the sources used for calibration for some of the overarching data and for the power and the transport sectors. Additional sources are included for areas where the methodology differed from the leading source.

Table 2: Sources by Sector

Sector	Leading Source	Additional Sources
Overarching	Shared Socioeconomic Pathways for GDP and Population growth: Moss et al. "The next generation of scenarios for climate change research and assessment." *Nature* 463, 747-756 (11 February 2010). Data obtained from https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about	
Power	New Energy Outlook 2015 from Bloomberg New Energy Finance	Carbon intensity growth rates: World Energy Outlook 2015 from the International Energy Agency
Transport	Global Transportation Roadmap Model from the International Council on Clean Transportation	Share of marine shipping: IHS Consulting, Electric Vehicle Sales: Deutsche Bank EV Report, Vehicle sales: The Organization of Motor Vehicle Manufacturing, Vehicle Ownership: Dargay et al. "Vehicle Ownership and Income Growth, Worldwide: 1960-2030". Energy Journal, 2007, Vol. 28, No. 4

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