Core Model Proposal #390: Base Year Update: Initial updates preparing for the new base year

Product: Global Change Analysis Model (GCAM)

Institution: Joint Global Change Research Institute (JGCRI)

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Related sector: model-wide

Type of development: data, code

Purpose: GCAM's current base year – the last historical year used for calibration – 2015, is considerably lagged compared to the present year, indicating out-of-date assumptions about near-past state of the resources, commodities, and technologies represented in GCAM. This proposal makes data and code changes to enable updating the GCAM base year easier by making the processing code more flexible and robust.

Philosophy

This CMP was motivated by the following goals / broader philosophy for the base year update:

- Write code more defensively, with more checks and, where warranted, automatic correction of problems (with reporting) and try to reduce the number of cryptic failures
- Write code more flexibly, without hard-coding years or assuming a specific relationship between base-year and last year in data (where possible/reasonable), and be consistent with the use of years constants
- Update raw input data wherever necessary for future base year updates e.g., GDP and population, electric generation technology/ATB costs, resource/fossil fuel prices, floor space, US state energy consumption, steel and aluminum sector production and consumption, among others
- Allow use of historical driver data time series (population, GDP, technology costs) after the model base-year, with projections diverging from historical data after the last historical year.
- Document the process so that future base-year updates are relatively less time-consuming and costly.
- Report any data or code update needs for future base year updates or general recommendations to improve gcamdata's robustness

Description of Changes

Summary of Changes

This proposal presents changes in the codebase, updates to raw input data, and sometimes a revision of the processing approach. A detailed item-by-item summary of changes could be found in the **Appendix # 2** and accompanying spreadsheet. The following is a high-level, inexhaustive summary of changes presented in this CMP. We have:

1. Added 5 new countries
2. Extended GDP deflator up to 2022
3. Decommission gSSPs socioeconomics and industry income elasticities
4. Updated ATB technology costs to 2022 (including a new algorithm for keeping temporal consistency)
5. Adopted fossil resource prices from BP and updated data (including breakout into fossil, renewable, & Uranium prices)
6. Updated unconventional oil production in Canada and Venezuela
7. Updated US energy consumption data (SEDS) for GCAM-USA
8. Updated residential and commercial floor space (AEO) for GCAM-USA
9. Updated iron and steel, aluminum and alumina industry data (including a data-relevant revamp)
10. Improved IPCC emissions factors for fugitive CO2 emissions from fossil fuels

11. Added road emissions estimates and fuel emissions data from GAINS
12. Automated updating of data consistent with changing base years
13. Harmonized the data system to use one constant to control processing related to final calibration years
14. Added a new feature to synthesize chunks and files documentation
15. Improved documentation of multiple chunks
16. Added checks, warnings, error messages throughout

gcamdata R chunk and Code Updates

This section presents major themes of in-code changes. More details could be found in the "Other Updates" section or in Appendix # 2 that presents changes of all files and chunks.

Harmonizing years

We have adopted MODEL_FINAL_BASE_YEAR to control base year related processing throughout the data system. This has impacted roughly more than 50 chunks (details can be seen in Appendix # 2). Currently the data system has two classes of years constants: continuous years and interval years. Continuous years have a yearly time series throughout the model time horizon (HISTORICAL_YEARS starting from 1971 and FUTURE_YEARS starting from HISTORICAL_YEARS+1 through 2100). Interval years have a time-step that was previously standardized to be a 5-year increment. These years include MODEL_BASE_YEARS with a predefined array, MODEL_FINAL_BASE_YEAR as maximum of MODEL_BASE_YEARS, and MODEL_FUTURE_YEARS as a 5-year increment starting from a predefined starting year. In principle continuous years and interval years do not necessarily have to coincide, particularly in time windows closer to the base year.

The upper tail of HISTORICAL_YEARS now represents historical data that could go past MODEL_FINAL_BASE_YEAR, and are no longer required to align perfectly with MODEL_BASE_YEARS. In the previous core-model setup max(HISTORICAL_YEARS) was the same as MODEL_FINAL_BASE_YEAR, however we have now decoupled these to allow using historical data past the base year to improve model behavior in the near-future years. We have changed max(MODEL_BASE_YEARS) to MODEL_FINAL_BASE_YEAR throughout the data system to provide more autonomy over controlling base years through dynamically configurable constants in constants.R.

Other changes include removing hard-code 5-year time steps, such as in zsocio_L2323.iron_steel_Inc_Elas_scenarios.R. and making final calibration year flexible to user input in model_time.cpp. Moreover, years constant are flexible and robust to changing base years, i.e., just changing HISTORICAL_YEARS would automatically change the base year, future years, AgLU years etc., so time shift conditions were removed as they could be controlled using dynamically configurable years constants in constants.R.

Automatic Updating

Several files and code instances (more than 35) have been either updated or automated in the code to interpolate or extrapolate data for the final base year. Previously it was common to extend data within .csv files instead of code, which was fragile and leads to cryptic errors elsewhere in the code. Sometimes the assumptions are indifferent to changing historical years, i.e., either the values are constant or change linearly throughout the model time horizon. Such instances have been automated to be updated with changing base years. For example, technology change percentages for fossil fuels under SSPs (A10.EnvironCost_SSPs used in zenergy_L210.resources.R) is a linear interpolation from zero to the value in 2100, so a code block was introduced to read in just 2100 value and linearly interpolate in the code. This way updating this file remains flexible irrespective of the base year.

Another case for the extrapolation is when grouped data changes over time. This complicates automatic updating and because not all combinations of data items remain the same for all categories over the years. One such example is Land_type_area_ha.csv which does not have "complete" nesting for countries, GLUs and land types, i.e., not all countries have all GLUs and land types in all years. This creates NAs in the final data frame due to irregular combinatorial grouping, even without extrapolation to the latest historical year recent than maximum year in the data, resulting in downstream errors at many places (e.g., solar capacity factors). Ideally, such cases need to be fixed in the data file itself, however, in the meantime, the latest available data year has been copied forward to the final base year, accompanied by a warning written out to inform the user of this assumed extrapolation.

Lastly, all input files that have assumptions for both history and the future inherently assume that the future starts from 2020. Automatic updating, if not done right, could be problematic in specific cases when the base year advances to a year more recent than 2020. These cases include when values change over both history and the future and a separation needs to be maintained e.g., in zwater_L1233.Elec_water.R. A careful deliberation is warranted in such cases to ensure that automatic extrapolation maintains the separation between historical and future years until the assumptions are valid and coincide with the real-world technological state. That's also why every extrapolation where values change over time is accompanied by a warning message or a hard stop depending on the severity of implications of automatic updating.

The table below synthesizes chunks that have the capability to automatically update the files with years in response to changing base years.

Table 1. Summary of chunks that automatically update the final base year.

Chunk	**Change**
zaglu_L100.0_LDS_preprocessing.R	extended land data system files to the final base year and write a warning

zaglu_L120.LC_GIS_R_LTgis_Yh_GLU.R	extend historical managed forest area through final base year and write a warning
zemissions_L112.ceds_ghg_en_R_S_T_Y.R	added road emissions estimates from GAINS for all historical years; updated GAINS fuel emissions data to incorporate emission factors for the base year; and estimate emissions from alumina for historical years only
zemissions_L231.proc_sector.R	extended prices of unlimited resources to the final base year and write a warning
zenergy_L100.IEA_downscale_ctry.R	filled population shares for some countries to downscale IEA data for all historical years and write a warning
zenergy_L119.solar.R	extended harvested area land types to final base year and write warnings for out-of-data land data and resulting missing data in irradiance potential that affects solar capacity factors
zenergy_L121.liquids.R	copied forward the gas-to-unconventional oil coefficient to the base year and wrote a warning
zenergy_L1231.elec_tech.R	explicitly specified extrapolation method for gas technology efficiency, max improvement and rate of improvement
zenergy_L210.resources.R	automatically extend technology change percentages for fossil fuels under SSPs; automatically interpolate environmental costs under SSPs; flexibly update environmental costs for the final base year under SSP4; interpolate non-energy technology costs and coefficient for fossils for final base year
zenergy_L222.en_transformation.R	automatically interpolate future costs of primary energy transformation technologies; automatically update shareweights of transformation techs and make sure that cellulosic ethanol has zero share-weight in the base year to avoid DDGS calibration errors
zenergy_L270.limits.R	extended renewable resource prices (bio_externality_cost) to final base year
zgcamusa_L143.HDDCDD.R	extrapolate census population data to the final base year

zgcamusa_L144.Commercial.R	extended floorspace from EIA AEO for all historical years including final base year
zgcamusa_L2234.elec_segments.R	extended fuel shares of electricity load segments to all base years
zgcamusa_L2244.nuclear.R	extended nuclear gen II generation by state and year to final base year
zgcamusa_L231.proc_sector.R	extended price information for unlimited resources till final base year
zsocio_L100.GDP_hist.R	extended GDP (MER) from USDA to final base year
zsocio_L180.GDP_macro.R	extended labor force calculations from SSP up to final base year for GCAM Macro
zwater_L110.water_demand_primary.R	extended nuclear efficiency coefficients to all historical years
zwater_L1233.Elec_water.R	extended water shares of cooling system elec gen techs to base year while keeping the separation between historical and future years
zwater_L171.desalination.R	extended EFW IO coefficients to all historical years for desalination
zwater_L173.EFW_manufacturing.R	extended EFW IO coefficients to all historical years for manufacturing water withdrawals
zwater_L174.EFW_municipal.R	extended EFW IO coefficients to all historical years for municipal water withdrawals

Besides years, on few other instances, codebase has been changed to automatically extract constants which were only used at one place in the data system. For example, gcamusa.SEDS_DATA_YEARS constant have been removed and now these years are determined automatically within the zgcamusa_L101.EIA_SEDS.R chunk, accompanied by a warning to notify if SEDS data is outdated compared to final base year.

Defensive Code and Descriptive Debugging Support

One of the goals of this CMP is to make codebase more defensive by introducing checks and error messages to avoid erroneous inputs infiltrating to model outputs. This avoids computational expense and redundancy in debugging, especially if the error could have been stopped/notified at the source.

In most cases where automatic extrapolation is introduced, either a warning or a hard-stop trigger is introduced to inform the user or stop the process depending on the severity of implications resulting from extrapolation, see exampled in Appendix # 1. Warnings have not been introduced in cases where the historical and future data do not change or where a value is needed merely as a placeholder for the base year.

In other cases, error reporting has also been improved by spelling out specific sources of error with values wherever possible. One example is writing increase in base year satiation demand and satiation level to improve error reporting in satiation_demand_function.cpp. Another example is in technology.cpp that now writes absolute difference between model output and calibration value to the main_log.txt to improve calibration error reporting. This helps to identify the direction of the error (negative difference would mean model output is lower and calibration value is higher), which is particularly useful when there are dozens of errors.

Data Updates

Decommissioning gSSP outputs

Up until now, the data system attempted to generate outputs labeled as "SSPs" and "gSSPs". SSP was meant to represent the SSP scenarios as originally deployed, while gSSPs represent SSP assumptions updated with newer values for near-term socioeconomic drivers such as population and near-term GDP projections. Since the recent Core Model Proposal to update the SSP database and a general plan to more regularly update them the need to produce near-term adjustments is no longer needed. Thus, we drop the gSSP outputs. Note that while the Core socioeconomics are just SSP2 we are going to need some way of differentiating it for the Macro total factor productivity which will be different than the true SSP2 scenario. Thus, we create a `socioeconomics_CORE` which is just the same as SSP2 however will pull the CORE TFP assumptions.

As a result, specific outputs related to income elasticities in detailed industry, building and transport sectors have been dropped for standard SSP and GCAM3 scenarios. These income elasticity files are now retained only for gSSPs, and removed from the outputs of all industry, building, and transport sectors.

In total 25 chunks have been impacted by this change, including 6 zsocio_*_Inc_Elas_scenarios.R files and 6 zenergy_xml_*_SSP.R files, among others, see Appendix # 2 for all files and details. Configuration and batch SSP batch configurations (batch_SSP_REF.xml, batch_SSP_SPA1.xml, batch_SSP_SPA23.xml, batch_SSP_SPA4.xml, batch_SSP_SPA5.xml) have also been adapted to read-in the appropriate socioeconomics and industry income elasticities.

Socioeconomics

Five new countries have been added in iso_GCAM_regID.csv to be consistent with the latest changes in population and GDP. gdp_deflator() has been updated up to 2022 in pipeline-helpers.R. Along with updating UN population data, constants socioeconomics.UN_HISTORICAL_YEARS and socioeconomics.FINAL_HIST_YEAR have been removed and instead they are extracted by reading values directly from input files.

Numerous chunks have been modified to incorporate changes to reflect gSSPs. These revisions in socioeconomic outputs have particularly impacted income elasticities within industry, building, and transport sectors, as explained in the decommissioning gSSPs section.

Industry

A data-related revmap of iron and steel and aluminum and alumina detailed industry sectors was required to comply with base year requirements and more transparent processing. For this, new mapping files, new data files and new data sources were added for both sectors. Specifically, the source of aluminum production and consumption data was updated to International Aluminum Institute (IAI) from IAA in IAI_ctry_region.csv. Also, we broke out alumina energy consumption and extended up to 2021 in original data units (TJ) by using Metallurgical Alumina Refining Fuel Consumption category from 1st Jan 1985 to 1st Jan 2022 (all) in alumina_energy_region_IAI.csv. Similarly aluminum energy consumption was also broken out and extended up to 2021 in original data units (GWh) by using Primary Aluminum Smelting Power Consumption category from 1st Jan 1980 to 1st Jan 2022 (all) in aluminum_energy_region_IAI.csv. We also updated country aluminum production up to 2020 from CEDS aluminum_prod_USGS.csv and deleted unused aluminum_prod.csv file for aluminum production. Most of the data pre-processing has been endogenized to avoid undocumented user preprocessing (calculating totals, formatting, unit conversion etc.) in zenergy_L1326.aluminum.R.

For iron and steel, a new mapping file to match World Steel Association country names to GCAM country isos WorldSteelAssociation_country_iso.csv has been added. In the previous core model processing, it was unclear how the shares of iron and steel production from Electric Arc Furnace (EAF) from scrap vs direct rolled iron (DRI) were determined. We have back-calculated these and have added the ratio of Electric Arc Furnace steel production from scrap to total (scrap + DRI) in steel_EAFratio.csv. In addition, Angola's historical steel production (in GCAM region 4) has also been corrected in steel_prod_process.csv.

GCAM-USA

Numerous updates for GCAM-USA have also been made to bring the most recent data in and improve code robustness to changing base years. A few examples include updates to residential and commercial floorspace for all historical years, including final base year, in USA as consistent with EIA AEO 2022 AEO_flsp.csv, zgcamusa_L144.Residential.R, zgcamusa_L144.Commercial.R; updates related to removing hard coded countries and dynamically determining which countries go to "other countries" category in the same aforementioned chunks, and adding filtering in case of partial input data to distinguish between residential and commercial cases in zenergy_L144.building_det_flsp.R. Electricity shares from nuclear for unreasonable values have also been adjusted in zgcamusa_L223.electricity.R.

Another data update is extending state energy consumption data (SEDS) from EIA up to 2020 in EIA_use_all_Bbtu.csv. Other updates include extrapolating census population data to the final base year in zgcamusa_L143.HDDCDD.R, extending fuel shares of electricity load segments to all base years in zgcamusa_L2234.elec_segments.R, extending nuclear gen II generation by state and year to final base year in zgcamusa_L2244.nuclear.R, and extending price information for unlimited resources till final base year in zgcamusa_L231.proc_sector.R. We have also incorporated NEI along with SEDS for determining end year for GCAM-USA SO2 emissions linear control in zgcamusa_L2722.nonghg_elc_linear_control.R. This was required because if either of the data is not updated to a more recent base year, then the end year for linear control does not get written currently in xmls.

Approach Updates

ATB – NREL Annual Technology Baseline

NREL ATB sometimes changes technology names and data between releases, so we adopted a new structure to consistently stitch new data together in historical years.

ATB processing approach has been revamped by breaking out capital, fixed and variable operations and maintenance (O&M) costs into yearly files, by creating workflows to resolve discontinuities and discrepancies within years, and by adding new functions to scale the cost time series based on slope thresholds. All the code changes are contained within the zenergy_L113.atb_cost.R chunk. This update also added separate yearly technology overnight capital cost assumptions, fixed O&M, and variable O&M cost assumptions for the period 2015 through 2050 from NREL 2017 ATB through NREL 2022 ATB – all files are named as NREL_ATB_*.csv.

Other specific changes include deleting ATB capital costs, variable O&M and fixed O&M costs with consolidated years and breaking out into separate files for each year to allow tracking discrepancies in years; updating technology details to be consistent with recent ATB data atb_gcam_mapping.csv; and adding new mapping file to track between ATB technologies in historical ATB datasets ATB_tech_mapping.csv.

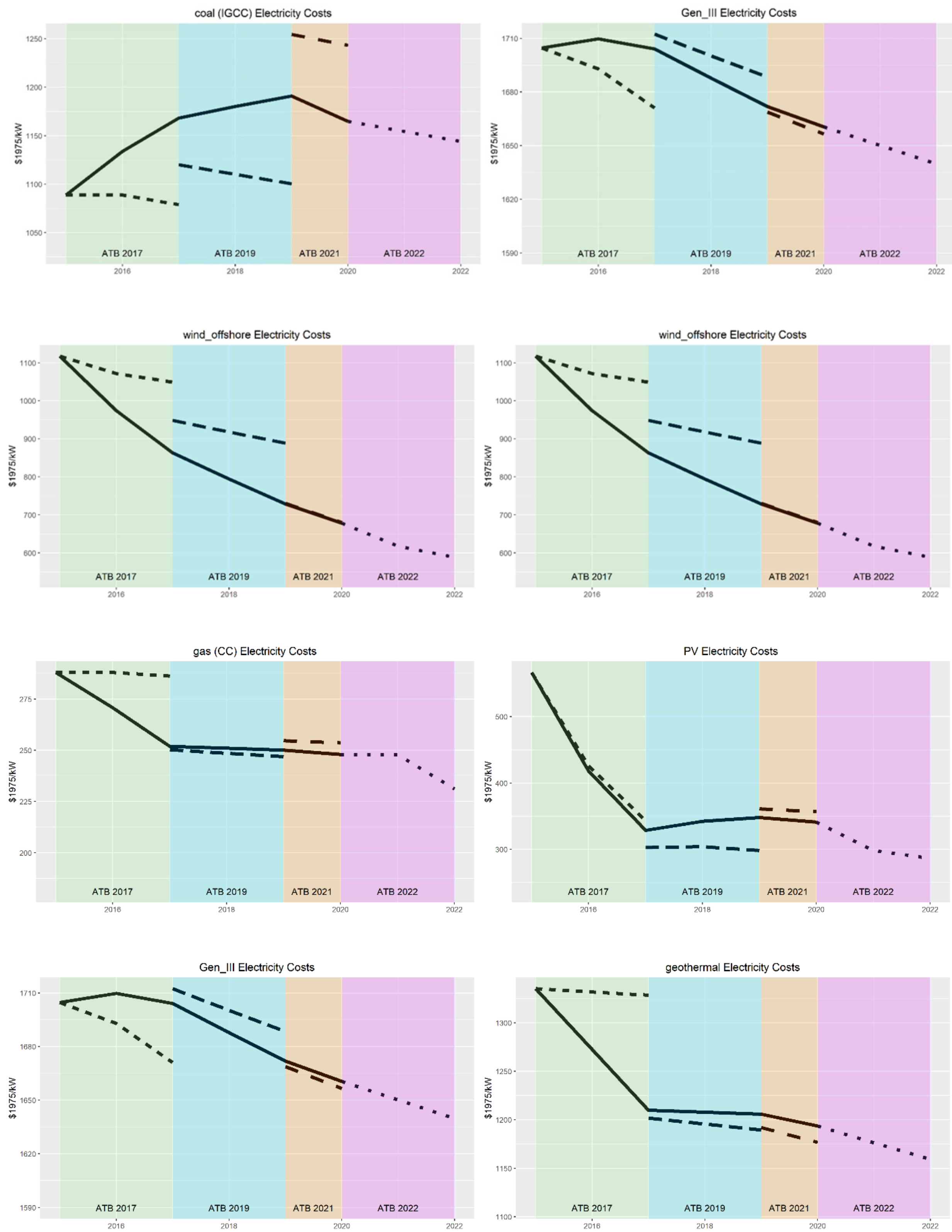


Figure 2. Select examples of new ATB processing approach (full line) to overcome discrepancies of technology cost between ATB data years (dotted lines).

Fuel Resource Prices

Instead of using legacy GCAM 3.1 model inputs, an update to fuel resource prices has been made by shifting to data from the EI Statistical Review of World Energy (formerly BP statistical review), for fossil fuel price timeseries A10.rsrc_info_fossils.csv, formerly contained in A10.rsrc_info.csv together with other resources. Historical Uranium price timeseries A10.rsrc_info_uranium.csv has also been updated based on recent NEA Uranium 2020 Redbook (using US long-term from Fig. 2.10 in 2020 report). Renewable and other resource prices have been broken out into a separate data object A10.rsrc_info_renewables_others.csv but the prices remain largely unchanged.

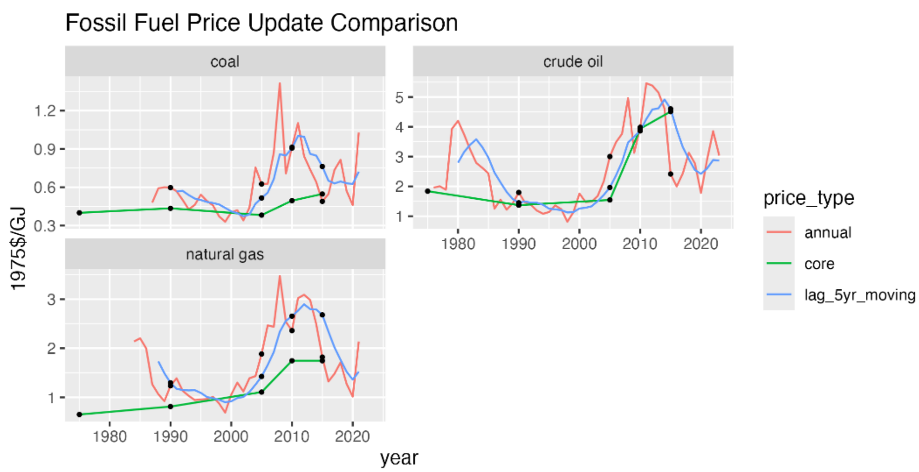


Figure 3. Historical prices of global fuel resource prices (coal, crude oil, and natural gas) in 1975USD/GJ for all resources. The green line represents the previous master, red line represents annual price time series, and the blue line shows updated resource prices in this CMP using a 5-year moving average.

Timeseries for historical fossil fuel prices has been provided for years starting in 1971 through 2021. Coal price timeseries is derived by averaging from two sources (Northwest Europe marker and Japan steam spot CIF), natural gas timeseries uses Average German Import prices, and crude oil uses Brent data. Raw data is kept in original units for comparability and traceability with original data source, and conversion coefficients have been introduced in constants.R and used in zenergy_L210.resources.R to convert from fuel units (barrels, MMBtu etc.) to energy units (EJ, GJ etc.).

Specifically, fuel resource prices update entails:

- splitting rsrc_info file into 3 files for fossils, renewables, and uranium due to varying data sources
- updating coal, oil, gas data source to EI Statistical Review of World Energy (also known as bp-stats-review)
- updating uranium prices according to NEA Red Book 2020

- adding conversion coefficients for oil (barrel to GJ), gas (MMBtu to GJ), and coal (tonne to GJ)
- creating rsrc_info instead of reading in A10.rsrc_info
- reading rsrc_info instead of A10.rsrc_info in all downstream chunks

Some downstream files that were directly reading in the fuel resource prices file (A10.rsrc_info) have also been impacted. For example, zenergy_L1322.Fert.R zenergy_L239.ff_trade.R zgcamusa_L2238.PV_reeds.R zgcamusa_L2239.CSP_reeds.R have been modified inputs to read in endogenously calculated fuel prices data object (L210.rsrc_info).

Other Updates

Energy system

A few other updates in the energy system were also necessary to enable future base year updates. For instance, population shares for some countries to downscale IEA data were filled for all historical years and a warning was introduced in zenergy_L100.IEA_downscale_ctry.R.

For CSP solar energy, a scaling was performed for direct normal irradiance (DNI) and DNI area relative to countries area in zenergy_L119.solar.R. If DNI for areas suitable for CSP is a small fraction of the area of the country, then this will overstate the potential for CSP since most countries will not have access to power generated by CSP. Countries with smaller DNI area to country's total area ratio were scaled to avoid overestimation of average solar capacity for countries such as Russia, Canada etc. for concentrated solar power (CSP) plants.

In the same chunk harvested area land types were extended to final base year and a warning was written for out-of-data land data, resulting in missing data in irradiance potential that affects solar capacity factors.

Data related updates include updating historical unconventional oil production in Canada and Venezuela up to 2021 in rsrc_unconv_oil_prod_bbld.csv. This also comes with an extension of historical gas to unconventional coefficient in the zenergy_L121.liquids.R chunk. Other updates include, updating capital cost of 2nd generation LWR nuclear reactors up to 2020 in A23.globaltech_capital.csv, extending advanced (cheaper) and low (expensive) nuclear capital costs up to 2020 in A23.globaltech_capital_adv.csv and A23.globaltech_capital_low.csv, extending both fixed and variable operations and maintenance costs up to 2020 in A23.globaltech_OMfixed.csv and A23.globaltech_OMvar.csv, and adding electricity technology shareweights for the base year in A23.globaltech_shrwt.csv.

We have improved the logic controlling trade "calibration" between IEA balances and COMTRADE data in zenergy_L2011.ff_ALL_R_C_Y.R. Regardless, a part of this calibration is redundant after CMP # 350 Detailed Natural Gas Trade because there are no NAs or negative trade values in data objects tracking trade flows. Moreover, the code in zenergy_L222.en_transformation.R automatically interpolates future costs of primary energy transformation technologies and automatically updates shareweights of transformation techs.7

Emissions

We have added road emissions estimates from GAINS for all historical years, updated GAINS fuel emissions data to incorporate emission factors for the base year, and estimated emissions from alumina for historical years only in zemissions_L112.ceds_ghg_en_R_S_T_Y.R. Prices for unlimited resources for miscellaneous emissions (A31.rsrc_info.csv) have also been extended to the final base year. This has also been automated in zemissions_L231.proc_sector.R and zgcamusa_L231.proc_sector.R with a warning message. .

Fugitive CO2 emission factors for unconventional oil were also updated in IPCC_unconventional_oil_fug_emfacts.csv and emissions.UNCONVENTIONAL.OIL.FUG.CO2.EMFACT constant was also modified to reflect this change (Bugfix). This improvement to the emission factors was done by excluding "oil sands upgrading" category from the calculation since these would be included in GCAM's existing "refining and processing" emissions not "fugitive" emissions.

Agriculture and Land Use (AgLU)

AgLU years have also been harmonized with dynamically configurable years, so when the base year changes, the relevant AgLU years will also change accordingly. One such example is zaglu_L162.ag_prodchange_R_C_Y_GLU_irr.R where we use AgLU historical years instead of historical years.

We have updated share-weight interpolation in zenergy_L222.en_transformation.R to delay adoption of cellulosic ethanol-based 2G bioenergy, along with an associated code change in zenergy_L222.en_transformation.R to make sure cellulosic ethanol has zero share-weight in the base year to avoid DDGS calibration errors. Other updates include removing negative values for oilcrop and soybean in some regions in recent historical years zaglu_L108.ag_Feed_R_C_Y.R; extending historical managed forest area through final base year and writing a warning, renaming the input file to be consistent with style guidelines zaglu_L120.LC_GIS_R_LTgis_Yh_GLU.R and include first year in calculating land cover change and rates zaglu_L125.LC_tot.R

Water

Energy-for-water input-output coefficients were extended to all historical years for desalination (A71.globaltech_coef.csv), manufacturing, and municipal water withdrawals in zwater_L171.desalination.R zwater_L173.EFW_manufacturing.R zwater_L174.EFW_municipal.R. Water shares of cooling system electricity generation technologies have also been extended to the base year while keeping the separation between historical and future years A23.CoolingSystemShares_RG3.csv. Nuclear efficiency coefficients were also extended to all historical years in zwater_L110.water_demand_primary.R. Finally, South Sudan's iso ssd mapping to Africa continent was also added in mfg_water_mapping.csv.

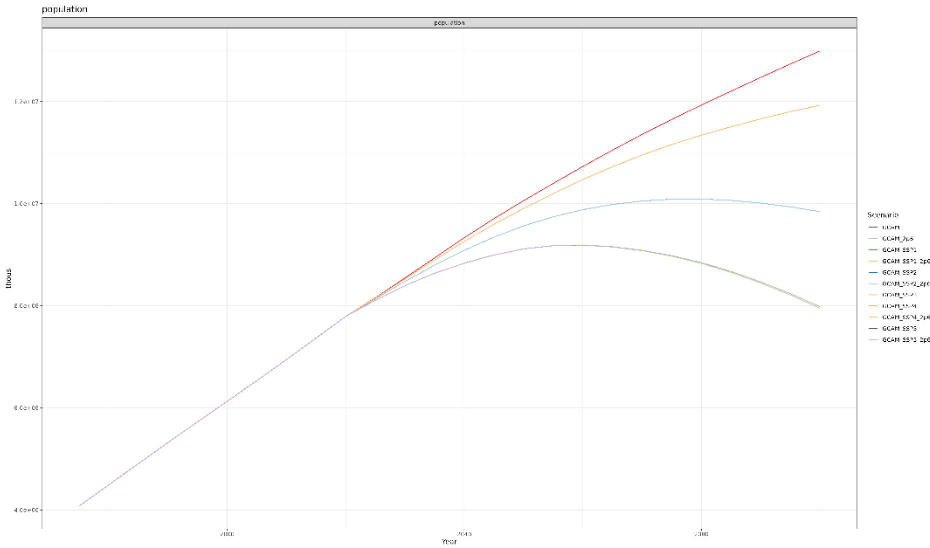
Other minor updates

Other minor updates include adding a "make_drake" make command capability in Makefile to run gcamdata using driver_drake() as a matter of convenience. The previous "xml" target which runs the standard driver() remains unchanged. This is particularly useful while running remote ssh sessions. objects.vcxproj has been modified to change visual studio platform tools version to be consistent with hector's toolset and avoid error in compiling locally on windows. Another issue that has been repeatedly faced by Windows users in running out of file path characters. The solution to debugging MAX_PATH error on windows is as simple as moving the root directory upstream or reducing the characters in the folder name; this has been clarified in driverdrake_vignette.Rmd. Minor updates from constants.R include changed string for disabled modules, add conversion coefficients for fossil fuels, updated fugitive CO2 emission factors for unconventional oil, removed a few constants and endogenized them in relevant chunks e.g., gcamusa.SEDS_DATA_YEARS, gcam.WESTERN_EUROPE_CODE etc.

Validation

All standard validation scenarios (Reference, SSPs, SSP_RCPs, USA, USA_RCP2.6) have solved.

Most changes in this CMP do not change results. However, the changes to the ATB costs primarily, and to a lesser extent primary energy prices, do have some impacts in the energy system.



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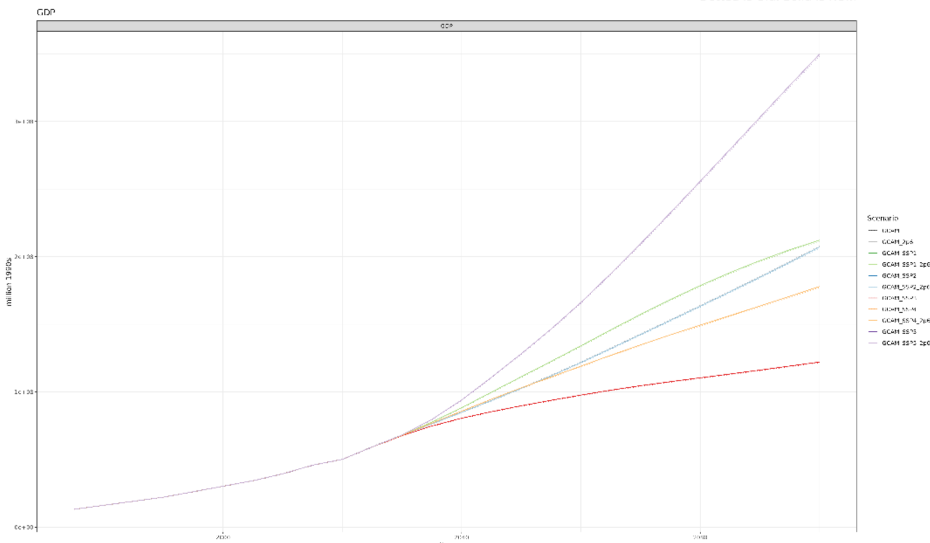

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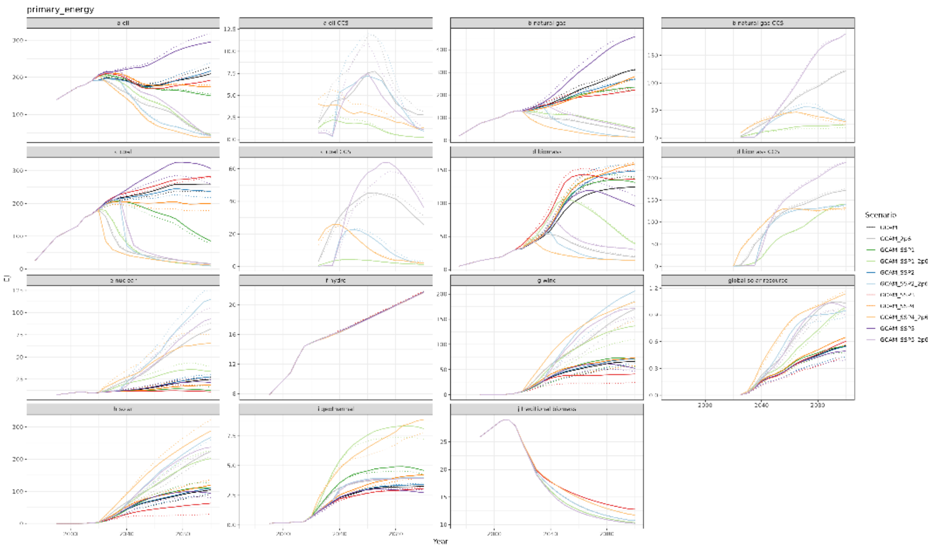

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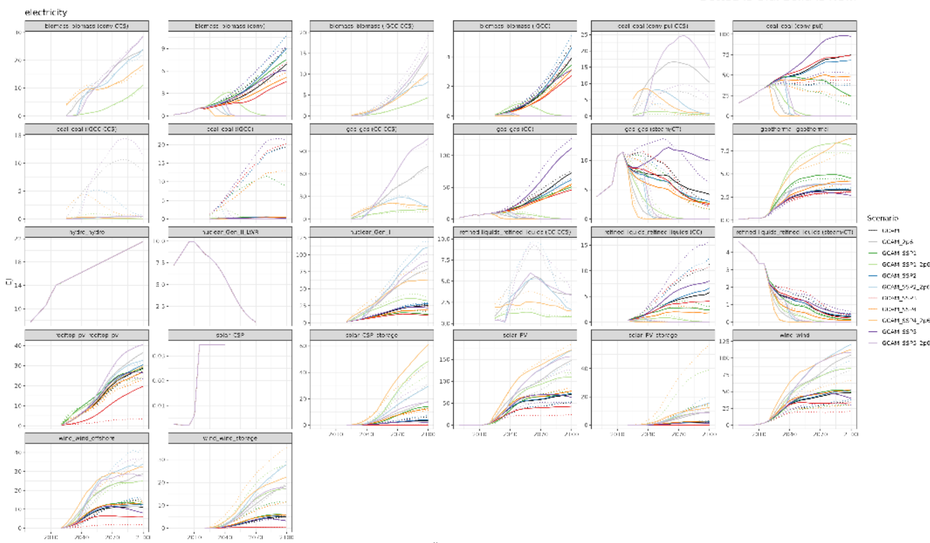
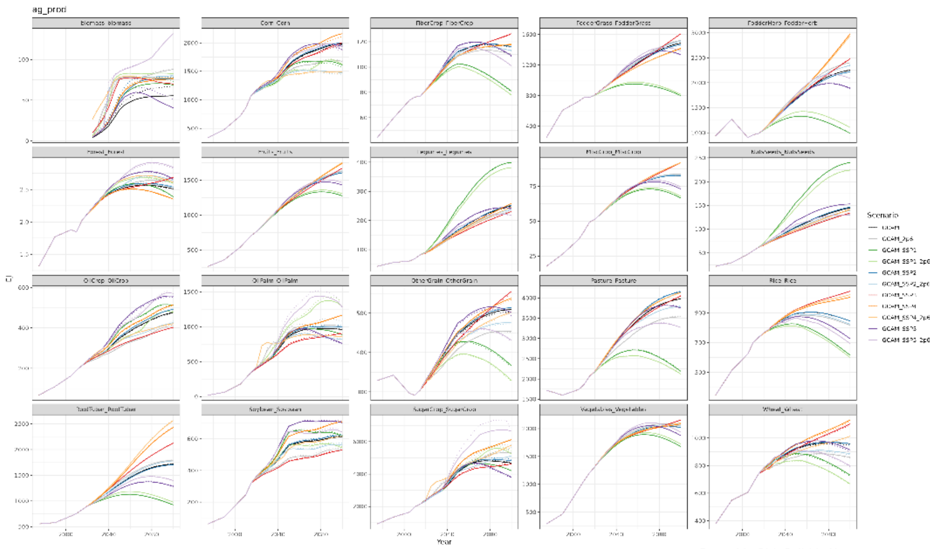


Dotted is Old. Solid is New.

Given no major changes in the Ag and Land use sectors, results there are largely unchanged.



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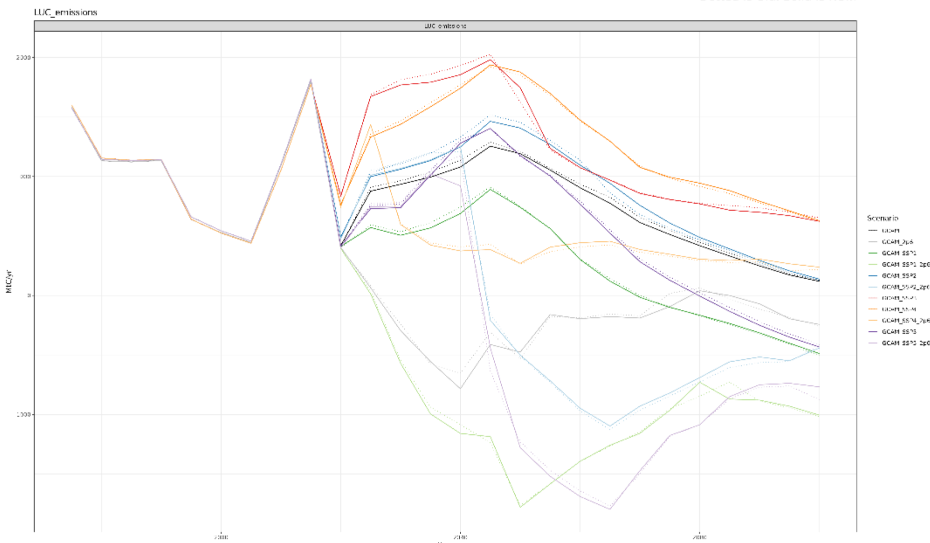
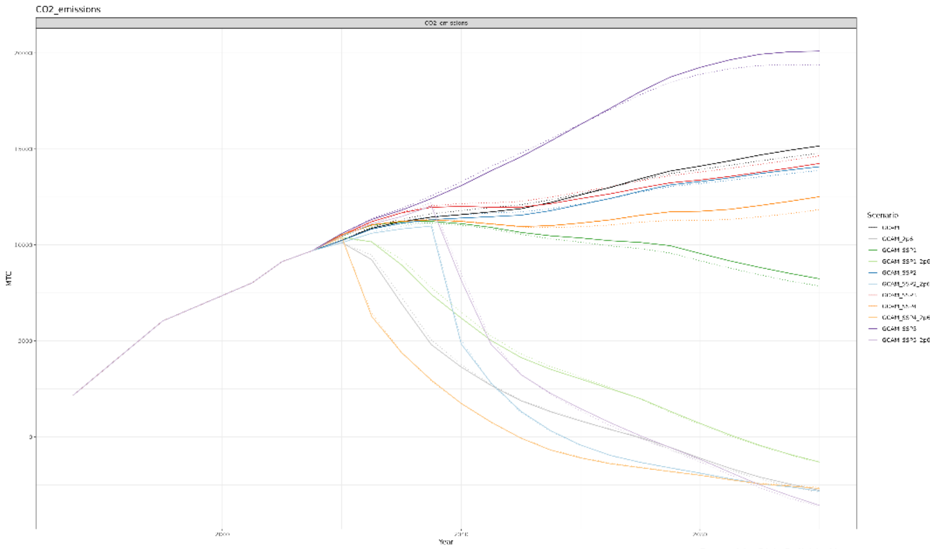
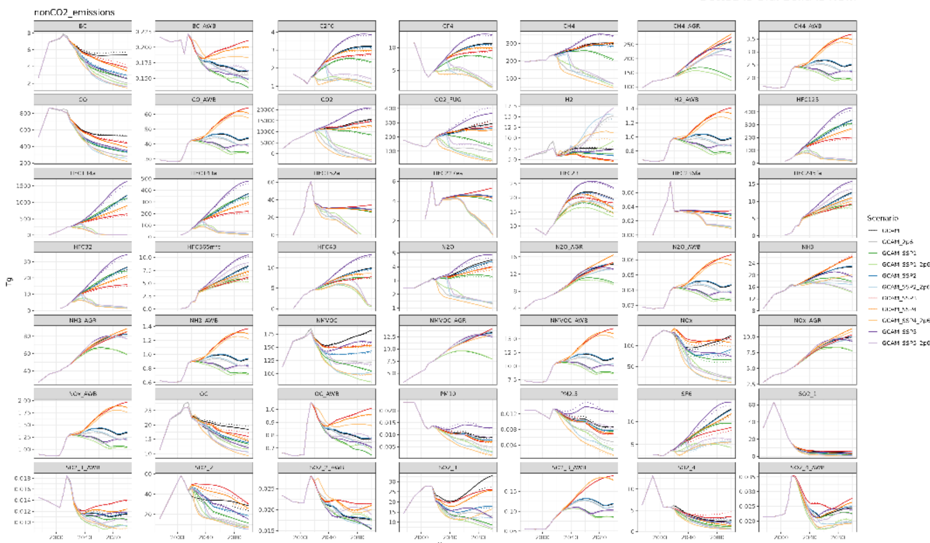


Dotted is Old. Solid is New.

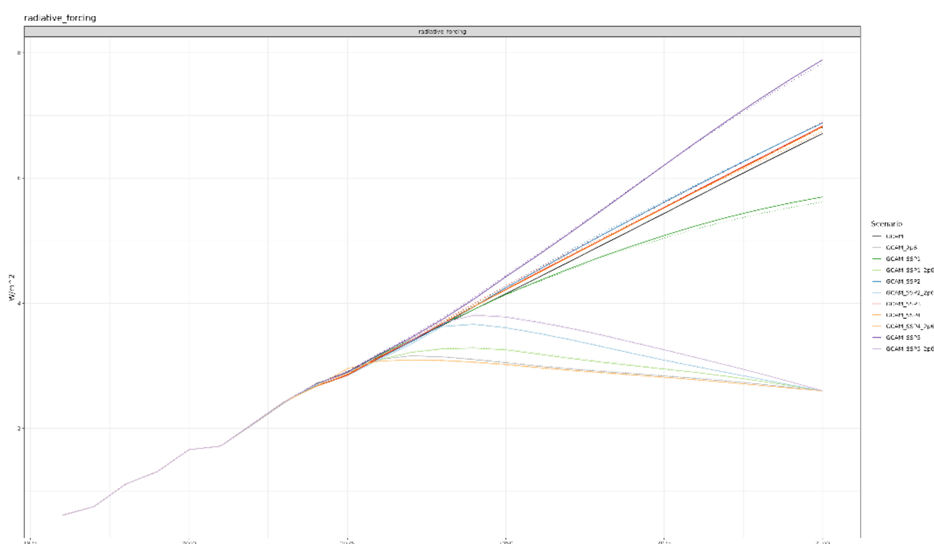
For emissions, while there were some bug fixes related to unconventional oil, most of the differences are a result of energy system changes. Which have higher CO2 emissions in most scenarios. However, also some compensating increase in SO2 emissions leaves the total radiative forcing in a similar place.



Dotted is Old. Solid is New.



Dotted is Old. Solid is New.



Dotted is Old. Solid is New.