

# Core Model Proposal #408: Cement Data Updates

**Product:** Global Change Analysis Model (GCAM)

**Institution:** Joint Global Change Research Institute (JGCRI)

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**Related sector:** energy

**Type of development:** methodology and data update

**Purpose:** This core model proposal updates cement production, emissions, and electricity/energy use with new datasets. Prior to this update, cement production data in GCAM was reliant on outdated data sets, with older historical data held constant for more recent historical years. Data availability for cement is still a challenge; some of the new data sets do not have complete global coverage. However, many of the new data sets introduced in this proposal are regularly updated; the proposal also includes data processing improvements that aim to streamline future updates. It also includes a small code change to address solution challenges during calibration.

## Description of Changes

In this update, cement production, emissions, and electricity/energy use are updated with new datasets where possible. Some additional checks are put in place to compare derived cement energy data with IEA energy balance data for nonmetallic mineral energy use.

### New Input Data Files

- energy/IEA\_cement\_thermal\_energy\_GJt\_clinker\_global\_trend
- energy/IEA\_cement\_elec\_kwht\_update
- energy/Andrew\_cement\_production
- emissions/Andrew\_cement\_emissions
- energy/mappings/Andrew\_iso\_correction

### Cement Emissions and Cement Production

Cement CO<sub>2</sub> emissions and production are now estimated using the Andrew Cement CO<sub>2</sub> data set, which provides CO<sub>2</sub> emissions, cement production, and other data not used here and is updated annually. The use of this data set should streamline future data updates for cement emissions and production. Andrew country codes are sometimes different from GCAM's iso mapping, so an iso correction mapping file is added.

However, Andrew's cement production and emissions have some inconsistencies which result in very low cement CO<sub>2</sub> emissions factors (EFs) in some cases. A significant number of countries/years, particularly in Western Africa, have non-zero cement "production" with zero or very low emissions because the Andrew data assigns cement production to countries that are importing clinker and grinding it with additives to "produce" cement locally. In these regions, the limestone calcination related CO<sub>2</sub> emissions (and the vast majority of the energy consumption) are taking place in other countries. Conversely, countries/years with clinker exports will report disproportionately high CO<sub>2</sub> emissions per production.

An ideal solution to this issue would be to represent cement/clinker trade, but that is currently out of scope. Instead, we implement a heuristic approach to reconciling the Andrew data which generally gives precedence to the CO<sub>2</sub> emissions data rather than the production data. We assign a minimum (EF<sub>min</sub>, 1st decile) and maximum (EF<sub>max</sub>, 10th decile) threshold for emissions factors, and update outlier emissions / EF data as follows:

- First, missing values for emissions are set to 0
- Second, EFs are re-set for cases where production is zero. If production is zero and emissions are non-zero, the EF is set to EF<sub>max</sub>. If production and emissions are zero, the EF is set to the median EF value.
- Third, production is re-set for cases where the EFs are out of bounds. If the computed EF falls below EF<sub>min</sub>, we reset production equal to emissions / EF<sub>min</sub>. If the computed EF falls above EF<sub>max</sub>, we reset production equal to emissions / EF<sub>max</sub>.

## **Limestone Use in Cement**

The method for estimating limestone consumption in cement is unchanged; limestone input-output coefficients are calculated from a universal value for limestone carbon content and the update cement CO<sub>2</sub> emissions.

## **Cement Electricity Use**

A time series for cement electricity use is derived by stitching together two IEA data tables which estimate cement electricity use for 2010 and 2018 and differ in their region/country coverage. For regions where estimates are not available in 2018, a global average (weighted by cement production) efficiency improvement is applied to the 2010 value to estimate electricity use in 2018.

## **Cement Thermal Energy**

Currently, historical cement thermal energy use in GCAM is estimated using a single IEA data table that estimates total cement energy use (including electricity) in 2010. We improve this methodology by utilizing another IEA table estimating cement clinker thermal energy use (global) from 2010 to 2021. This data is used to calculate efficiency improvements for thermal energy use in cement from 2010 to 2021; that efficiency improvement is applied to the existing 2010 cement total energy use table to derive a time series. Later, cement electricity use is subtracted from cement total energy to estimate cement thermal electricity.

## **Cement Fuel Shares**

Fuel shares for cement energy use are taken from IEA non-metallic mineral sector. This sector also includes glass and ceramic production, but no other up to date, cement specific data was found to be available. Fuel shares are calculated from IEA intermediate output files. When no data is available from IEA for historical years, the share of fuels is assumed to be 100% coal to avoid NA values and having data dropped entirely (this missing data usually occurs in small countries with little to no cement production and in years prior to the 2021 final base year).

## **Cement Energy Consumption Check**

Final cement energy use values are compared against the IEA nonmetallic minerals sector by GCAM region and fuel. If final values estimated via the methods described above are larger than IEA nonmetallic minerals, then the values are replaced with the IEA values.

## **Outstanding Challenges**

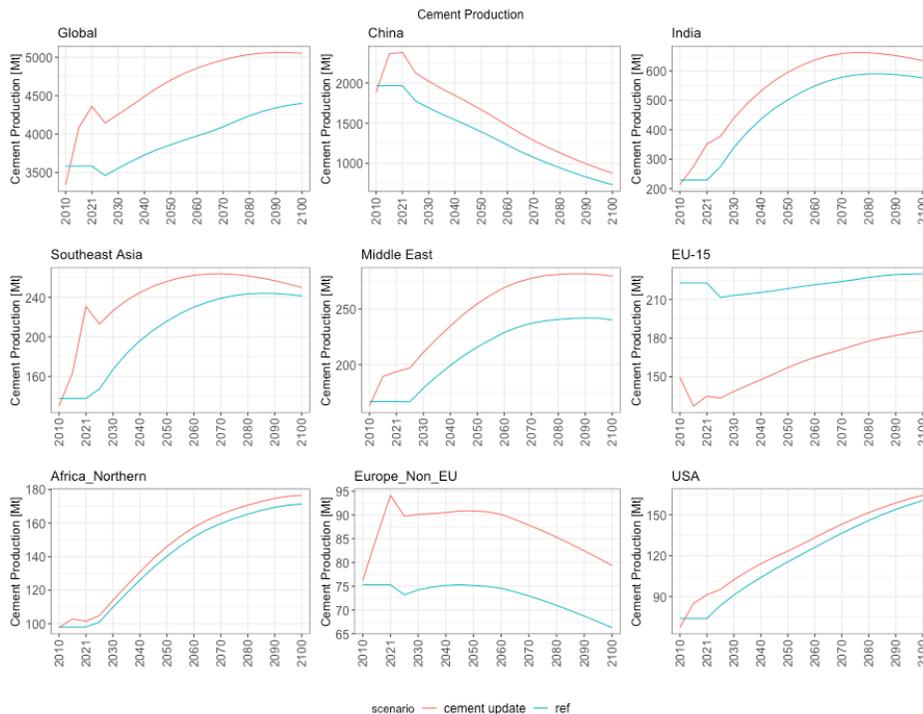
Currently, historical other industrial energy use values are adjusted at the end of the cement script. These updates involve correcting negative energy use calibration values that appear in earlier scripts. This existing methodology leads to negative calibrated cement values (very small) in a handful of fuel-region combinations. These are currently zeroed out and do not affect model

calibration / solution, although it would be preferable to address the negative values further upstream.

### Calibration bugfix

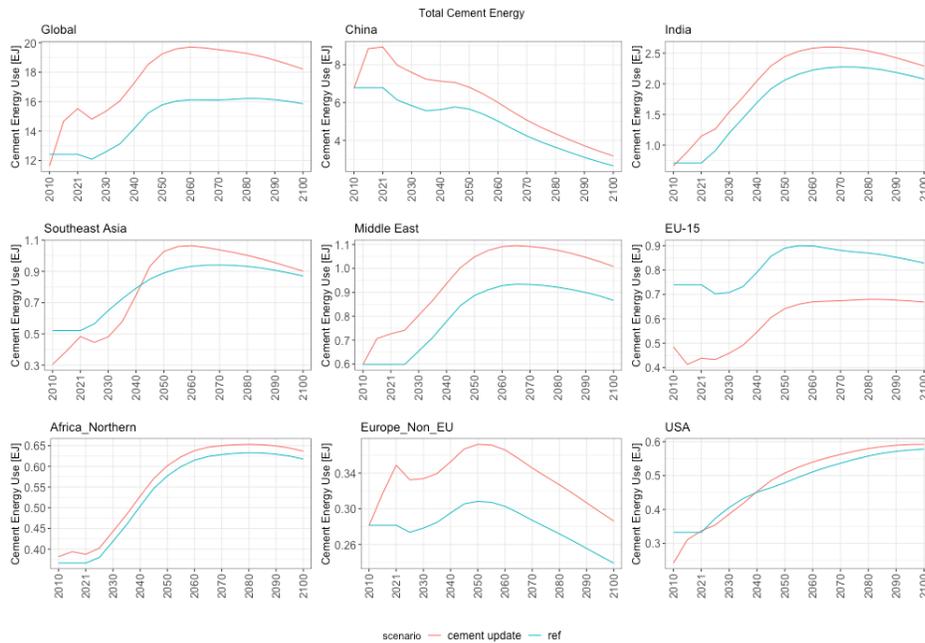
This proposal includes a small change to subresource.cpp which fixes the "fully-calibrated" logic to ensure that fully calibrating zero production / consumption works as intended. The "fully-calibrated" flag works in conjunction with the solver configuration to ensure that the solver does not attempt to change the price of those markets as doing so would lead to a "singular Jacobian". This fix addresses the solution challenges during calibration model periods that have impacted users attempting to fully calibrate zero production / consumption since GCAM v8.2.

## Validation – GCAM Reference Scenario



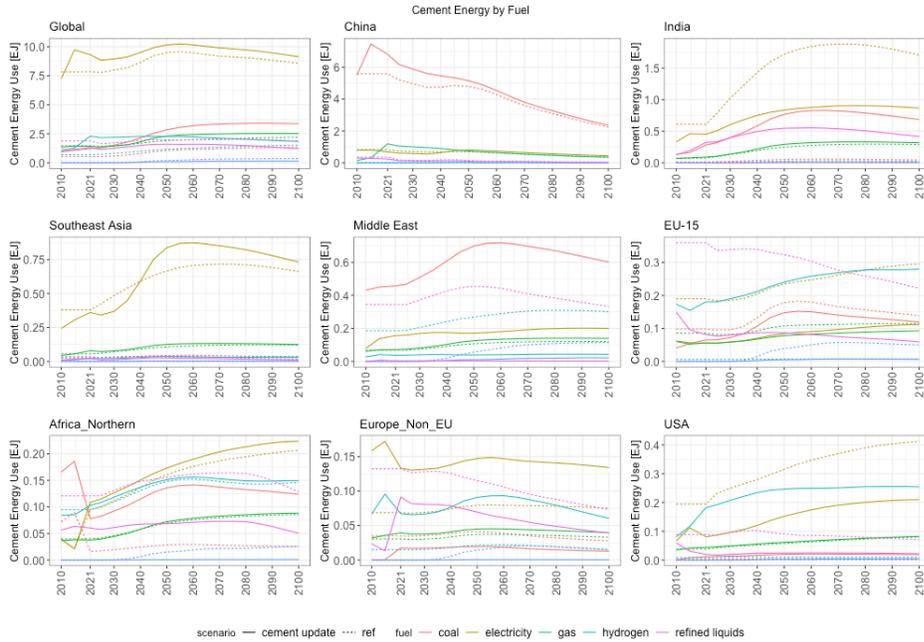
***Cement Production: Cement production in the GCAM reference scenario for the current GCAM core (“ref”) and this proposal (“cement update”), globally and for the top 8 cement producing regions.***

This update corrects the artificially flat cement production from 2010 through 2021 which impacted all GCAM regions. Updated cement production values are higher globally and for many regions, but not all.

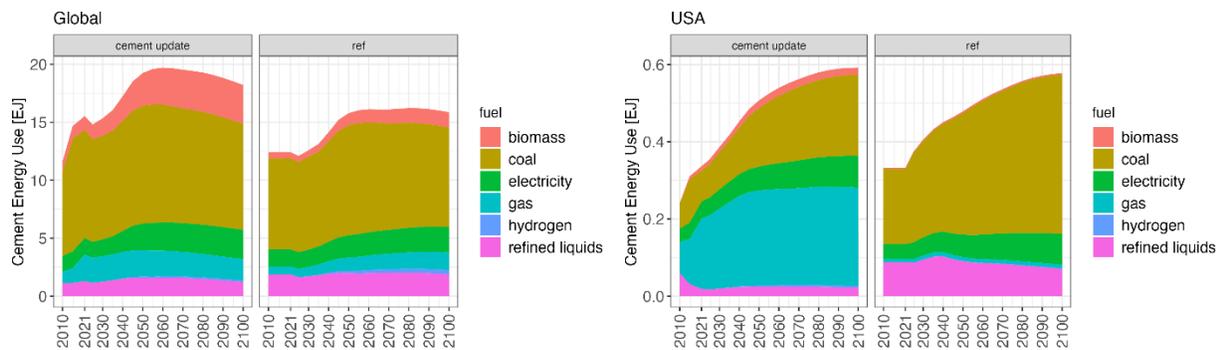


***Total Cement Energy Use (thermal and electricity): Energy Use in the cement sector in the GCAM reference scenario for the current GCAM core (“ref”) and this proposal (“cement update”), globally and for the top 8 cement producing regions.***

Total cement energy use is generally increasing with increased production, but as the method for estimating the thermal and electricity intensity of cement production has been updated, the dynamics between changes in production and total energy use is not consistent across regions. For most regions, total energy is higher than the previous estimate consistent with higher production estimates. However, for a handful of regions such as the USA, updates in thermal and electric energy intensities data yield smaller total energy estimates in near future years.



**Cement Energy Use by Fuel (line graph):** Energy use in the cement sector by fuel in the GCAM reference scenario for the current GCAM core (“ref”) and this proposal (“cement update”), globally and for the top 8 cement producing regions



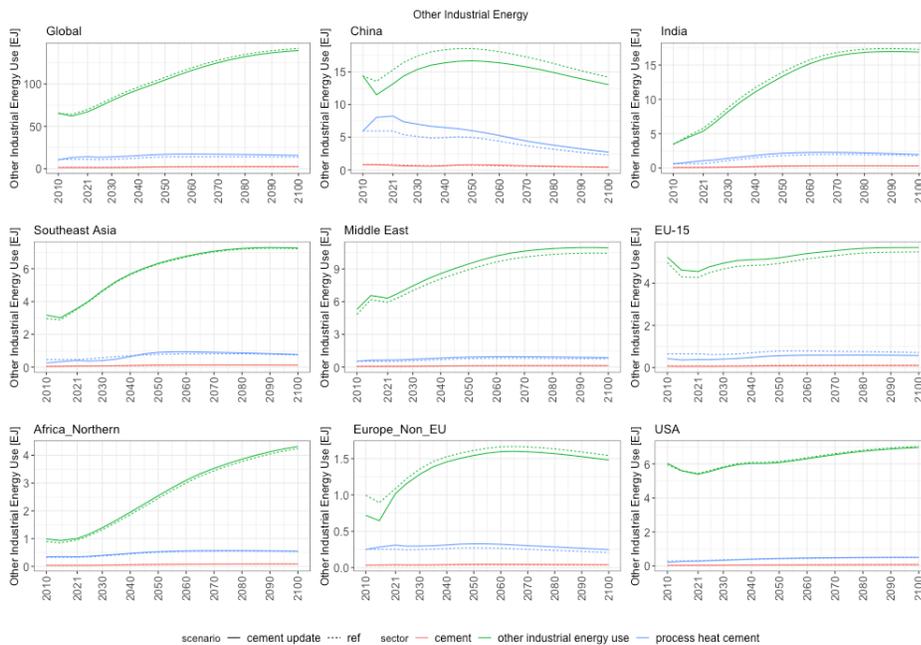
**Cement Energy Use by Fuel (stacked area):** Energy use in the cement sector by fuel in the GCAM reference scenario for the current GCAM core (“ref”) and this proposal (“cement update”), globally and for the USA.

Changes in fuel mix for total cement energy (process heat and electricity) are shown in line graphs for the top 8 regions, and in stacked area for global and the USA. The difference in fuel use in the line graphs reflects the change in fuel shares as well as the change in total energy and thermal and electricity input-output coefficients. The fuel shares in some regions (such as the USA, shown) have changed significantly as an entirely new data set is used to derive fuel shares.

Fuel shares are now estimated using IEA nonmetallic minerals sector. This includes cement as well as glass, and particularly for the USA, new fuel mix estimates better reflect available data.

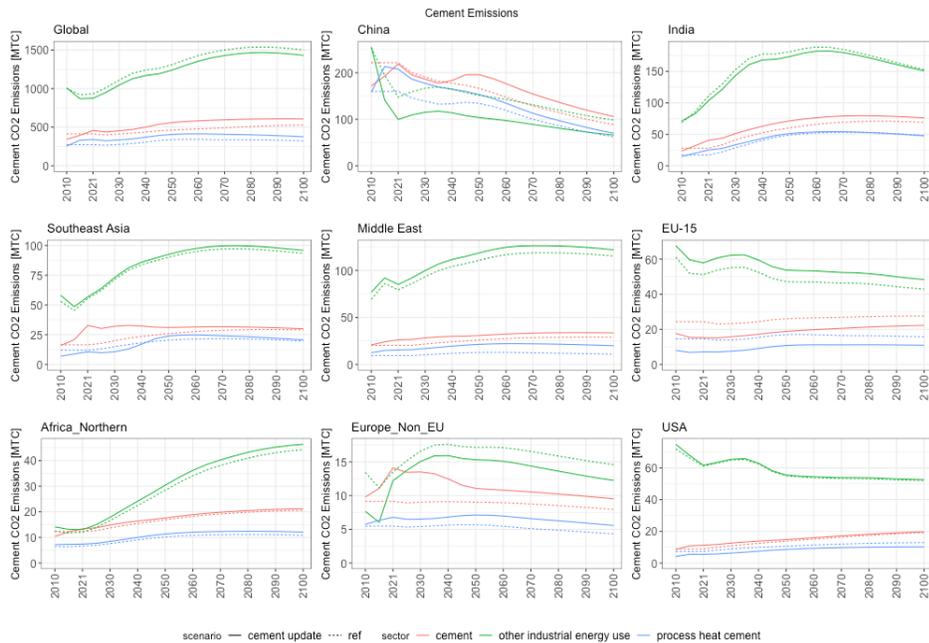
Some regions see significant changes in fuel use/share including:

- India: less coal, more gas
- Middle East: more biomass, less refined liquids, less gas
- EU-15: less refined liquids
- USA: less coal and refined liquids, more gas



***Cement and Other Industrial Energy Use: Energy Use in the cement and other industrial energy use sectors in the GCAM reference scenario for the current GCAM core (“ref”) and this proposal (“cement update”), globally and for the top 8 cement producing regions***

Energy use in other industrial sectors is largely unchanged by the cement update, except in isolated cases, where (usually) the food processing sector sees some very small changes. Changes in cement energy use are balanced completely by changes in other industrial energy use to maintain historical energy balances. Changes in total cement energy/other industrial energy use are at maximum only around 6%.

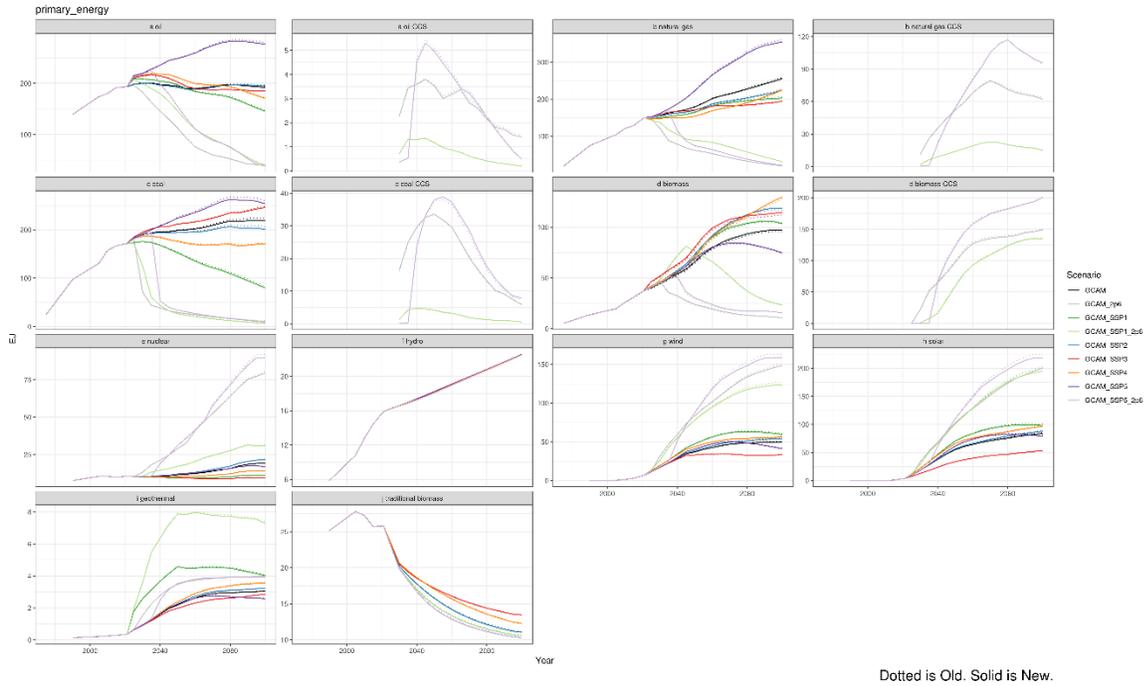


***Cement CO<sub>2</sub> emissions: CO<sub>2</sub> emissions from cement and other industrial sectors in the GCAM reference scenario for the current GCAM core (“ref”) and this proposal (“cement update”), globally and for the top 8 cement producing regions***

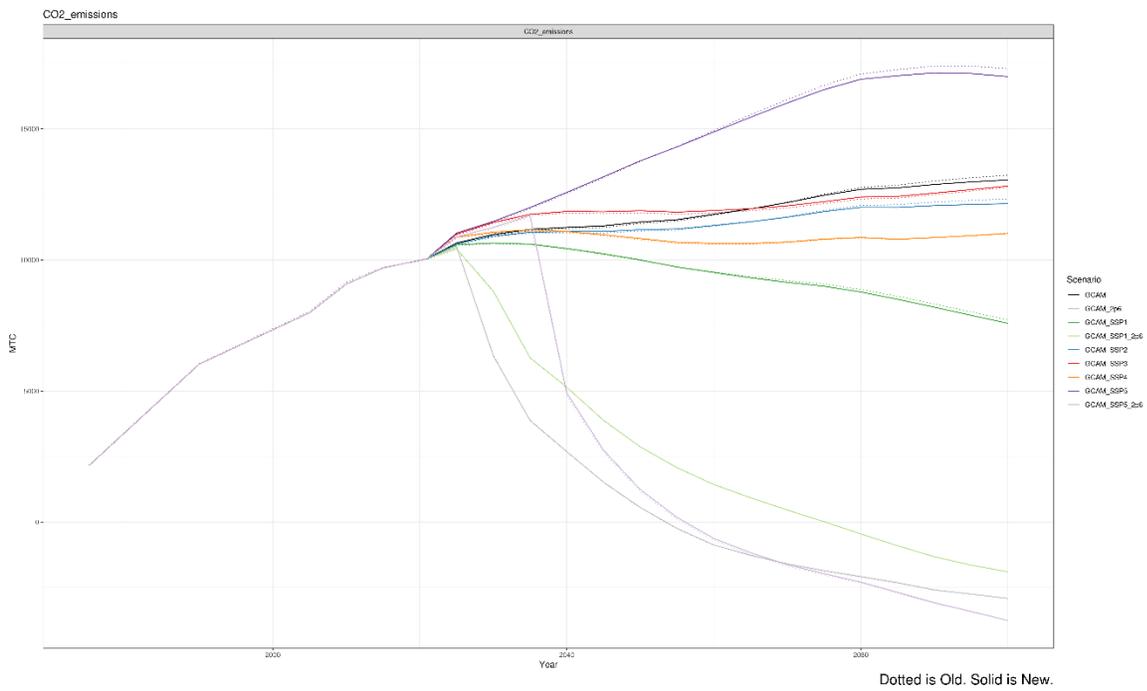
While energy mostly balances between the cement and other industrial energy sectors, CO<sub>2</sub> emissions do not as the fuel mix in these sectors have changed. Compared to previous estimates, changes in CO<sub>2</sub> emissions from cement sectors reflect both the increased production (and thus cement energy) estimates and the new fuel share estimates. Changes in the other industrial sector result from the changes in energy and fuel to balance changes in cement energy. Globally this results in a small decrease in CO<sub>2</sub> emissions across these sectors. CO<sub>2</sub> emissions in other sectors do not change significantly.

## Validation – Other Scenarios

As expected, there are small changes in global primary energy (decrease in coal and increase in biomass) and CO<sub>2</sub> emissions (small increase) across validation scenarios.



**Change in primary energy across validation scenarios (time series).**



**Change in CO<sub>2</sub> emissions across validation scenarios (time series)**

## Summary

Updates to cement estimates include new data sets and methodology for cement production and emissions, thermal and electricity intensities, and fuel shares. This results in increases in production and total energy use in the cement sector in most regions. Changes in cement energy use result in balancing changes in the other industrial energy sector, which balance to maintain the historical IEA energy balances. Changes in CO<sub>2</sub> emissions are a result of both changes in total production and energy use and fuel changes, resulting in a small increase in global CO<sub>2</sub> emissions. Changes in other industrial sectors and other parts of the energy system are minimal as the cement and other industrial sectors are relatively small with little growth across validation scenarios.

## Documentation Updates

branch: <https://github.com/JGCRI/gcam-doc/tree/cmp-408-cement-bugfix>

PR: <https://github.com/JGCRI/gcam-doc/pull/229>

## References

Andrew, R. M. (2025). Global CO<sub>2</sub> emissions from cement production (Version 250226) [Data set]. Zenodo. <https://doi.org/10.5281/zenodo.14931651>

IEA (2021), Electricity use per tonne of cement in selected countries and regions, 2018, IEA, Paris <https://www.iea.org/data-and-statistics/charts/electricity-use-per-tonne-of-cement-in-selected-countries-and-regions-2018>

IEA (2023), Global thermal energy intensity of clinker production by fuel in the Net Zero Scenario, 2010-2030, IEA, Paris <https://www.iea.org/data-and-statistics/charts/global-thermal-energy-intensity-of-clinker-production-by-fuel-in-the-net-zero-scenario-2010-2030>